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Geothermal Development in Iceland 2005-2009

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ABSTRACT

Due to it´s location Iceland has very favourable conditions for geothermal development. The geothermal resources are utilized both for electricity generation and direct heat application. The share of geothermal energy in the nation´s primary energy supply is 62%. Space heating is the most important direct utilization of geothermal energy in Iceland, covering 89% of all houses in the country. Other sectors of direct use are swimming pools, snow melting, industry, greenhouses and fish farming. The total direct use of geothermal energy was estimated to be 26,280 TJ (7,300 GWh) in 2009. Generation of electricity by geothermal energy has increased rapidly during the past few years, mainly due to increased demand in the energy intensive industry. The total installed capacity is now 573 MWe and the annual generation in 2009 was 4,400 GWh, which is about 26% of the total produced in the country.

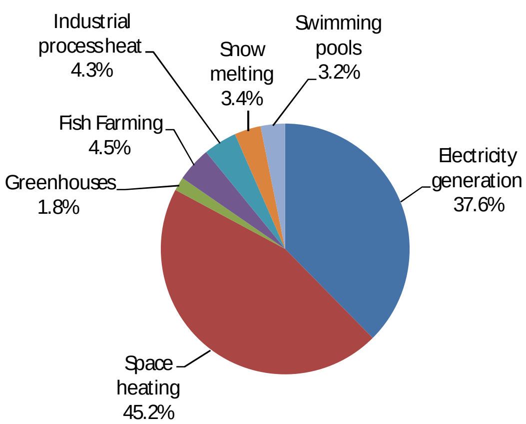
1. INTRODUCTION

The location on the Mid-Atlantic Ridge places Iceland in the group of countries that have huge geothermal potential. The country is mountainous and volcanic, with much precipitation, making the hydropower resources abundant. The population of Iceland is about 320,000, of which almost two third live in the capital area. During the course of the 20th century, Iceland went from what was one of Europe's poorest countries, dependent upon peat and imported coal for its energy, to a country with a high standard of living where practically all stationary energy, and roughly 82% of the primary energy comes from indigenous renewable sources (62% geothermal, 20% hydropower). The rest of Iceland´s energy sources come from imported fossil fuel used for fishing and transportation. Iceland´s energy use per capita is among the highest in the world and the proportion provided by renewable energy sources exceeds most other countries.

Both high temperature and low temperature resources are utilized to a great extent. In the high-temperature (>200°C) fields geothermal steam is utilized for electricity generation and in some cases also for hot water production in so-called co-generation plants. The low-temperature (<150°C) fields are used mainly to supply hot water for district heating. The 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. For the potential generation of electricity in Iceland the energy reserves are estimated at roughly 50 TWh per year, of which 30 TWh come from hydropower and 20 TWh from geothermal. This is after deducting the resources, which are unlikely to be developed for environmental reasons. The annual electricity generation has now reached one third of the total potential. A master plan assessing the economic feasibility and the environmental impact of the proposed power development projects is being prepared.

It has been the policy of the government of Iceland to increase the utilization of renewable energy resources even further for the power intensive industry, direct use and the transport sector. A broad consensus on conservation of valuable natural areas has been influenced by increased environmental awareness. Thus, there has been opposition against large hydropower and some geothermal projects. The ownership of energy resources in Iceland is based on the ownership of land. However, exploration and utilization is subject to licensing.

Figure 1 gives a breakdown of the estimated utilization of geothermal energy in Iceland for 2009. Direct use of geothermal energy that year, i.e. for heating, totalled 26,280 terajoules (TJ), which corresponds to 7,300 GWh. This is based on estimated inlet and outlet water temperature for each category (35°C outlet temperature for space heating). In addition, electricity production by geothermal amounted to 4,400 GWh in 2009. The 45.2% share of space heating was by far the greatest, followed by electricity production, accounting for 37.6%.



	Installed power	Energy consumption	
	MW	TJ/year	GWh/year
Space heating	1,500	19,044	5,290
Greenhouses	45	744	207
Fish Farming	75	1,900	528
Industriy	75	1,817	505
Snow melting	125	1,440	400
Swimming pools	80	1,335	371
Direct uses total	1,900	26,280	7,300
Electricity generation	573	15,840	4,400
Geothermal utilization total	2,473	42,120	11,700

Figure 1: Sectoral share of geothermal utilization in Iceland 2009.

2. GEOLOCICAL BACKGROUND

Iceland is a young country geologically. It lies on one of the earth's major fault lines, the Mid-Atlantic Ridge. This is the boundary between the North American and Eurasian tectonic plates, one of the few places on earth where one can see an active spreading ridge on land. The two plates are moving apart about 2 cm per year. As a result of its location, Iceland is one of the most tectonically active places on earth, resulting in a large number of volcanoes and hot springs. Earthquakes are frequent, but rarely cause serious damage. More than 200 volcanoes are located within the active volcanic zone running through the country from the southwest to the northeast, and at least 30 of them have erupted since the country was settled over 1100 years ago. In this volcanic zone there are at least 20 high-temperature areas containing steam fields with underground temperatures reaching 250°C within 1000 m depth (Fig. 2). These areas are directly linked to the active volcanic system. About 250 separate low-temperature areas with temperatures not exceeding 150°C in the uppermost 1000 m are mostly in the areas flanking the active zone. Over 600 hot spring areas (temperature over 20°C) have been located.

3. SPACE HEATING

In the year 2008, 100 years of geothermal space heating in Iceland was celebrated. Utilization of geothermal energy for space heating on a large scale began in Reykjavík in 1930. Following the oil price hikes of the 1970s, the government took the initiative in expanding district heating, with the result that the share of geothermal energy increased from 43% in 1970 to 89% in 2009. This development is illustrated in Figure 3. About 30 separate geothermal district heating systems are operated in towns and villages in the country and additionally some 200 small systems in rural areas. This achievement has enabled Iceland to import less fossil fuel, and has resulted in a very low heating cost compared to most other countries. Using geothermal energy, which is classified as a renewable energy source, for space heating has also benefited the environment.

Besides the economic and environmental benefits, the development of geothermal resources has had a desirable impact on social life in Iceland.

3.1 Reykjavik District Heating

Reykjavík Energy (Orkuveita Reykjavíkur) is responsible for distribution and sale of both hot water and electricity as well as the city's waterworks and sewage system. The total number of employees is about 650 and the turnover in 2008 was 24,200 million ISK (277 million US$ based on the average 2008 exchange rate). Reykjavík Energy is by far the largest geothermal district heating utility in Iceland. It serves over 200,000 people, the entire population of Reykjavik, plus neighbouring communities as well as some additional villages (see Table 1).

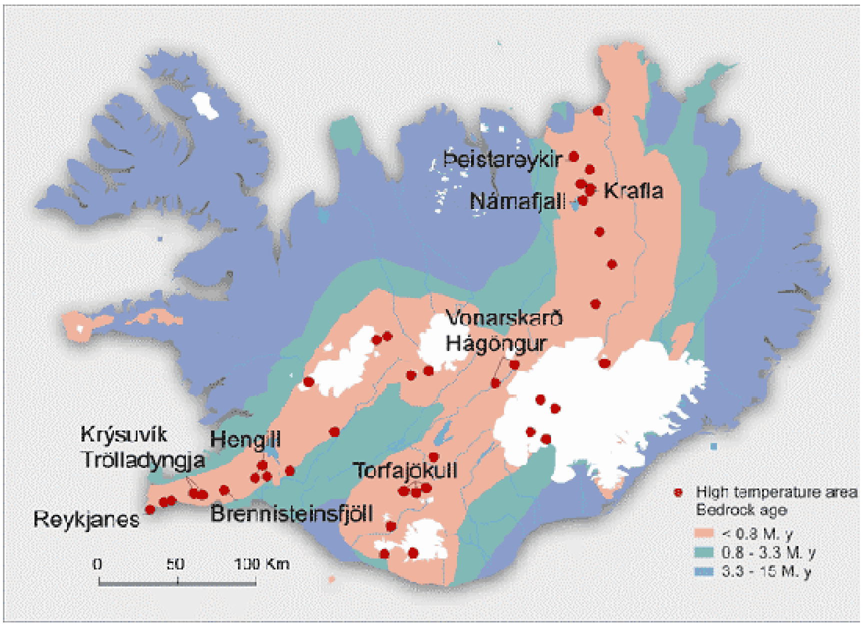


Figure 2: Characteristics of geysers and hot springs in high-temperature geothermal areas.

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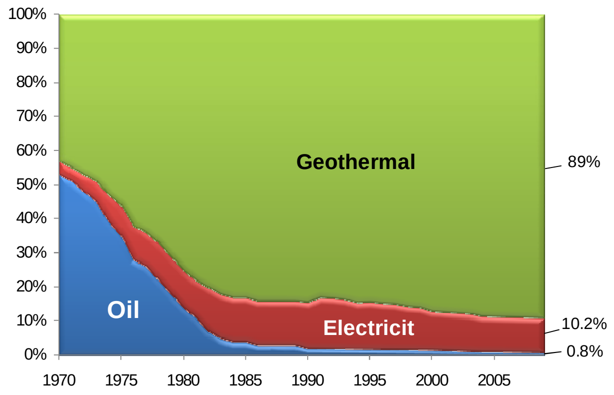

Figure 3: Energy sources used for space heating in Iceland 1970-2009.

District heating in Reykjavík began in 1930 when some official buildings and about 70 private houses received hot water from geothermal wells, located close to the old thermal springs in Reykjavík. In 1943 delivery of hot water from the Reykir field, 18 km from the city, started. Today Reykjavik Energy utilizes low-temperature areas within and in the vicinity of Reykjavik as well as the high-temperature field at Nesjavellir, about 27 km away. At Nesjavellir, fresh water is heated in a cogeneration power plant. A new plant at Hellisheidi will add hot water production in 2010 to meet future demand. Reykjavik Energy has taken over several district heating systems in the south and western parts of the country. Some are small systems in rural areas, but others are among the largest geothermal district heating systems in the country.

Table 1: Reykjavik Energy – district heating 2008

Number of people served	202,871
Volume of houses served	59,500,000 m^3
Water temperature at user end	75°C
Number of wells in use	91
Installed capacity	1,150 MWt
Peak load	950 MWt
Total pipe length	2,984 km
Water delivered	83,400,000 m^3/year

3.2 HS-Orka and HS-Veitur

In the beginning of 2009 the former Hitaveita Sudurnesja (Sudurnes Regional Heating), which was the second largest geothermal energy company in Iceland, was split into two companies: HS-Orka, now privately owned, which is responsible for production and sale of electricity and heat, and HS-Veitur, which takes care of the non-competitive distribution of energy. HS-Orka is the first energy company in Iceland to be privatized. Hitaveita Suðurnesja was a pioneer in building the cogeneration power plant at Svartsengi on the Reykjanes peninsula in 1977. It is located about 50 km SW of Reykjavik. The plant utilizes 240°C geothermal brine from the Svartsengi field to heat fresh water for district heating (150 MWt), and to generate electricity (74 MWe). On Reykjanes there is a new plant (100 MWe) for electricity generation only. HS-Veitur serves four communities on the Reykjanes peninsula with totally about 20,000 inhabitants with hot water, electricity and water. They also serve about 30,000 inhabitants in Hafnarfjordur and neighbouring communities with electricity.

3.3 Akureyri District Heating - Nordurorka

Akureyri is a town of 17,500 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 five different geothermal fields. In addition to this, two 1.9 MWt heat pumps have supplied a small part of the annual energy production most of the time since 1984, but their contribution has been insignificant the last four years. During the last few years several small district heating systems in neighbouring communities have merged with Nordurorka. Thus, the total number of people served is now about 23,000. The total installed capacity is 94 MWt and the annual hot water consumption about 7.3 million m^3.

4. OTHER DIRECT UTILIZATION

4.1 Swimming pools

For centuries mainly natural hot springs were used for bathing, but since early in the last century outdoor swimming pools as we know them today have been gaining popularity and they are today a part of the daily life of a large part of the nation. There are about 175 swimming pools in the country, 150 of which use geothermal heat. The combined surface area of the geothermally heated pools is about 34,000 m^2. Most of the swimming pools are open to the public throughout the year. They serve for recreational purposes and are also used for swimming lessons, which are compulsory in schools. Swimming is very popular in Iceland and swimming pool attendance has increased in recent years. In the greater Reykjavik area alone there are fourteen public outdoor pools and a few indoor ones. The largest of these is Laugardalslaug with 1,500 m^2 outdoor pools, 1,250 m^2 indoor pool and five hot tubs where the tub temperature ranges from 35 to 42°C. Other health uses for geothermal energy are the Blue Lagoon, the bathing facility at Bjarnarflag close to Lake Myvatn and the Health Facility in Hveragerdi, comprising geothermal clay baths and water treatments. 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 outdoor swimming pool uses as much hot water as is needed to heat 80-100 single-family dwellings. The total geothermal energy used for heating swimming pools in Iceland is estimated to be 1,335 TJ per year.

4.2 Snow melting

For a long time, geothermal water has been used to some extent in Iceland to heat pavements and melt snow during the winter. These uses have been gradually increasing and today almost all new buildings in areas with geothermal heating have snow melting systems. Iceland´s total area of snow melting systems is around 925,000 m^2, mostly in the capital area. Used water from the houses, at about 35°C, is thus used for de-icing sidewalks and parking spaces. Most of the larger systems have the possibility to mix the spent water with hot water (80°C) when the load is high. The main purpose is often to prevent icing or to make removal of the snow easier, rather than directly melt the snow. In downtown Reykjavík, a snow-melting system has been installed under most sidewalks and some streets, covering an area of 40,000 m^2. This system is designed for a heat output of 180 W/m^2 surface area and the annual energy consumption is estimated to be 430 kWh/m^2. About two thirds of that energy come from return water from the space heating systems and one third directly from hot supply water. The total installed power of all snow melting systems in Iceland is estimated to be 125 MWt and the annual energy consumption 1,440 TJ.

4.3 Industrial uses

The seaweed drying plant Thorverk, located at Reykhólar in West Iceland, uses geothermal heat directly in its production. The company harvests seaweed found in the waters of Breidafjordur in NW-Iceland using specially designed harvester crafts. Once landed, the seaweed is chopped and dried on a band dryer that uses large quantities of air heated to 85°C by geothermal water in heat exchangers. The plant has been in operation since 1975, and produces about 6,000 tonnes of rockweed and kelp meal annually using 35 l/s of 112°C water for the drying process.

Since 1986, a facility at Haedarendi in Grímsnes, South Iceland, has produced commercial liquid carbon dioxide (CO_2) derived from the geothermal fluid. The Heidarendi geothermal field has an intermedium temperature (160°C) and a very high gas content (1.4% by weight). The gas discharged by the wells is nearly pure carbon dioxide with a hydrogen sulphide concentration of only about 300 ppm. Upon flashing, the fluid from the Haedarendi well would produce 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. Through this process, the geothermal fluid is cooled and the solubility of calcium carbonate sufficiently increased to prevent scaling. The plant uses approximately 6 l/s of fluid and produces some 3,000 tonnes CO_2 annually, which is sufficient for the Icelandic market. The production is used in greenhouses, for manufacturing carbonated beverages and in other food industries.

Geothermal energy has been used in Iceland for drying fish for about 30 years. The main application has been the drying of salted fish, cod heads, small fish, stockfish and other products. Until recently, cod heads were traditionally dried by hanging them on outdoor stock racks. Because of Iceland´s variable weather conditions, indoor drying is preferred. Hot air is blown over the fish in batch dryers. Today about 10 companies dry cod heads indoors and all of them use geothermal hot water. The annual consumption of geothermal energy in this sector is about 600 TJ. The annual export of dried cod heads is about 15,000 tonnes. The product is shipped mainly to Nigeria where it is used for human consumption.

The industrial use of geothermal energy in Iceland decreased considerably when Kisilidjan, a diatomite plant at Lake Myvatn, closed down in late 2004. Before that time Kisilidjan was one of the largest industrial users of geothermal steam in the world.

Several other industrial processes utilizing geothermal energy have been operated in Iceland in the past. Among them are a salt production plant on the Reykjanes peninsula utilizing geothermal brine and seawater, drying of imported hardwood in Húsavík by geothermal water, 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 1,817 TJ per year.

4.4 Greenhouses

Apart from space heating, heating of greenhouses is one of the oldest and most important uses of geothermal energy in Iceland. For years, naturally warm soil had been used for growing potatoes and other vegetables when geothermal heating of greenhouses started in Iceland in 1924. The majority of the greenhouses are located in the south, and most are enclosed in glass. 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 through government subsidies on electricity for lighting. CO_2 enrichment in greenhouses is common, primarily by using CO_2 produced in the geothermal plant at Haedarendi. Outdoor growing at several locations is enhanced by soil heating with geothermal water, especially during early spring (total 120,000 m^2).

Greenhouse production is divided between different types of vegetables (tomatoes, cucumbers, paprika etc.) and flowers for the domestic market (roses, potted plants etc.). After a steady increase in the total surface area of greenhouses for several decades (1.9% per year between 1990 and 2000) this industry has experienced considerable changes during the past few years. Increased competition on the market requires increased productivity. Artificial lighting, which also produces heat, has contributed to diminishing demand for hot water supply to greenhouses. By lengthening of the growing season the utilization of greenhouses has been improved and the need for new constructions is less than before.

The total surface area was about 196,000 m^2 in 2008 including plastic tunnels for bedding- and forest plants. This is somewhat less than a few years back. Of this area, 50% is used for growing vegetables and strawberries, 26% for cutflowers and potted plants and 24% are nurseries for bedding- and forest plants. The total geothermal energy used in Icelandic greenhouses is estimated to be 744 TJ per year.

4.5 Fish farming

Fish farming has been a slowly growing sector in Iceland for a number of years. After a rapid growth from 2002 the total production reached about 10,000 tonnes in 2006, mainly salmon. Since then salmon production has almost stopped and the total production reduced accordingly to about 5,000 tonnes per year. In 2008 there were about 50 registered fish farms in Iceland. The dominating species is now arctic char but production of cod started a few years back and has since been about 1,500 tonnes annually. Initially, Iceland´s fish farming 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 for juvenile production. The beginning of the 21st century saw growing interest in developing sea cage farming of salmon in the sheltered fjords on Iceland's east cost. Two large farms were established and remained in operation for a few years, but today only two small cage farms are in operation. The main use of geothermal energy in the fish farming sector in Iceland is for juveniles production (char, salmon, cod). In land-based char production geothermal energy is also used for post-smolt rearing. The total geothermal energy used in the fish farming sector in Iceland is estimated to be 1,900 TJ per year.

5. ELECTRIC POWER GENERATION

Electricity generation using geothermal energy has increased significantly in recent years. Figure 4 shows the development in the period 1970-2009. The total installed capacity of geothermal generating plants is now 573 MWe. The production in 2008 was 4,400 GWh, which is about 26% of the total electricity production in the country.

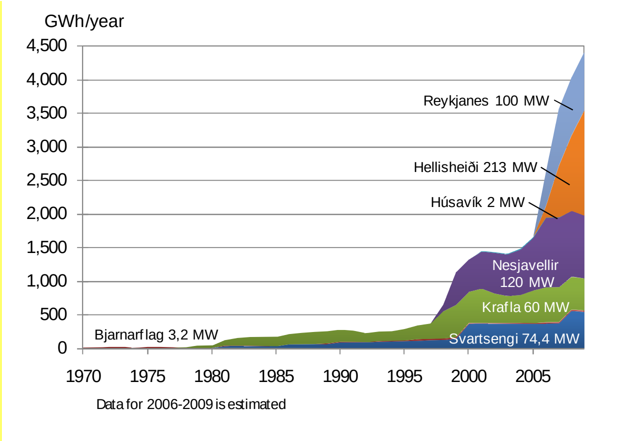

Figure 4: Electricity generation using geothermal energy in Iceland 1970-2009.

5.1 Bjarnarflag

The oldest geothermal power plant in Iceland is in Bjarnarflag (Namafjall field) where a 3.2 MWe back pressure unit started operation in 1969. The power plant has been operated successfully ever since the beginning except for three years in 1985-1987 when the plant was closed, partly due to volcanic activity in the area.

5.2 Krafla

The Krafla power plant in north Iceland has been in operation since 1977. Two 30 MWe double flash condensing turbine units were purchased, but due to unexpected difficulties with steam supply the plant was run with only one installed turbine for the first 20 years. The shortfall of steam was due to volcanic activity that injected volcanic gases into the most productive part of the geothermal reservoir. 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. Preparations are underway to build a new 150 MWe power plant in the area if the market situation requires.

5.3 Svartsengi and Reykjanes

The Svartsengi co-generation power plant of HS-Orka 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 20,000 people. The reservoir fluid is a brine at 240°C and with a salinity of about two thirds of sea water. The total production from the reservoir is about 400 kg/s. Of that between 50 and 75% is reinjected. Geothermal heat is transferred to freshwater in several heat exchangers. After expanding the plant in several steps the total installed capacity in Svartsengi is now 150 MWt for hot water production and 74 MWe for electricity generation. Of that 8.4 MWe come from Ormat binary units using low-pressure waste steam. A part of the effluent brine from Svartsengi (40 l/s) goes to a 5,000 m^2 surface pond called the Blue Lagoon. It is getting increasing popularity by tourists with an annual number of visitors over 400,000, making it one of Iceland's most popular tourist attractions. There is also a psoriasis clinic that takes advantage of the therapeutic effects of the geothermal brine. The Blue Lagoon company offers a line of skin care products that contain unique natural ingredients, silica, minerals and algae.

HS-Orka started operation of a new 100 MWe geothermal power plant at Reykjanes in May 2006 (two 50 MWe twin steam turbines with sea cooled condensers). An expansion of the plant by 80 MWe is under preparation. Of that 30 MWe will be produced by using brine from high pressure separators.

5.4 Nesjavellir and Hellisheidi

Reykjavik Energy has been operating a co-generation power plant at Nesjavellir high temperature field north of the Hengill volcano 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 hot water in heat exchangers. The capacity for hot water production is 300 MWt (1640 l/s of 83°C water). The power plant started generating electricity in 1998 with two 30 MWe steam turbines. In 2001, a third turbine was installed and the plant enlarged to 90 MWe and to 120 MWe in 2005. Reykjavik Energy started operation of a new 90 MWe geothermal power plant at Hellisheidi in the southern part of the Hengill area in October 2006. It was expanded by a 33 MWe low pressure unit in 2007 and further by installing two 45 MWe units in late 2008, increasing the total installed capacity of the plant to 213 MWe. Further expansion of the plant as well as hot water production (300–400 MWt) for district heating in Reykjavik is under construction.

5.5 Húsavík

At Húsavík, in Northeast Iceland, the generation of electricity using geothermal energy began in 2000 when a Kalina binary-fluid 2 MWe generator was put into service. It was one of the first of its kind in the world. The plant utilizes 120°C water as an energy source to heat a mixture of water and ammonia, which in closes circuit acts as a working fluid for heat exchangers and a turbine. Part of the hot water leaving the generating plant at 80°C is used for the town´s district heating, as well as the local swimming pool. Due to operational problems the plant had in late 2009 not been running for almost two years.

6. NEW DEVELOPMENTS

Production and drilling activities

Before the economic crisis hit Iceland in late 2008 the geothermal industry had grown rapidly over a number of years. This resulted in the present total generating capacity of geothermal power plants of 573 MWe, which is almost three times the capacity five years ago. In 2009 the Icelandic energy companies reduced considerably their geothermal activities compared to their previous plans. Figure 5 gives an overview of the drilling activity in the country in the period 1970 to 2008.

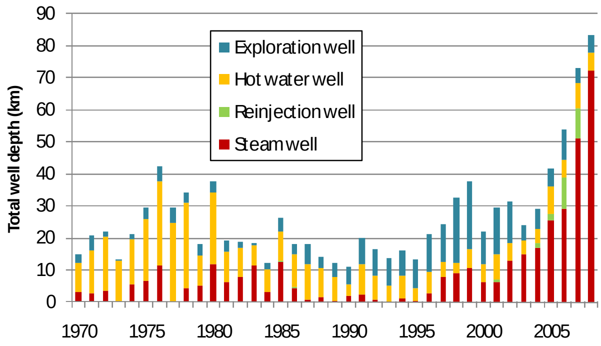

Figure 5: Total depth of geothermal wells drilled annually in Iceland 1970-2008.

CarbFix project

Reykjavik Energy in cooperation with Icelandic and foreign scientists is carrying out an experiment with storing CO_2 from the Hellisheidi geothermal plant in basaltic rocks. CO_2 from the plant will be dissolved in water and injected through wells down to 400-800 m. The liquid will react with calcium from the basalt and form calcite. This process occurs naturally and the mineral calcite is stable for thousands of years in geothermal systems. After laboratory studies field testing is now being carried out.

Methanol production in Svartsengi

The Icelandic-American company Carbon Recycling International (CRI) started in October 2009 the construction of a plant that uses CO_2 emissions of the Svartsengi geothermal power plant of HS-Orka to produce methanol to blend with gasoline to fuel cars. Production is expected to start in late 2010 and derive daily around 12,500 litres of fuel from 18 tonnes of CO_2.

Theistareykir geothermal field

Of the high-temperature geothermal fields in Iceland that have not yet been utilized, Theistareykir is the one that has been most intensively investigated in recent years. Theistareykir is located in North-East Iceland, about 25 km North-West of the Krafla geothermal field. A consortium of Icelandic energy companies has already drilled 6 exploration wells in the area. It is estimated that they could be used for production of about 45 MWe. The plans for building a power plant in the area (up to 200 MWe) to supply electricity to an Aluminium smelter are still being worked on.

Iceland Deep Drilling Project (IDDP)

A consortium of Icelandic energy companies and international organizations has for about 10 years been preparing drilling of 4-5 km deep wells into high-temperature hydrothermal systems in Iceland to reach 400-600°C hot supercritical fluid. The main purpose of the IDDP project is to find out if it is economically feasible to extract energy and chemicals out of hydrothermal systems at supercritical conditions. Drilling of the first well started in the Krafla field in late 2008 and continued in 2009. After considerable drilling problems further drilling had to be abandoned when magma was hit by the drill bit at 2114 m depth. Due to this the IDDP has postponed the planned drilling of two additional wells in other geothermal fields in Iceland. Meanwhile the Krafla well is being tested and preparations for further drilling being made.

7. DISCUSSION

During the last century Iceland has developed the indigenous energy resources, hydropower and geothermal energy, to increase the standard of living and make the country less dependent upon imported fossil fuel. There is a large potential for increased utilization of geothermal energy. Geothermal electricity generation is expected to increase in the coming years, but direct uses will most likely only grow at a moderate rate.

The Icelandic energy companies have plans for considerable expansion in the geothermal electricity generation as can been seen in Table 1 below. This is based on expected increase in the electricity consumption due to new aluminium smelters or other energy intensive industry. The future of these plans is now uncertain due to several issues that have not been resolved like for example exploration licenses, environmental concerns and limited credit opportunities.

The Geothermal Training Programme of the United Nations University (UNU) has operated in Iceland since 1979 with six months annual courses for about 20 professionals from developing countries. Specialized training is offered in different geothermal disciplines. Most of the candidates receive scholarships financed by the Government of Iceland and the UNU. A MSc. programme was started in 2000 and a PhD programme in 2008 in cooperation with the University of Iceland. Also, annual workshops/short courses are held in Africa, Central America, and Asia. From the beginning a total number of 424 scientists and engineers from 44 countries have completed the six month courses and 20 have completed the MSc. programme.

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TABLE 1. PRESENT AND PLANNED PRODUCTION OF ELECTRICITY

	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 2009	573	4400	120	3	1879	12427					2572	16830
Under construction in December 2009	90	700									90	700
Funds committed, but not yet under construction in December 2009	140	1100									140	1100
Total projected use by 2015	1118	8600	120	3	2224	15072					3462	23675

TABLE 2. UTILIZATION OF GEOTHERMAL ENERGY FOR ELECTRIC POWER GENERATION AS OF 31 DECEMBER 2009

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 2009 if available, otherwise for 2008. 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 2009[3)] GWh/yr	Total under Constr. or Planned MWe
Bjarnarflag	Bjarnarflag	1969	1		1F	3.2	15	90
Krafla	Krafla	1978/97	2		2F	60	470	150
Svartsengi	Svartsengi	1977/99	2		1F	36	250	
Svartsengi	Svartsengi	1989/93	7		B	8.4	60	
Svartsengi	Svartsengi	2007	1		D	30	215	
Nesjavellir	Nesjavellir	1998/05	4		1F	120	940	
Húsavík	Húsavík	2000	1		B	2	0	
Hellisheidi	Hellisheidi	2006/08	5		1F	213	1600	225
Reykjanes	Reykjanes	2006	2		1F	100	850	80
Total			25			572.6	4400	545

TABLE 3. UTILIZATION OF GEOTHERMAL ENERGY FOR DIRECT HEAT AS OF 31 DECEMBER 2009 (other than heat pumps)

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)

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

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

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

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	5311	80	35			1000	2388	14173	0.45
Seltjarnarnes	DBIS	185	80	35			35	56	335	0.30
Mosfellsbær	DBGIS	156	80	35			29	79	468	0.50
Sudurnes	DBISF	693	82	35			136	370	2291	0.53
Akranes and Borgarfj.	DBGF	36	78	35			7	12	69	0.33
Akranes	DBGIS	182	78	35			33	62	353	0.34
Borgarnes	DBGIS	50	82	35			10	24	146	0.47
Stykkishólmur	DB	41	80	35			8	18	108	0.45
Dalabyggd	D	24	65	35			3	12	46	0.48
Reykholar	DBG	17	95	35			4	3	24	0.17
Sudureyri	DB	22	70	35			3	9	44	0.42
Drangsnes	DB	10	60	35			1	2	7	0.21
Hvammstangi	DB	31	77	35			5	11	62	0.36
Blönduós	DB	58	64	35			7	25	96	0.43
Skagafjordur	DBGIS	174	72	35			27	88	432	0.51
Siglufjordur	DBI	45	70	35			7	18	83	0.40
Ólafsfjordur	DBI	89	62	35			10	38	136	0.43
Dalvik	DBISF	135	64	35			16	42	161	0.31
Hrísey	DB	24	79	35			4	8	45	0.33
Akureyri	DBIS	521	78	35			94	175	994	0.34
Húsavík	DBIF	139	80	35			26	54	322	0.39
Reykjahlíd	DB	24	99	35			7	11	89	0.43
Eskifjordur	DB	39	82	35			8	9	55	0.23
Egilsstadir	DBGIS	96	73	35			15	28	138	0.29
Rangæinga	DBI	100	74	35			16	33	172	0.33
Flúdir	DBGI	145	98	35			38	39	324	0.27
Blaskogabyggd	DBGI	156	85	35			33	83	545	0.53
Selfoss	DBI	358	75	35			60	103	542	0.29
Hveragerdi	DBGI	360	82	35			71	61	377	0.17
Thorlakshofn	DBIF	49	94	35			12	25	192	0.51
Reykholar	I	42	112	55			10	34	253	0.80
Other users	DGBSIF	1275	80	35			240	539	3200	0.42
TOTAL		10586					1975	4458	26280	0.42

**TABLE 4. GEOTHERMAL (GROUND-SOURCE) HEAT PUMPS
AS OF 31 DECEMBER 2009**

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. (°C) - outlet temp. (°C)] 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 (°C)[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	1900	2	O	4.75		1	
Other				W			4	
TOTAL							5	

TABLE 5. SUMMARY TABLE OF GEOTHERMAL DIRECT HEAT USES AS OF 31 DECEMBER 2009

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 enthalpy (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

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]	1500	19044	0.40
Air Conditioning (Cooling)			
Greenhouse Heating	45	744	0.52
Fish Farming	75	1900	0.80
Animal Farming			
Agricultural Drying[5]			
Industrial Process Heat[6]	75	1817	0.77
Snow Melting	125	1440	0.37
Bathing and Swimming[7]	80	1335	0.53
Other Uses (specify)			
Subtotal	1900	26280	0.44
Geothermal Heat Pumps	4	5	0.04
TOTAL	1904	26285	0.44

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, 2005 TO DECEMBER 31, 2009 (excluding heat pump wells)

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

Purpose	Wellhead Temperatu	Number of Wells Drilled				Total Depth (km)
		Electric Power	Direct Use	Combined	Other (specify)	
Exploratior	(all)		70			17
Production	>150° C	40		45		195
	150-100° C		5			6
	<100° C		40			30
Injection	(all)	18				22
Total		58	115	45		270

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 Prog.
(6) Private Industry

Year	Professional Person-Years of Effort					
	(1)	(2)	(3)	(4)	(5)	(6)
2005	45	34	9			90
2006	55	36	10			90
2007	70	38	11	2		90
2008	70	40	12	1		90
2009	60	40	12	1		90
Total						

TABLE 8. TOTAL INVESTMENTS IN GEOTHERMAL IN (2009) 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$	%	%
1995-1999	13	76	20	174		100
2000-2004	37	72	10	80		100
2005-2009	58	881	37	925		100