

Geothermal Energy in Iceland

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Abstract. Due to Iceland's location on the Mid-Atlantic ridge, the island is provided with a great amount of geothermal energy. Hence, Iceland is well on the way to becoming completely independent of fossil fuels. Whereas high-temperature areas are mainly used for electricity generation, the more frequent low-temperature areas are utilized for direct application like space heating, bathing and greenhouses. Research done on the IDDP, which deals with Supercritical Geothermal Systems, is expected to be of global significance. In 2005, geothermal energy amounted for just over half of the country's primary energy needs. The advantages of utilizing geothermal heat are expressed in Iceland by an exceptional migration into the urban area of Reykjavik.

Facts about Iceland

Iceland is located in the North-Atlantic Ocean, close to the Arctic Circle. With 307,000 inhabitants on an area of 103,000 km², Iceland is the second largest island state in Europe after Great Britain. Simultaneously it also has the smallest population density in Europe. The cause for that is among other things that Iceland is able to do justice to its name: In the ice ages nearly the whole country was covered up with ice sheet. Today still 11 % (11,800 km²) of Iceland is covered with glaciers. The biggest glacier in Europe, Vatnajökull, is situated in the south-west of the island. It covers about 8,300 km² and reaches a thickness of about 1 km. Nearly 54 % of Iceland is wasteland, above all the Icelandic Uplands in the centre of the country. The remaining countryside is divided into 10 % lava area, 3 % inland waters and 20 % floor space. More than 93 % of the population live in cities; about 60 % live in the metropolitan area of the capital Reykjavik. The exportation of fish, tourism and metal processing are the main sectors of economy. Despite the fact that the industrial development of Iceland is only modest to this day, it is a coveted site for energy intense productions, above all aluminium smelting. The reason for that is the comparatively cheap electricity current due to Iceland's

huge energy resources, both hydro and especially geothermal, which plays nowhere else a greater role for the energy supply of a country than in Iceland (BARTH 1997; NOWAK et al. 2005; Wikipedia I & II).

Tectonical Setting of Iceland

Concerning its geological age of approx. 15 Ma to 20 Ma, Iceland is one of the youngest countries of the earth. The reason for that is its unique tectonical setting: First, Iceland is located at a **spreading center** – the Mid-Atlantic ridge – which is the boundary between the North American and the Eurasian tectonic plates. The two plates are moving apart about 2 cm/a. One special feature of this active spreading ridge is that it is one of the few which can be partly observed *above* sea-level. An especially spectacular place might be the national park Þingvellir, where the extension crevice named Almannagjá is about 6 km long and 80 m deep.

Secondly, Iceland is a **hot spot**, because it is situated where an asthenospheric magma-flow interacts with a deep-seated mantle plume. As a consequence of the buoyancy of the Iceland plume, the Iceland plateau results in a dynamic uplift. Thus the elevation of Iceland above sea-level can be declared. Furthermore, the magma-flow leads not only to a thick crust, but also to an increased volcanic activity, which favours and speeds up the expansion of Iceland (BARTH 1997; ELDERS et al. 2003).

Hence, it is needless to say that the geothermal resources in Iceland are closely associated with its special geological background.

Geothermal Energy and Concepts

Origin, Types and worldwide Reserves of Geothermal Energy

Geothermal energy has its derivation in the interior of the earth: The heat is constantly produced due to the decay of radioactive material and storage in the earth mantle and core. By transport processes like conduction and convection the heat is moved to the earth's surface.

Hot rocks and magma intrusions heat also the ground water, which then rises in direction of the lowest pressure – towards the surface. In order to use the geothermal energy of rocks in great depths, the rocks have to be run through by water, which acts as a heat exchanger. In these **hydrothermal systems** aquifers are used for energy production of heat or electrical current in dependence on the temperature. After CLAUSER 2006, the fluids of geothermal reservoirs can be subdivided into two types, depending on their pressure and temperature conditions: The **water dominated type**, appearing as warm water or wet steam, predominates at tem-

peratures $< 150^{\circ}\text{C}$. On the other hand, the **vapour dominated type**, which is marked by dry steam, occurs at temperatures $> 150^{\circ}\text{C}$.

The mean heat flow of the earth amounts to about 65 mW/m^2 . The remarkable amounts of energy stored in the earth can be best illustrated by comparison with the global production of primary energy in the year 2001 – about 420 EJ (1 EJ = $1 \cdot 10^{18} \text{ J}$) – or the annual primary energy requirements for the current century, estimated to 600 EJ to 1800 EJ. Thus, the geothermal energy resource could almost cover the nowadays energy consumption worldwide. In spite of that, it fails because of technical problems to harness this energy amount (CLAUSER 2006; FLÖVENZ 2006; LUND 1978; MERKEL 2006).

Special Geothermal Phenomena in Iceland

Usually, 10 m to 20 m under the earth's surface temperatures of approx. 15°C are predominant; the temperature increases by the so-called **geothermal gradient**, which comes to 35°C/km . Nevertheless, in countries with geothermal heat anomalies local gradients up to 300°C/km occur (BAHLBURG and BREITKREUZ 2004). For instance, in the poorly permeable basaltic bedrock in Arskogsstrond (N-Iceland) a temperature gradient over 200°C/km has been measured (FLÖVENZ et al. 2000).

In Iceland this geothermal energy is indicated by about 30 volcano systems and approx. 600 hot springs and geysers. The Støri-Geyser in Haukadalur was first of all described in the middle of the 17th century by a bishop, who gave him the name geyser, which means “bubble up”. But it was not till the middle of the 19th century, that the German chemist Robert BUNSEN (1811–1899) studied the phenomenon of the geysers: By the measurement of the water temperature in different depths of the spring shaft he found out, that the water pressure – and consequently the boiling point, too - increases with the depth. Due to that a drop in pressure leads to boiling of water; and the water vapour speeds up the underlying water which results in a sudden ejection of the geyser. In contrast to the Støri-Geyser, which is nearly inactive today, the nearby Strokkur breaks out every 10 minutes and reaches heights of 25 m. In former times these ejections were often provoked by the lowering of the ground water table or even the use of curd soap, but the latter is forbidden by environmental care since 1922 (BARTH 1997; NOWAK 2005).

Geothermal Areas in Iceland

General Overview

The general principle of geothermal energy production is shown in Fig. 1; the functioning differs depending on the particular geothermal type. Areas where geothermal resources have not been identified are so-called “**cold areas**” (LOFTSDOTTIR and THORARINSDOTTIR 2006). After FLÖVENZ 2006, geothermal

resources are divided into **conventional fields** – including high- and low-temperature areas – and **unconventional fields**, which are subdivided into petrothermal systems (often called EGS or HDR) and Supercritical Geothermal Systems (SGS). Almost all geothermal power plants in the world are conventional, and they differ in their geological properties and tectonical location.

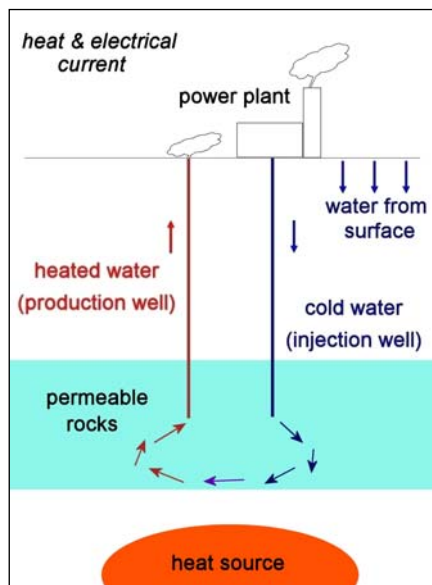


Fig. 1: Principle sketch of geothermal energy production by a power plant. Above a heat source, for instance a magma chamber, at least two wells are founded. Cold water is injected in the injection well and flows through the permeable rocks. Heated by the hot rocks the water begins to rise. Due to the density differences the water circulates. Eventually the heated water or steam is conveyed to the surface by the production well. On grounds of environmental care the water transported by the production well is nowadays reinjected after cooling again (cp. chapter “Environmental Aspects of Geothermal Energy”). Cold water from the surface ensures the natural recharge. While dry steam can be used directly to power a turbine for electricity generation, hot water is usually applied to heat exchangers or direct heating of buildings. Produced by the author 2006.

Conventional Fields

The **high-temperature areas** are directly linked to active volcanic systems or along their periphery. Consequently they are found only at the volcanic belt running through Iceland from south-west to north-east (Fig.2). Thus the heat sources are in general shallow magma intrusions. There, the water temperature is not less than 200°C to 250°C^a within 1 km depth. Due to the location on high ground and the high permeability of the rather young rock material, the ground water table is comparatively deep. The ground water itself is assumed to be mostly of meteoric origin and to undergo density-driven vertical circulation. Being heated in the underground, the water is able to dissolve various minerals. These substances are well utilized in research on geothermal energy. For instance, the characteristic smell of hot water can be attributed to dissolved H₂S. By measuring the concentra-

^a The author does apologize for not committing oneself to an exact value, but the figures of the water temperatures differ widely in dependence on their authors.

tion of dissolved minerals in the water e.g. from boreholes, useful information about the potential use of the area can be obtained. Due to the high content of dissolved minerals and gases the water from high-temperature resources cannot be utilized directly for heating. Nevertheless, the high steam pressure and high temperature are well suited for heating up fresh water as a hot water supply and for generating electricity with conventional turbines. At least 28 high-temperature areas have been identified to this day; the main areas are on the Reykjanes Peninsula, Krisuvik, Hengill (all in SW-Iceland), Torfajökull, Grimsvötn (S-Iceland), Namaskarð and Krafla (N-Iceland). Certainly, the soil in these areas is generally inhospitable for vegetation because of the high acidity, but the landscape is characterized by a pronounced diverse surface activity: Fumaroles, hot springs, mud pots and geysers indicate the great geothermal potential. High-temperature areas are supposed to be capable of developing into low-temperature areas as they extend outward from the centre of the volcanic belt as a result of continental drift (ANONYMOUS VI; BJORNSSON 2006; FLÖVENZ 2006; GISLASON 2000; LOFTSDOTTIR and THORARINSDOTTIR 2006; RAGNARSSON 2000).

By contrast, the **low-temperature areas** can be found all over Iceland, as they are all located in areas flanking the active volcanic zone – that is outside the active zone (Fig.2). The water temperature decreases with distance from the volcanic belt and is always below 150 °C to 100°C^a at a depth of 1 km. The largest resources are situated in south-west Iceland, especially in Reykir and Reykholt. The surface activity is usually restricted to hot springs; some systems even have no manifestations on the surface. In all, about 250 separate areas with 600 hot springs (temperature over 20°C) are known to this day. The maximal flow rate amounts to 180 l/s from a single spring. As a result of the rather low temperature the concentration of minerals and gases is low enough to use the water directly for hot water supply. In addition to that it is mainly used directly for heating purposes. Due to the better conditions the vegetation often reaches up to the banks. Like high-temperature areas, also low-temperature areas are in most cases marked by water of meteoric origin. The most important heat source for low-temperature resources is believed to be Iceland's extremely hot crust. Nevertheless, the faults and fractures caused by tectonic activity play another essential role by providing channels for the circulating water. These systems are often characterized by a great horizontal extension and constitute practically steady state phenomena. The most powerful systems are believed to be transient, as they are localized to convection systems with water undergoing vertical circulation in fractures several kilometres deep: The heat of the deeper rocks is then washed out at a much faster rate than it is renewed by conduction from the surroundings; so the geothermal activities of this areas draws to a close after some thousands of years (ANONYMOUS VI; BJORNSSON 2006; FLÖVENZ 2006; GUNNLAUGSSON et al. 2000; LOFTSDOTTIR and THORARINSDOTTIR 2006; RAGNARSSON 2000).

Sometimes an additional category for conventional fields is included – **medium-temperature areas**. These fields are marked by water temperatures between 150°C and 200°C^a. Not only high flowrates, but also binary systems – more complex and expensive equipment in comparison to conventional turbines – are needed for electricity production (FLÖVENZ 2006).

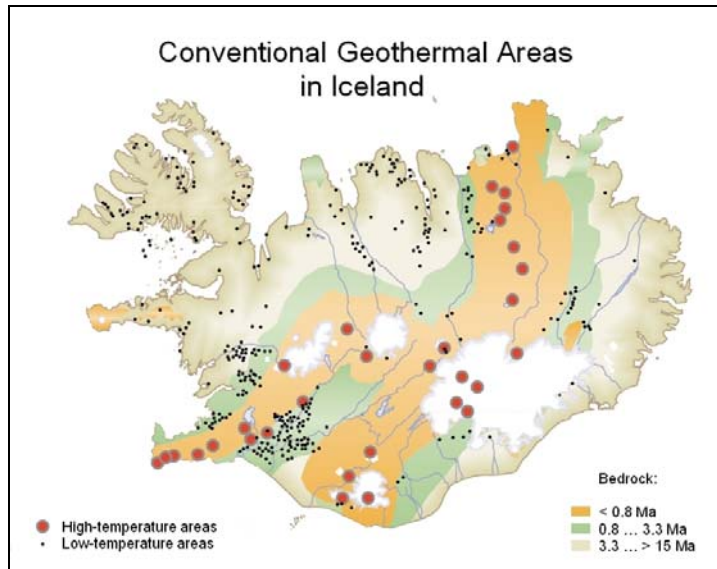


Fig. 2: Location of the conventional geothermal areas in Iceland. While the high-temperature fields are located within the active volcanic zone running through Iceland from south-west to north-east, the low-temperature fields are mostly in areas flanking the active volcanic zone. The age of the bedrock rejuvenates in direction of the active zone. Modified after PALSSON and JONNASSON 2006.

Unconventional Fields

Even in case of absence of ground water geothermal energy can be utilized: **Petrothermal systems**, which are often called **Enhanced Geothermal Systems (EGS)** or **Hot-Dry-Rock-Systems (HDR)**, are based on hydraulically broken fissures, in which water is artificially forced into. Due to the enhanced permeability the water is able to circulate between the boreholes (cp. Fig.1). These unconventional geothermal systems can be used for production of both heat and electrical current. After some decades petrothermal reservoirs are cooled down and can be used after a heat recover time of some decades or centuries again. These systems are still a subject to research, but they are believed to be suitable for improving the output of conventional medium-temperature areas. Hitherto these geothermal systems were not used in Iceland (FLÖVENZ 2006; MERKEL 2006; WEIBFLOG 2007).

Another type of unconventional geothermal energy is **Supercritical Geothermal Systems (SGS)**, which are characterized by supercritical hydrous gases having very low density and viscosity and thus extremely high flow rates. These fluids are the only phases existing at temperatures and pressures above the **critical point**, which occurs at 374.15°C and 221.2 bars for pure water and slightly higher in waters with dissolved components. These systems can be found at greater

depths below water dominated, conventional high-temperature areas, approx. in 3.5 to 5 km depth. In the year 2000 the **Iceland Deep Drilling Project (IDDP)**, a long-term programme, was established in order to enhance the economics of geothermal energy by tapping supercritical fluids in Iceland, e.g. on the Reykjanes peninsula - the landward extension of the Reykjanes-Ridge. Supercritical fluid with temperatures $> 450^{\circ}\text{C}$ is able to tenfold the energy output in comparison with conventional steam. Thus, if successful, this expensive technology might be used in many high-temperature areas in the world; so the IDDP will be of global significance (BJORNSSON 2006; ELDERS et al. 2003; FRIDLEIFSSON and ALBERTSSON 2000).

Utilization of Geothermal Energy in Iceland

Energy Reserves in Iceland

Fig. 3 shows the estimated source of Iceland’s geothermal energy. With 121 PJ ($1 \text{ PJ} = 1 \cdot 10^{15} \text{ J}$) – corresponding to 434 GJ ($1 \text{ GJ} = 1 \cdot 10^9 \text{ J}$) per capita – the annual primary energy supply in Iceland is the highest in the world. The development of the annual primary energy supply in the period 1940-2005 is illustrated in Fig. 4, classified by energy sources. In 2005 geothermal energy amounted for just over half of Iceland’s primary energy needs – 54.9 % of the total; another renewable energy - hydropower - provided after all 16.3 %. The rest of Iceland’s energy sources came from imported fossil fuel – petroleum products with 25.9 % and coal with 3 % – used for fishing and transportation.

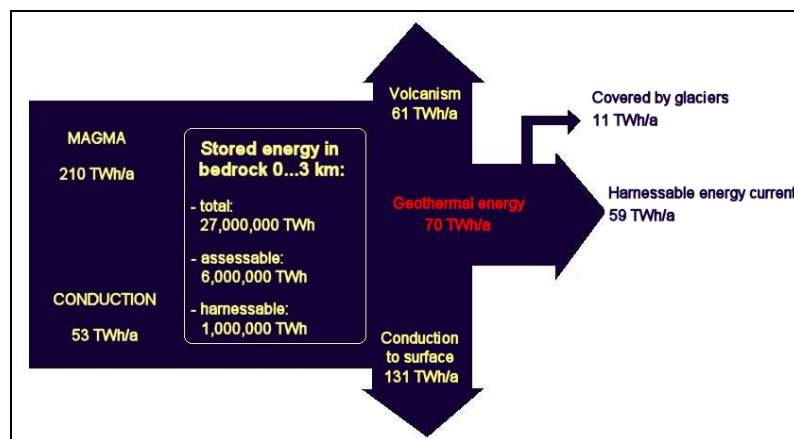


Fig. 3: Terrestrial energy current through the crust of Iceland. About 84 % – 59 TWh/a ($1 \text{ Wh} = 3.6 \text{ kJ}$) – of the available geothermal energy is usable. Modified after LOFTSDOTTIR and THORARINSDOTTIR 2006).

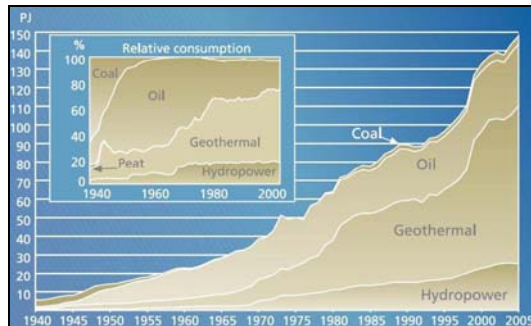


Fig. 4: Development of primary energy consumption in Iceland since 1940. The impact of rising oil prices in the 1970s can be seen clearly. Modified after PALSSON and JONNASSON 2006.

Historical Overview of Energy Development

Fossil fuels

With the beginning of the settlement around the year 870 Icelanders plugged away at finding energy to heat their houses due to the country's cold climate. The first heat source was wood burned in open fire. As a result of the scarcity of wood, later they relied upon the use of turf and seaweed and later even imported coal. Energy utilization in the modern sense, however, only started with the industrial revolution: With the beginning of the 20th century the use of coal for heating increased, and also Iceland's dependence on oil began. With the erection of the first electric power plants in the 1930's heating with electricity became more common. By 1950 about 20% of families used oil for heating, 40% used coal and about 25% enjoyed geothermal heating services. In the 1950s, the equipment to utilize oil for heating improved, and as a result coal was practically eliminated from space heating in Iceland around 1960. By the end of the century central heating using hot water, circulating throughout houses in closed circuits, was widely developed (BJORNSSON 2006; LOFTSDOTTIR and THORARINSDOTTIR 2006).

Geothermal Energy

The utilization of geothermal heat by the first settlers of Iceland was primarily confined to bathing, cooking and laundering via the hot water of hot springs. In the late 19th century geothermal energy was first used for market gardening and at the beginning of the 20th century for heating greenhouses. However, modern use of geothermal energy did not start until the 1907, when a farmer in West-Iceland succeeded in conveying steam from a hot spring for heating purposes through a concrete pipe and into his house, which stand several meters above the hot spring. The use of geothermal for space heating on a large scale began in Reykjavik in the late 1920's: In this time, the first drilling for geothermal water began, and shortly afterwards the first district heating service – the Reykjavik District Heating – became reality. In 1930 a 3 km long pipeline was built to transport hot water from

boreholes in Laugardalur to a primary school in the eastern part of Reykjavik, which then became the first structure in Reykjavik to be supplied with hot water. At that time 14 l/s of water at 87°C were provided. This hot water utility proved so successful that people foraged for looking for more geothermal areas near the city to fulfil the increasing requirements. In the next decade about 30 boreholes were drilled, especially in the Reykir area. Soon more public buildings and swimming pools, as well as about 60 family homes were connected to the hot water supply. A major step was reached when in 1940 the first storage tank was built and in 1943, when a new 18 km pipeline was put into use. By the end of 1945 there were 2,850 houses provided with geothermal heat. Soon many communities around the country built their heating distribution systems in places where hot springs or successful drillings generated geothermal water. After all, about 200 l/s of water at 86°C could be delivered. Until the 1950's about half of the residents had access to hot geothermal water. In 1970 about 50% of the population was served by geothermal district heating systems. After the oil crisis in the 1970's, high priority was given to replacing imported oil with the indigenous energy sources hydro and geothermal energy. At the end of 1972 about 97% of houses in Reykjavik used geothermal water for heating purposes. Moreover, pipelines were laid to nearby municipalities, which are now supplied with geothermal water through the Reykjavik District Heating system. Today, the Reykjavik District Service is the largest geothermal district heating service in the world (ANONYMOUS VI; BJORNSSON 2006; GUNNLAUGSSON et al. 2000; LOFTSDOTTIR and THORARINSDOTTIR 2006).

Energy Use

Geothermal utilization is generally divided into two categories – **direct application** and **electricity production**. The minimum production temperatures in a geothermal area, which are required for the different types of use, are shown in the Lindal-Diagram (Fig. 5), named after its developer Baldur LINDAL (1918-1997). The main sectors of geothermal energy use and their proportions are illustrated in Fig.6.

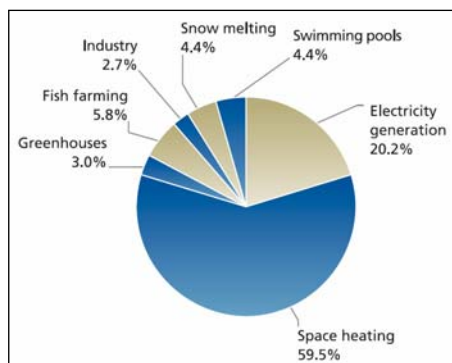
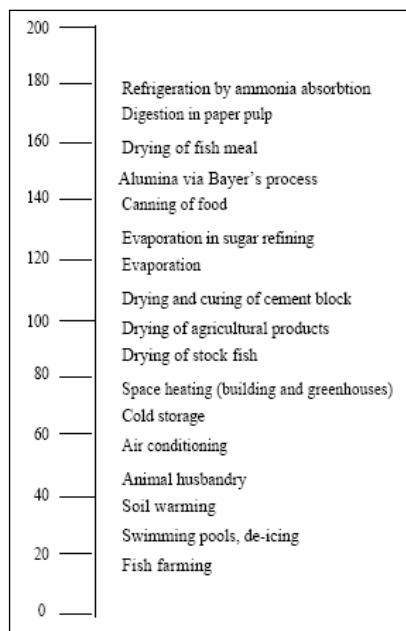


Fig.5 (left): The Lindal-Diagram (temperatures in °C). Modified and simplified after FRIEDLEIFFSON 1998.

Fig.6 (right): Sectoral share of utilization of geothermal energy in Iceland in 2005. Direct application, above all space heating, is the main sector. Modified after PALSSON and JONNASSON 2006.

Space Heating

Over the last 60 years there has been notable development in the use of energy for space heating in Iceland. Today geothermal space heating is not only the main utilization of geothermal energy, but also the most common in Iceland's households: It accounts about 89%, the rest is by electricity (10%) and oil (1%). The total geothermal energy used for space heating in Iceland is about 15,600 TJ per year. In recent years, the increased utilization of geothermal energy for space heating is a result of the population increase in the capital area. In addition, a number of small heating utilities have been established in rural areas. The share of geothermal energy in space heating is expected to rise in the near future. This achievement has enabled Iceland to import less fuel, and has resulted in lower heating prices.

Snow Melting

During the winter it is not uncommon to see pavement, streets and parking spaces in the urban area clear of snow and ice. This is due to the snow melting systems installed beneath the earth's surface, which have been installed increasingly, especially during the past two decades. Snow melting systems work quite ecologically as they distribute the about 35°C warm return water, which was for space heating in buildings before. If necessary, most snow melting systems are even able to mix the spent water with hot water (80°C). The total area of snow melting systems installed in Iceland is estimated to be about 840,000 m²; in Reykjavik the snow melting systems cover an area of approx. 550,000 m². Due to the fact, that the energy consumption is strongly dependent on the weather conditions, there can be just given an average value of about 1,150 TJ per year. About two third of that come from spent water used for space heating in houses and one third from 80°C hot water.

Electricity Production

The first geothermal power plant started in 1969 in Bjarnarflag (N-Iceland) and is still operating. As a result of the large expansion within the Iceland's energy intensive industry, the demand for electricity generated by geothermal energy has increased within two years from 50 Mwe and totals now some 200 Mwe. The total production in 2005 was 1,658 Gwh, which equals 19.1% of the country's total electricity production. About 84 % came from another regenerative energy, hydro power, and the rest from fuels.

Bathing

Heating of swimming pools is the third most important type of utilization of geothermal energy. In 130 of about 160 swimming pools in Iceland geothermal heat is used. The combined surface area comes to 28,000 m² and the average temperature is about 28-30°C. Most swimming pools possess at least one so-called hot pot, in

which the water temperature ranges from 35 to 42°C. Other health uses, such as the Blue Lagoon (to the north of Grindavik), comprising geothermal clay baths and water treatments, are gaining popularity. The total annual water consumption in geothermally heated swimming pools in Iceland is estimated to be 6,500,000 m³.

Industrial Uses

The first use of geothermal energy for industry purposes on a large scale was in 1967, when a diatomite plant at Myvatn near the Namafjall high-temperature field began to utilize geothermal steam for drying, but also for other purposes such as preheating 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. Thus this plant was one of the world's largest industrial users of geothermal steam until its closure in 2004.

A seaweed processing plant at Reykholar uses geothermal water for drying since 1976. About 34 l/s of 107°C hot water are used for heating air up to 85°C in heat exchangers. The annual use of geothermal energy in the plant is about 150 TJ; the production of seaweed and kelp has been 2,000-4,000 tonnes per year.

From 1974 to 1994 salt plant was in operation on the Reykjanes Peninsula. From geothermal brine and seawater the plant produced salt for the domestic fishing industry as well as low-sodium health salt for export.

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.

Since 1986 a facility at the Haedarendi geothermal field in south-Iceland has produced commercially liquid carbon dioxide (CO₂) from geothermal fluid, which is used in greenhouses for manufacturing carbonated beverages, and in other food industries. The area is marked by a temperature of 160°C and very high gas content of 1.4% by weight. The gas discharged by the well is nearly pure carbon dioxide with a low hydrogen sulphide concentration of about 300 ppm. Upon flashing, the fluid from the Cold water is pumped 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 increases to prevent scaling. The plant uses approx. 6 l/sec of fluid and produces some 2,000 tones annually.

In addition to the above mentioned uses of geothermal energy one could mention drying of pet food at several locations, retreading of car tires and wool washing, curing of cement blocks 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.

Greenhouses

One of the oldest and most important usage of geothermal energy in Iceland is for heating greenhouses. Before it was used first in 1924, naturally warm soil has been used for growing potatoes and other vegetables. Most greenhouses are located in the south, and the majority is enclosed in glass. The growing season and improved greenhouse utilization has been increased by artificial lightening and the use of additional CO₂-enrichment in recent years. The total area under glass was about 195,000 m² in 2002. Of this area, 55% is used for growing vegetables and 45% for flowers. Outdoor growing at several locations is enhanced by soil heating though geothermal water, especially during early spring. Soil heating enables growers to thaw the soil so vegetables can be brought to market sooner. It is estimated that about 105,000 m² of fields are heated this way. The total geothermal energy used in the greenhouse sector in Iceland is estimated to be 790 TJ per year.

Fish Drying and Fish Farming

Geothermal energy has been used for drying fish in Iceland for about 25 years. With about 70% of the production Salmon is the main species, but arctic char and trout are also raised. Until recently, cod heads were traditionally dried by hanging them on outdoor stock racks. Due to Iceland's variable weather conditions, indoor drying is preferred. The moisture from the raw material is removed by hot air blown over the fish. Today about 17 of 20 small companies dry cod heads indoors by means of geothermal hot water or rarely by geothermal steam. The annual export of dried cod heads is about 15,000 tones; the biggest proportion is shipped to Nigeria where it is used for human consumption. Geothermal water is also used mainly in the hatchery stage. Geothermal water, commonly 20-50°C, is used to heat fresh water in heat exchangers, typically from 5 to 12°C. The total production in fish farms in Iceland has been slowly increasing the last years to about 4,000 tonne per year. The total geothermal energy used in Iceland's fish-farming sector is estimated to be 1,680 TJ per year, of which about 65% is used for raising trout. (ANONYMOUS I; BJORNSSON 2006; LOFTSDOTTIR and THORARINSDOTTIR 2006; RAGNARSSON 2000).

Environmental Aspects of Geothermal Energy

In comparison with the beginning of the 20th century, when Icelandic buildings were heated by burning imported fossil fuels, nowadays the "smoke bay" of Reykjavík is – thanks to the utilization of geothermal energy – very unsoiled. Regardless, alternative energy is not automatically a clean energy. Whereas the content of gases and dissolved minerals in the fluids of low-temperature areas can be usually neglected, the substances in fluids of high-temperature areas can reach rather high concentrations. Above all, the greenhouse gases CO₂, H₂O and CH₄ might be emitted in huge amounts, which might affect the ozone hole negatively and course

changes in climate. In dependence on the geological background and the water-rock-interaction of the geothermal area, also environmental endangering substances like heavy minerals, metalloids, H₂, H₂S, S, N₂, NH₃, Rn and B can be released. For instance, due to reduced conditions in the ground water, the oxidation of H₂S to SO₂ in the atmosphere results in acid rain. Although the removal of many chemicals is a routine matter, the monitoring is to be handled responsibly. In order to minimize the contamination risk of rivers and lakes, which are situated nearby the geothermal area, nowadays the disposal water is reinjected into the bore wells. Due to the forced closed circuit, the substances are not released into the environment. Positive side-effects are less corrosion and an increased productivity as a result of the constantly high pore-pressure; but on the other hand the latter might cause fractures tending to micro-seismicity and ground subsidence.

Leaky borewell-walls might effect so-called steam “blow-outs”. These explosions are seldom and more unlikely than e.g. the risk of fire while oil- or gas-drillings. Other impairments are the typical “rotten egg” smell of most geothermal areas as a result of H₂S; and the noise, especially during drills and well-tests.

Another intensively discussed aspect of geothermal energy is its impact on the soil: Not only regions around power plants, but also natural geothermal areas are often characterized by acid soil being inhospitable for plants. On the other hand, it should be noted, that Iceland’s unique colourful landscape is not seldom a result of special mineral accumulations provoked by geothermal activity. Indeed, very little land is needed for building power plants, but subversion of characteristic landscape and ensuring of infrastructure are significant requirements for the utilization of geothermal energy.

The most considerable advantage of geothermal energy is of course, that it is permanently available, above all in hot spot areas like Iceland. Even if some decades or centuries are needed for renewing the area’s geothermal energy, on geological scale it is infinite. In Iceland, the intense use of geological energy has stirred up not only migration into cities, because people prefer to live in areas where geothermal heat is available, but also an improved quality of life due to the advantages of direct use.

Regardless, in future research has to be done; for both monitoring and technologies (ANONYMOUS II-VII; BALLZUS et al. 1999; GISLASON 2000; GUNNLAUGSSON et al. 2000; GUNNLAUGSSON 2000; JOLIE 2006; MERKEL 2006).

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