Proceedings World Geothermal Congress 2005
Antalya, Turkey, 24-29 April 2005

Geothermal Development in Iceland 2000-2004

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Keywords: Iceland, geothermal energy, district heating, direct use, power generation

ABSTRACT

Because of the location of Iceland on the Mid-Atlantic Ridge the geothermal resources are abundant. Over half of the primary energy supply in the country comes from geothermal energy. The main use of geothermal energy is for space heating and about 87% of all houses are heated by this energy source. Other sectors of direct use are swimming pools, snow melting, industry, greenhouses and fish farming. An expansion in the energy intensive industry has led to rapid increase in electricity demand in the country. This has stimulated the development of geothermal power production and resulted in new plants under construction. Two of the largest energy companies in Iceland, Reykjavik Energy and Hitaveita Suðurnesja, both have a new power plant for electricity production under construction. The total capacity of these two plants plus an expansion being made at Nesjavellir power plant is approximately 200 MWe. This will double the existing capacity in the country.

1. INTRODUCTION

Iceland is a country of 290,000 people, located on the Mid-Atlantic Ridge. It is mountainous and volcanic, with much precipitation. The geographical peculiarities lead to a situation where geothermal and hydropower are abundant. During the course of the 20th century Iceland changed from being among Europe's poorest countries, dependent upon peat and imported coal for its energy, to a country with a high living standard where practically all stationary energy and about 72% of the primary energy comes from indigenous renewable sources (54% geothermal, 18% hydropower). The rest is imported fossil fuel that is used for fishing and transportation. The energy use per capita in Iceland is among the highest in the world and the proportion of this provided by renewable energy sources is greater than in other countries. Nowhere else doe's geothermal energy play a greater role in energy supply. Iceland is among those nations with the highest utilization of this energy resource. Almost three-quarters of the population live in the southwestern part of the country, where geothermal resources are abundant.

Despite the fact that Iceland possesses extensive unexploited energy reserves, these are not unlimited. Only very rough estimates are available on the size of these energy reserves, resulting in considerable uncertainty when it comes to assessing to what extent they can be harnessed with regard to what is technically possible, cost-efficient, and environmentally desirable. The estimated figures generally proposed for hydropower potential are 30 TWh annually, and for electricity production from geothermal resources 20 TWh annually, totaling 50 TWh per year. This is after deducting the resources, which are unlikely to be developed for environmental reasons. In 2003, electricity production in Iceland amounted to around 17% of this estimated harnessable energy. Current utilization of geothermal energy for heating and other direct uses is considered to be only a small fraction of what this resource can provide.

2. GEOLOGICAL BACKGROUND

Iceland is a geologically young country that lies on one of the major fault lines in the earth's crust, the Mid-Atlantic Ridge. This is the boundary between the North American and Eurasian tectonic plates. It is one of the few places on earth where you can see an active spreading ridge above sea level with the two plates moving apart about 1 to 2 cm per year. As a result of its location Iceland is one of the most tectonically active places on earth with a large number of volcanoes and hot springs. Earthquakes are frequent but rarely cause serious damage. More than 200 volcanoes are situated on the island and at least 30 of them have erupted in historic times. The most famous of the volcanoes is Hekla (1,491 m).

The geothermal resources in Iceland are closely associated with the country's volcanism. The high-temperature resources are located within the active volcanic zone running through the country from southwest to northeast, while the low- about 250 separate low-temperature areas with temperature resources are mostly in the areas flanking the active zone. To date 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.

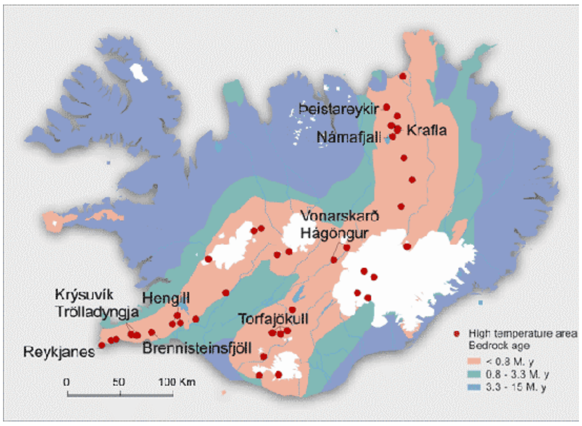

Figure 1: Characteristics of geysers and hot springs in high-temperature geothermal areas.

3. OVERVIEW OF GEOTHERMAL UTILIZATION

As has previously been mentioned, geothermal sources account for just over half of Icelanders' primary energy needs. From the earliest times, geothermal energy has been used for bathing and washing. Late in the 19th century, experiments began with utilizing geothermal energy in market gardening; and early in the 20th century geothermal sources were first used to heat greenhouses. Around the same time, utilization of geothermal energy for heating swimming pools and buildings began; and today space heating is the largest component in direct use of geothermal energy in Iceland.

Figure 2 gives a breakdown of the utilization of geothermal energy in 2001. These percentages are for energy utilized rather than primary energy. Direct use of geothermal energy that year, i.e. for heating, totaled around 23,800 terajoules (TJ), which corresponds to 6,600 GWh. In addition, electricity production amounted to 1,451 GWh. As Figure 2 shows, the 60% share of space heating was by far the greatest, followed by electricity production, accounting for 18%.

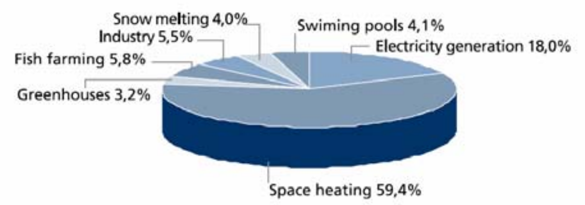

Figure 2: Sectoral share of geothermal utilization in Iceland 2001.

4. SPACE HEATING

Utilization of geothermal energy for space heating on a large scale began with the laying of hot water piping from the hot springs of Laugardalur in Reykjavík in 1930. The formal operations of Reykjavík District Heating (now Reykjavík Energy) began in 1943. Following the oil price hikes of the 1970s, the government took the initiative in expanding district heating utilities, with the result that the share of geothermal energy in space heating increased from 43% in 1970 to 87% in 2002. This development is illustrated in Figure 3.

In recent years, utilization of geothermal energy for space heating has increased mainly as a result of the population increase in the capital area. Most prominent among recent district heating utilities in towns is that of Stykkishólmur, West Iceland, which came into service at the end of 1999. A heating utility at Drangsnes in Northwest Iceland was taken into service at about the same time, and in the town of Budardalur and the surrounding districts of West Iceland about a year later. In addition, a number of small heating utilities have been established in rural areas. There are some 200 small, rural utilities of this type in Iceland. As the result of changing settlement patterns, and the continuing search for geothermal sources in the so-called "cold" areas of Iceland, the share of geothermal energy in space heating is expected to increase to 92% in the next few decades.

In recent years there have been changes in the ownership structure of many district heating systems in Iceland. The larger companies have either bought or merged with some of the smaller systems. Also it is getting increasingly common to run both district heating and electricity distribution in one municipally owned company. This development should be viewed in connection with the process of deregulation in the electricity market going on in Iceland and the expected increased competition in the energy market in the future.

The Eastern part of Iceland is an area with low geothermal activity and only one district heating system in operation (Egilstaðir). Geothermal exploration in recent years has resulted in a well with sufficient 70°C hot water close to the village Eskifjordur, which has about 1,000 inhabitants. A geothermal district heating system for Eskifjörður is now under preparation.

I spite of intensive geothermal exploration in W-Iceland it has until now not succeeded to find hot water close enough to the village Grundarfjörður (900 inhabitants) to build a district heating system in an economical way. A new bridge crossing a fjord on the distance between Grundarfjörður and a potential well will change this by reducing the transmission pipeline length from 20 to 10 km. The realization of the project is now under preparation.

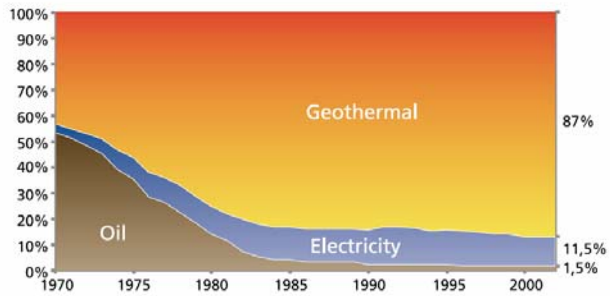

Figure 3: Energy sources used for space heating 1970-2002.

4.1 Reykjavík

Reykjavík Energy (Orkuveita Reykjavíkur) was established in 1999 by the merger of Reykjavik District Heating and Reykjavik Electricity. The company is responsible for distribution and sale of both hot water and electricity as well as the waterworks in the city. The total number of employees is 492 and the turnover in 2003 was 183 million US$.

District heating in Reykjavík began in 1930 when some official buildings and about 70 private houses received hot water from geothermal wells close to the old thermal springs in Reykjavík. Reykjavik District Heating (now Reykjavík Energy) was formally established in 1943 when production of hot water from the Reykir field, 17 km from the city, started. Reykjavík Energy is by far the largest of the 26 municipally owned geothermal district heating system in Iceland. It 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 180,000 people or practically the whole population in Reykjavik and six neighboring communities, see table 1.

Table 1: Reykjavík Energy – district heating 2003

Number of people served	179,085
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 2003	593 MWt
Total pipe length	2,157 km
Water delivered	59,600,000 m^3/year

During the past few years Reykjavik Energy has been expanding by taking over several district heating systems in the SW part of the country. Some of them are small systems in rural areas but others are among the largest and oldest geothermal district heating systems in the country. In 2000 they bought the municipally owned district heating system in the village Þorlákshöfn with about 1,400 inhabitants. It is still operated as a separate company, Hitaveita Þorlákshafnar.

Hitaveita Akraness and Borgarfjarðar had been serving the towns Akranes and Borgarnes in W-Iceland with geothermal hot water since 1979 when they merged with Reykjavík Energy on 1st of January of 2002. About 7,000 inhabitants live in the area served by this district heating system.

The third of the main district heating systems in Iceland taken over by Reykjavik Energy in the last years is Hitaveita Hveragerðis which serves about 1,700 inhabitants. From 1st of September 2004 it is owned by Reykjavík Energy. All of these systems that Reykjavík Energy has taken over are separate systems within a radius of 50 km from Raykjavík. The tariffs have been changed to be the same as in Reykjavík and in some cases this has led to considerable reduction in heating costs for the consumers.

4.2 Suðurnes

Hitaveita Suðurnesja (Sudurnes Regional Heating) owns the co-generation power plant at Svartsengi on Reykjanes peninsula, about 50 km SW of Reykjavík. The plant has been in operation since 1977. It serves four communities on the Reykjanes peninsula with totally about 17,000 inhabitants with hot water and electricity. In addition to that the plant serves about 25,000 inhabitants in Hafnarfjordur and other communities in the vicinity of Reykjavik with electricity. In 2002 Hitaveita Suðurnesja merged with Bæjarveitur Vestmannaeyja, which supply 4,400 inhabitants of the Westman Islands with electricity and district heating based on electrical boilers.

During the last few years Hitaveita Suðurnesja has been preparing a new power plant at Reykjanes for electricity production. This will be discussed further in chapter 10.6.

4.3 Akureyri

Akureyri is a town of 16,000 inhabitants located in the central N-Iceland. It has been heated by geothermal energy since the end of the seventies. Hot water is pumped to Akureyri from four different geothermal fields, Eyjafjordur 12-14 km south of the town, Glereardalur 2 km west of the town, Thelamork 10 km north of the town and, since the beginning of 2004, Hjalteyri 19 km north of the town. In addition to this two heat pumps have supplied about 3% of the annual energy production since 1984. They use return water from the district heating system, partly as a heat source and partly as a new supply water. The original heat pumps were replaced by two new heat pumps in 1998. They are 1.9 MWt each and designed for a COP-factor of 4.75. They use ammonia as refrigerant. Return water from part of the heating system is re-injected at 12°C to the Eyjafjordur field to sustain reservoir pressure and mine heat from the surrounding formations. The total installed capacity of the district heating system is 87 MWt and the annual hot water consumption is about 5 million m^3.

After many years with insufficient supply of hot water from the geothermal fields a new high potential field at Hjalteyri was found. A well drilled in 2002 gave very good results and it is estimated that by the new field the water production can be doubled. This will secure hot water supply for district heating in the area for many years to come. The transmission pipeline built in 2003 from Hjalteyri to Akureyri is 19 km long, 300 mm in diameter and has a capacity of 120 l/s. Because of the abundant geothermal water district heating is now under development in the rural areas surrounding Akureyri.

The energy company Norðurorka was established 1 August 2000 with the merger of Akureyri Electricity Utility and the Akureyri Heating and Water Utilities. On 1 January 2003 it was converted to the limited company Norðurorka owned by Akureyri municipality. The company is responsible for energy supply in Akureyri and the surrounding area.

5. SWIMMING POOLS

Until early in the last century, the use of geothermal energy in Iceland was limited to bathing, washing of clothing and cooking. These uses are today still significant and heating of swimming pools is among the most important types of uses after space heating. There are about 160 swimming pools in operation, 130 of which use geothermal heat. Based on their surface area, 89% of the pools are heated by geothermal sources, 7% by electricity, and 4% by burning oil.

Of the geothermally heated pools about 100 are public swimming pools and about 30 pools in schools and other institutions. The combined surface area of them is about 28,000 m^2. Most of the public pools are open-air pools in 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 swimming pool attendance has increased in recent years. In 2002 it was the equivalent of 15 visits by every Icelander. 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 also very popular. The latest development in this field is a bathing facility in Bjarnarflag using effluent geothermal water from well supplying Kísiliðjan with stem.

In the last five years, about six 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. This means that a new, middle-sized swimming pool uses as much hot water as is needed to heat 80-100 single-family dwellings. The total annual water consumption in geothermally heated swimming pools in Iceland is estimated to be 6,500,000 m^3 which corresponds to an energy use of 1,200 TJ per year.

6. SNOW MELTING

Geothermal energy has been utilized to a limited extent for heating pavements and melting snow in wintertime, with this usage increasing during the last two decades. 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. In downtown Reykjavík a snow-melting system has been 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 of snow melting systems installed in Iceland is around 740,000 m^2, of which about 550,000 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 430 kWh/m^2. The total geothermal energy used for snow melting is estimated to be 1,150 TJ per year. Over half of this energy comes from used, return water from space heating systems.

7. INDUSTRIAL USES

The diatomite plant at Lake Myvatn, near the Námafjall high temperature geothermal field, uses more direct geothermal energy than any other industrial enterprise in Iceland. The plant, which employs about 50 people and has been operational since 1967, produces some 28,000 tonnes of diatomite filter aids for export annually. It is one of the world’s largest industrial users of geothermal steam. The raw material is diatomaceous earth found on the bottom of Lake Myvatn. 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. Each year the plant uses some 230,000 tonnes of geothermal steam under 10 bar pressure (180°C), primarily for drying. This corresponds to an energy use of 444 TJ per year. For several technical and marketing reasons the plant will be closed down at the end of 2004. The owners of the plant plan to convert it to producing synthetic silica from imported quartz. If problems with financing the project will be solved and these plans realized the utilization of geothermal steam in the plant will probably increase by a factor of 2-3.

The seaweed product manufacturer Thorverk, at Reykhólar in West Iceland, also uses geothermal heat directly in its production. They harvest seaweed found in the waters of Breidafjordur in NW-Iceland using specially designed harvester crafts. Once landed the weed is chopped and dried on a band dryer that uses large quantities of clean dry air, heated to 85°C by hot geotherml water in heat exchangers. The plant has been operated since 1976 and produces 2,000-4,000 tonnes of rockweed and kelp meal annually, using 34 l/sec of 107°C hot water for drying. The product has been certified organic. The annual use of geothermal energy in the plant is about 150 TJ.

A salt production plant was operated on the Reykjanes peninsula for a number of years. From geothermal brine and seawater the plant produced salt for the domestic fishing industry as well as low-sodium health salt for export. During the last years the operation of the plant has been intermittent. Another example of industrial application that has faced financial fifficulties is drying of imported hardwood in Húsavík by geothermal water. After few yars of operation the plant was closed down in 2002.

Since 1986, a facility at Haedarendi in Grímsnes, South Iceland, has produced commercially liquid carbon dioxide (CO_2) from geothermal fluid. 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. 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. The plant uses approximately 6 l/sec of fluid and produces some 2,000 tonnes annually. The production is used in greenhouses, for manufacturing carbonated beverages and in other food industries.

Geothermal energy has been used for fish drying in Iceland for about 25 years. The main application has been indoor drying of salted fish, codheads, small fish, stockfish and other products. Yarlier cod heads were traditionally dried by hanging them on outdoor stock racks. Because of the wether conditions indoor drying is much to prefer. Hot air is blown over the fish and the moisture from the raw material removed. Today about 20 small companies are drying cod heads indoors and 17 of them use geothermal hot water and 1 geothermal steam. The annual export of dried codheads is about 15,000 tonnes, mainly to Nigeria, where thay are used for human consumption. In 2001 about 2 million tonnes of geothermal hot water were used for fish drying which corresponds to about 550 TJ. In addition to this drying petfood is a new and growing industry in Iceland with an annual production of about 500 tonnes.

Examples of additional industriel uses of geothermal energy on a small scale are retreading of car tires and wool washing in Hveragerdi, curing of cement blocks at Myvatn and steam baking of bread at several locations. The total geothermal energy used as process heat in industry in Iceland is estimated to be 1,600 TJ per year.

8. GREENHOUSES

Apart from space heating, one of the oldest and most important usages of geothermal energy in Iceland is for greenhouse heating. Naturally warm soil had been used for a long time for growing of potatoes and other vegetables when geothermal heating of greenhouses started in Iceland in 1924. 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. The heating installations are by unfinned steel pipes hung on the walls and over the plants. Undertable or floor heating is also common. It is common to use inert growing media (volcanic scoria, rhyolite) on concrete floors with individual plant watering. The increasing use of electric lighting in recent years has lengthened the growing season and improved greenhouse utilization. This development has been encouraged by state subsidies on electricity for lighting. CO_2 enrichment in greenhouses is common, mainly by using CO_2 produced in the geothermal plant at Haedarendi.

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.). Of this area 55% is used for growing vegetables and 45% for flowers. The total area under glass increased by 1,9% per year in the period 1990 to 2000 and was about 195,000 m^2 in 2002. In the coming years it is expected that the total surface area of greenhouses will decrease in spite of increasing total production. This is because the competition with imported products and increased use of artificial lighting is expected to result in increased productivity in the greenhouse sector.

At several locations outdoor growing is enhanced by soil heating using geothermal water, especially during early spring. Soil heating has the main benefit of early thawing of the soil and the vegetables can be brought to market sooner. It is estimated that about 105,000 m^2 of fields are heated this way. Soil heating is not an increasing application, partly because similar results are commonly obtained at a lower cost by covering the plants by plastic sheets.

The total geothermal energy used in the greenhouse sector in Iceland is estimated to be 940 TJ per year.

9. 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 almost collapsed. Since 1992 the production has been slowly increasing to totally 4,000 tonnes in 2002 in about 50 plants. Salmon is the main species with about 70% of the production but arctic char and trout are also raised.

In the beginning fish farming in Iceland was mainly in shore-based plants. Geothermal water, commonly 20-50°C, is used to heat fresh water in heat exchangers, typically from 5 to 12°C. It requires large consumption of both freshwater and seawater and this adds considerably to the operating cost. However, this is still common, especially in raising trout. The electricity consumption is reduced by injecting pure oxygen into the water and thus cutting down on the waterchanges. Farming fish in cages floating along the shore is getting more common and has proved to be more economical than shore based plants in raising salmon. After many years with ocean ranching of salmon this production method was not found to be profitable and has now been given up.

The total geothermal energy used in the fish farming sector in Iceland is estimated to be 1,680 TJ per year. Of that about 65% is used for raising trout. It is expected that the production in fish farmimg in Iceland will grow at an increase rate in the future. This will mean increased geothermal utilization, especially in smolt production (trout and salmon).

10. GEOTHERMAL ELECTRIC POWER GENERATION

Electricity generation using geothermal energy has increased significantly in recent years. Figure 4 shows the development in the period 1970-2003. The installed capacity of geothermal generating plants now totals some 200 MWe. The total production in 2003 was 1,406 GWh which is 16,6% of the total electricity production in the country.

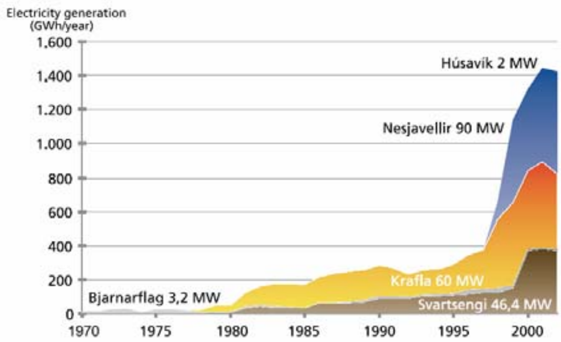

Figure 4: Electricity generation using geothermal energy 1970-2003. *(will be updated)*

10.1. Bjarnarflag

The oldest geothermal power plant in Iceland is in Bjarnarflag (Namafjall field) where a 3 MWe back pressure unit started operation in 1969. This field also supplied steam to the Kisilidjan diatomite plant while it was in operation. 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 2003 was 12 GWh.

10.2 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. The capacity of the Krafla power plant was expanded in 1997 from 30 to 60 MWe, and preparations are underway to increase the plant's output by an additional 40 MWe in the next stage. There are also plans for building a new plant in the Krafla area.

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 2003 was 401 GWh.

10.4 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.

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 2003 was 368 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 2003 was 1.5 GWh.

10.3 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 bar (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. This increased the efficiency of the plant significantly. In 2001 the plant was enlarged to a capacity of 90 MWe with the installation of a third turbine. Further expansion to 120 MWe is under construction and will be completed in 2005.

The total electricity generation of the Nesjavellir power plant in 2003 was 615 GWh.

10.5 Húsavík

At Húsavík, in Northeast Iceland, electricity generation using geothermal energy began around mid-year 2000, when a Kalina binary-fluid 2 MWe generator was taken into service, among the first in the world of its kind. It utilizes hot water cooling from 120°C down to 80°C and satisfies about three-quarters of the electricity needs of the town of Húsavík. Part of the hot water leaving the generating plant is used by the district heating system for public heating.

10.6 New developments

As a result of a rapid expansion in the energy intensive industry in Iceland the demand for electricity has increased considerably. This has partly been met by increased geothermally produced electricity and two new project are now being carried out.

Reykjavik Energy is constructing a geothermal power plant at Hellisheiði in the southern part of the Hengill area. In the first stage the installed power will be 80 MWe and production startup is sheduled for 1st october 2006. Further expansion of the plant is expected later as well as hot water production for district heating in Reykjavík. At the end of 2004 10 wells had been drilled to supply steam te the Hellisheiði plant and 8 more are planned in the next few years.

Hitaveita Suðurnesja has been undertaken exploration and utilization on a small scale in the Reykjanes geothermal field for many years. In 2003 it was decided to build a new power plant on Reykjanes. Two turbines will be installed in the first stage, 50 MWe each. The plant will start production in 2006. A further expansion to 150 MWe is foreseen in the future. In connection with the plant 7 new wells have been drilled on Reykjanes during the last 5 years and 5 more are planned.

To meet the increing demand for high temperature geothethermal wells the drilling company Jarðboranir invested in a new drilling rig that started opereation in the summer 2004. The new rig, that is called Geysir, can drill up to 4,000 deep wells. It is the biggest and most advanced drilling rig in operation in Iceland.

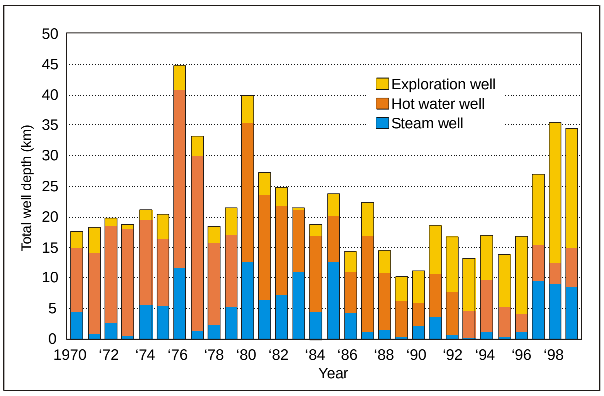

Figure 5: Total depth of geothermal wells drilled annually in Iceland 1970-2004. *(will be updated)*

11. DISCUSSION

The development in direct use of geothermal energy has been rather slow in Iceland for a number of years. Geothermal space heating is slowly increasing and according to a new energy forecast it is expected that in the long run the share of geothermal in space heating will increase from the present 87% to 92%. In spite of high potential it has not succeeded to find new industrial users that use geothermal energy on a large scale.

The main geothermal activity in Iceland during the last few years has been in high temperature geothermal exploration and drilling. This is expected to contionu for some time. The power plants that are planned or under construction will approximately double the existing 200 MWe installed capacity of geothermal power plants in the country.

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. 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. A MSc. programme was started in 2000 in cooperation with the University of Oceland. From the beginning a total number of 300 scientists and engineers from 39 countries have completed the six month courses.

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TABLE 1. PRESENT AND PLANNED PRODUCTION OF ELECTRICITY (Installed capacity)

	Geothermal		Fossil Fuels		Hydro		Nuclear		Other Renewables (specify)		Total	
	Capac-ity MWe	Gross Prod. GWh/yr	Capac-ity MWe	Gross Prod. GWh/yr	Capac-ity MWe	Gross Prod. GWh/yr	Capac-ity MWe	Gross Prod. GWh/yr	Capac-ity MWe	Gross Prod. GWh/yr	Capac-ity MWe	Gross Prod. GWh/yr
In operation in December 2004	202	1,406	122	5	1,150	7,084					1,474	8,495
Under construction in December 2004	210	1,680			690	4,540					900	6,220
Funds committed, but not yet under construction in December 2004												
Total projected use by 2010	412	3,086	122	5	1,840	11,624					2,374	14,715

TABLE 2. UTILIZATION OF GEOTHERMAL ENERGY FOR ELECTRIC POWER GENERATION AS OF 31 DECEMBER 2004

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 (explain)
3F = Triple Flash O = Other (please specify)
D = Dry Steam

3) Data for 2004 if available, otherwise for 2003. Please specify which.

Locality	Power Plant Name	Year Com-missioned	No. of Units	Status[1)]	Type of Unit[2)]	Total Installed Capacity MWe	Annual Energy Produced 2004[3)] GWh/yr	Total under Constr. or Planned MWe
Krafla	Krafla	1977/97	2		2F	60	401	
Námafjall	Námafjall	1969	1		1F	3.2	12	
Svartsengi	Svartsengi	1978	2		1F	2	7	
Svartsengi	Svartsengi	1981	1		1F	6	49	
Svartsengi	Svartsengi	1989/92	7		B	8.4	61	
Svartsengi	Svartsengi	1999	1		1F	30	251	
Reykjanes	Reykjanes	1983	1		1F	0.5	1	
Nesjavellir	Nesjavellir	1998	2		1F	60	615	30
Húsavík	Húsavík	2000	1		B	2	9	
Hellisheiði	Hellisheiði							80
Reykjanes	Reykjanes							100
Total			18			172.1	1,406	210

TABLE 3. UTILIZATION OF GEOTHERMAL ENERGY FOR DIRECT HEAT AS OF 31 DECEMBER 2004 (other than heat pumps)

1) I = Industrial process heat
C = Air conditioning (cooling)
A = Agricultural drying (grain, fruit, vegetables)
F = Fish farming
K = Animal farming
S = Snow melting
H = Individual space heating (other than heat pumps)
D = 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. (^oC) - outlet temp. (^oC)] 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. (^oC) - outlet temp. (^oC)] 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)/Capacity (MWt)] x 0.03171
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.

Note: please report all numbers to three significant figures.

Locality	Type[1)]	Maximum Utilization					Capacity[3)]	Annual Utilization		
		Flow Rate	Temperature (^oC)		Enthalpy[2)] (kJ/kg)			Ave. Flow	Energy[4)]	Capacity
		(kg/s)	Inlet	Outlet	Inlet	Outlet	(MWt)	(kg/s)	(TJ/yr)	Factor[5)]
Reykjavík	DBGISF	3,591	80	35			734	1,955	11,287	0.49
Seltjarnarnes	DBIS	156	80	35			33	56.4	326	0.31
Mosfellsbær	DBGIS	134	80	35			27	72.1	435	0.51
Suðurnes	DBISF	545	86	35			125	287.6	1703	0.43
Akranes of Borgar	DBGF	149	78	35			3	7.2	40	0.42
Akranes	DBGIS	111	78	35			22	58.4	322	0.46
Borgarnes	DBGIS	54	82	35			9	23.5	144	0.51
Stykkishólmur	DB	31	80	35			8	19.2	103	0.41
Reykhólar	DBG	8	95	35			4	3.1	24	0.19
Suðureyri	DB	10	81	35			2	4.6		0.00
Drangsnes	DB	6	60	35			2	1.9	6	0.10
Hvammstangi	DB	32	77	35			5	13.9	89	0.56
Blönduós	DB	42	64	35			6	27	94	0.50
Skagafjörður	DBGIS	125	72	35			29	79.1	391	0.43
Siglufjörður	DBI	35	70	35			5	16.8		0.00
Ólafsfjörður	DBI	47	62	35			11	38	132	0.38
Dalvík	DBISF	59	62	35			10	34.2	132	0.42
Hrísey	DB	9	79	35			4	7.4	41	0.33
Akureyri	DBIS	308	78	35			55	161.4	849	0.49
Húsavík	DBIF	84	87	35			20	63.3	365	0.58
Reykjahlíð	DB	17	99	35			6	10	82	0.43
Egilsstaðir	DBGIS	60	73	35			10	27.9	136	0.43
Rangæinga	DBI	43	74	35			5	31.8	143	0.91
Brautarholt	DBG	7	70	35			1	2.2		0.00
Flúðir	DBGI	82	98	35			25	34.9	282	0.36
Laugarás	DGI	38	100	35			19	62.7	522	0.87
Laugarvatn	DBG	17	93	35			7	12	89	0.40
Selfoss	DBI	193	74	35			33	94.8	486	0.47
Hveragerði	DBGI	98	85	35			30	44.4	285	0.30
Þorlákshöfn	DBIF	39	94	35			11	30.4	210	0.61
Reykhólar	I	35	107	50			8	20		0.00
Kísiliðjan, Mývatn	I	9	180		2778		21	7	521	0.79
Other users	DBGISF	900	80	35			169	397.9	2362	0.44
TOTAL		7,074					1,459	3,706	18,718	0.41

**TABLE 4. GEOTHERMAL (GROUND-SOURCE) HEAT PUMPS
AS OF 31 DECEMBER 2004**

This table should report thermal energy used (i.e. energy removed from the ground or water) and report separately heat rejected to the ground or water in the cooling mode. Cooling energy numbers will be used to calculate carbon offsets.

Report the average ground temperature for ground-coupled units or average well water or lake water temperature for water-source heat pumps
Report type of installation as follows: V = vertical ground coupled (TJ = 10^{12} J)
H = horizontal ground coupled
W = water source (well or lake water)
O = others (please describe)
Report the COP = (output thermal energy/input energy of compressor) for your climate
Report the equivalent full load operating hours per year, or = capacity factor x 8760
Thermal energy (TJ/yr) = flow rate in loop (kg/s) x [(inlet temp. (^oC) - outlet temp. (^oC)] x 0.1319
or = rated output energy (kJ/hr) x [(COP - 1)/COP] x equivalent full load hours/yr

Note: please report all numbers to three significant figures

Locality	Ground or water temp. (^oC)[1]	Typical Heat Pump Rating or Capacity (kW)	Number of Units	Type[2]	COP[3]	Heating Equivalent Full Load Hr/Year[4]	Thermal Energy Used (TJ/yr)	Cooling Energy (TJ/yr)
Akureyri	35	1.9	2	O	4.75		16	
Frenivík	19			W			2	
Other							2	
TOTAL								

**TABLE 5. SUMMARY TABLE OF GEOTHERMAL DIRECT HEAT USES
AS OF 31 DECEMBER 2004**

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

[2] Annual Energy Use (TJ/yr) = Ave. flow rate (kg/s) x [inlet temp. (^oC) - outlet temp. (^oC)] 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

Note: please report all numbers to three significant figures.

Use	Installed Capacity[1] (MWt)	Annual Energy Use[2] (TJ/yr = 10^{12} J/yr)	Capacity Factor[3]
Individual Space Heating[4]			
District Heating [4]	1,350	17,223	0.40
Air Conditioning (Cooling)			
Greenhouse Heating	55	940	0.54
Fish Farming	65	1,680	0.82
Animal Farming			
Agricultural Drying[5]			
Industrial Process Heat[6]	65	1,600	0.78
Snow Melting	182	1,150	0.2
Bathing and Swimming[7]	70	1,200	0.54
Other Uses (specify)			
Subtotal	1,787	23,793	0.42
Geothermal Heat Pumps	4	20	0.16
TOTAL	1,791	23,813	0.42

[4] Other than heat pumps
[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, 2000 TO DECEMBER 31, 2004 (excluding heat pump wells)

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)		200			50
Production	>150° C	18		5		50
	150-100° C		10			10
	<100° C		30			10
Injection	(all)					
Total		18	240	5		120

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

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

Year	Professional Person-Years of Effort					
	(1)	(2)	(3)	(4)	(5)	(6)
2000	33	34	5			42
2001	33	34	5			43
2002	34	34	5			44
2003	34	34	5			45
2004	35	34	5			45
Total						

TABLE 8. TOTAL INVESTMENTS IN GEOTHERMAL IN (2004) 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$	%	%
1990-1994	13	15	89	7		100
1995-1999	21	50	63	90		100
2000-2004						