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CO_2 SAVING BY USING GEOTHERMAL ENERGY FOR HOUSE HEATING IN ICELAND

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ABSTRACT

Geothermal activity is very common in Iceland and can be directly connected to the volcanic activity. It pays a major role in the energy economy of Iceland where over 60% of the primary energy used in Iceland comes for geothermal. The principal use of geothermal energy is for space heating but it is also used for swimming pools, snow melting, greenhouses, fish farming and industrial uses. Geothermal energy is increasingly used for electrical production. Geothermal energy is one of the cleanest energy sources available. In the case of Reykjavík the use of geothermal water has reduced CO_2 emission by 100 million tonnes or 3-4 million tonnes annually.

1. INTRODUCTION

Iceland is located on the Mid-Atlantic Ridge, a plate margin characterized by high heat flow. Due to the high heat flow hot springs are very abundant in the country. About 1000 geothermal localities have been recognized in Iceland and hot springs have also been identified in a few places on the sea floor surrounding the country.

The average temperature in January is -1 °C and 11°C in July. Due to the low summer temperature, the heating season lasts throughout the year and is therefore suitable for district heating of houses and variable production cost is small part of the total production cost.

2. GEOTHERMAL ACTIVITY

Geothermal water is generally of meteoric origin, i.e. it is rainwater which has fallen to earth and sinks deep beneath the earth´s surface where it is heated up by hot substrata and magma intrusions. There are two types of geothermal areas that are low-temperature areas and high-temperature areas (Figure 1). The division is based on temperature and geological characteristics of the areas.

The general definition of the low-temperature areas is that its temperature is less than 150°C at a depth of approximately 1000 meters. These fields are characterized by warm and hot springs with little or no alteration around the springs, and vegetation often reaches up to the banks. In the high-temperature areas the water temperature is not less than 200°C at a depth of 1000 meters. The surface activity of these areas is much more diverse than that of the low-temperature areas. Fumaroles are found along with boiling hot springs, mud pots and geysers. Generally the soil is very acidic making it inhospitable to vegetation.

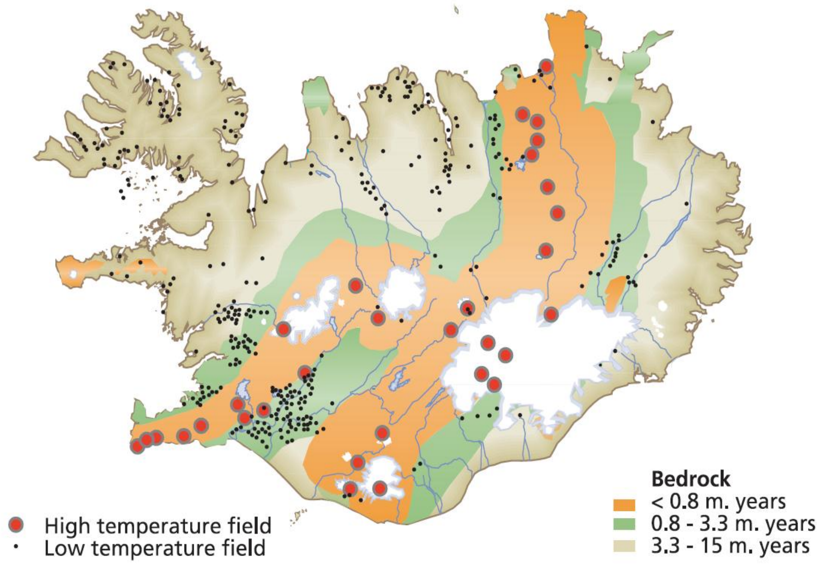

FIGURE 1: High and low temperature geothermal areas

The low-temperature geothermal systems are all located outside the volcanic zone passing through Iceland. The largest such systems are located in SW-Iceland on the flanks of the volcanic zone, but smaller systems are found throughout the country. The surface manifestations of the low-temperature activity are in most cases hot or boiling springs, while a few such systems have no surface manifestations. Spring flow rates range from almost zero to a maximum of 180 L/s from a single spring. The heat-source for the low-temperature activity is believed to be the abnormally hot crust of Iceland, but faults and fractures, which are kept open by the continuously ongoing tectonic activity also play an essential role by providing the channels for the water circulating through the systems and mining the heat.

3. THE USE OF GEOTHERMAL ENERGY

Iceland is among those nations with the highest relative utilization of geothermal energy. Harnessing of this energy source has been one of the key factors in improving the quality of life in Iceland. In addition to geothermal energy, Iceland´s energy supply is based on hydropower and imported fossil fuels. The share of domestic renewable energy sources has grown in recent decades and is in 2006 about 77% of total energy consumption (Figure 2).

About 23% of the primary energy in Iceland is imported and about 77% domestic, renewable energy. The major share of imported petroleum products is used for fishing and transportation. Figure 3 gives a breakdown of the utilization of geothermal energy in 2006. It is mainly used for space heating (54%), then electricity generation (28%), fish farming (5%), swimming pools (4%), snow melting (4%), greenhouses (3%) and industry (2%).

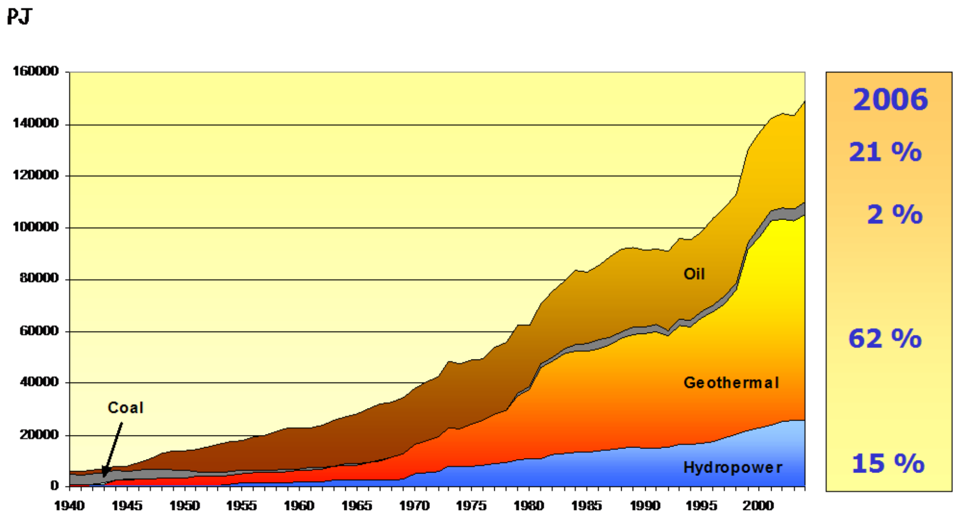

FIGURE 2: Primary energy consumption in Iceland, 1940-2005 (Orkustofnun 2007).

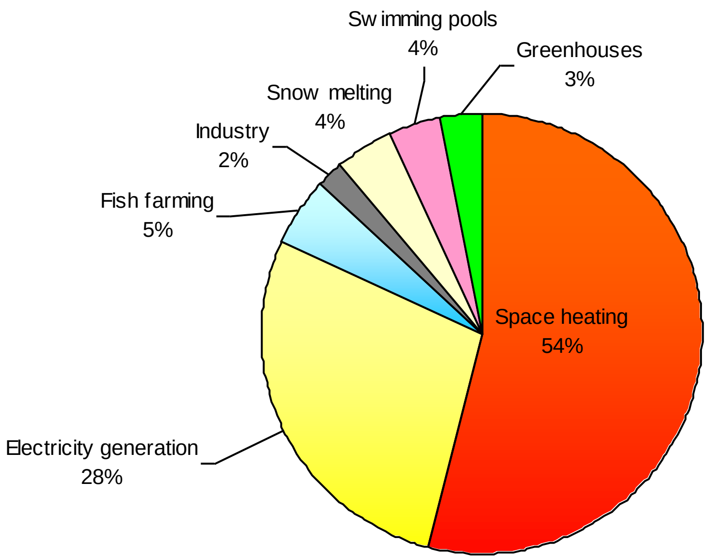

FIGURE 3: Utilization of geothermal energy in Iceland 2006 (Orkustofnun 2007).

4. HARNESSING GEOTHERMAL WATER FOR HOUSE HEATING

For centuries, the utilization of geothermal heat was primarily limited to cooking, bating and laundering. In the Icelandic sagas which were written in the 12^{th} – 13^{th} century A.D. bathing in hot springs is often mentioned. The bathing pools seem to have been rather primitive. Commonly bath was taken in brocks where hot water from often boiling springs would be mixed with cold water. The famous saga writer Snorri Sturluson lived at Reykholt in west Iceland in the 13^{th} century. At that time there was a bath at Reykholt but no information is about its age, size and structure. There are implications that geothermal water or steam was conducted to the house for heating (Sveinbjarnardóttir 2005).

When Icelanders moved out of houses made of turf into houses of wood or concrete at the end of the nineteenth and the beginning of the twentieth century the need for space heating of some sort was necessary. At first it was fulfilled by burning coal or peat in stoves or ovens. In many houses central heating with coal furnaces was installed. Soon after the introduction of coal furnaces the idea of utilizing geothermal heat for space heating popped up. Experiments proved that it was technologically possible and could be advantageous (Jonason and Thordarson, 2007). A farmer at Sudurreykir, close to Reykjavík, piped water from a geothermal spring to his house in 1908 and in 1911 a farmer at Sturlureykir in Borgarfjordur, West Iceland, harnessed steam from a hot spring for space heating. The first large scale heating using geothermal water was initiated during the First World War by an owner of a woollen factory who led hot water from nearby spring in pipes into the factory and worker's housing. The practice spread throughout the country and in 1930 at least 10 farmhouses in the south of Iceland were heated with geothermal water.

5. DISTRICT HEATING IN REYKJAVÍK

5.1 Historical development

For hundreds of years, the residents of Reykjavík used the thermal springs in Reykjavík to wash their laundry. District heating in Reykjavík began in 1930, utilizing water from boreholes in the Laugarnesfield closed to thermal springs in the area. This was the first district heating system with geothermal water. The water was piped 3 kilometres to a primary school in the eastern part of Reykjavík, which thereby became the first building in Reykjavík to be supplied with natural hot water. Soon more public buildings, including the national hospital, swimming pool as well as about 60 private dwelling houses were connected to the hot water supply.

It was clear from the beginning that more geothermal water would have to be found to fulfil the requirements of the town of Reykjavík. A large geothermal area 17 km east of Reykjavík, the Reykir-Reykjahlíð field, was considered to be ideal both relatively close and capable of producing quantities of geothermal water. Shallow drillholes were drilled in this area and a pipeline build to Reykjavík. The first house was connected to the distribution system from this area in 1943. From the beginning the distribution system was interconnected and then the Reykjavík District Heating could deliver 200 L/s of water of 86°C. By the end of the following year the number of connected houses reached 2850.

Research and test drilling resulted in more geothermal water to be found in the vicinity of the old thermal springs in Reykjavík. In the beginning of 1962 many wells were harnessed and pumps installed to increase their output. Several holes were drilled between 1967 and 1970 in another geothermal field by the Elliðaár River, within the city limits of Reykjavík. It was also necessary to re-drill older boreholes in Reykir-Reykjahlíð to increase their output.

By 1970 nearly all the houses in Reykjavik were receiving hot water for heating. Moreover, pipelines were laid and sales began to nearby municipalities.

Today Reykjavik District Heating serves 99.9% of the population in Reykjavik and neighbouring communities total about 183,000 people or about 58% of the total population of Iceland.

5.2 The geothermal fields today

Three low temperature geothermal areas are utilized for district heating in Reykjavík and a high-temperature geothermal field at Nesjavellir. In the low-temperature fields, there are a total of 52 exploitation wells with a total capacity of about 2600 l/s (Table 1).

TABLE 1: Summary of the low temperature geothermal fields used for district heating in Reykjavík.

Field	Temp °C	Capacity l/s	MWt	No. of exploitation wells
Laugarnes	125-130	340	125	10
Elliðaár	85-95	260	50	8
Reykir-Reykjahlíð	85-100	1980	370	34

The exploitation of geothermal water from the ***Laugarnes field*** began in 1928-1930 with the drilling of 14 shallow wells near the Þvottalaugar thermal springs. The deepest well was 246 m deep and the well field delivered 14 l/s of artesian water at a temperature of 87°C. This water was used for heating schoolhouses, hospital, swimming pools, and about 70 residential houses.

In 1958, further drilling in the Laugarnes area commenced with a new type of rotary drilling rig, which was able to drill deeper and wider wells than previously possible. Deep well pumps pumped the water from the wells, whereas the water previously extracted in the area had been free artesian flow from the wells. The yield increased to 330 l/s of 125 to 130°C water.

Now there are 10 production wells in the field, which cover about 0.28 km^2 and is located at a junction of a caldera and a fault-scarp. The temperature is 110-125°C at 400 to 500 m depths and increases with depth. The highest measured temperature is 163°C at 2,700 m depth. The main aquifers are at 1,000 to 2,000 m depth.

The ***Elliðaár field*** had minor surface manifestations before drilling with a maximum temperature of 25°C. Drilling began in the area in 1967 finding aquifers with 85-110°C. The exploitation area covers 0.08 km^2 but the manifestations cover 8 – 10 km^2.

Prior to drilling in the ***Reykir-Reykjahlíð field***, the artesian flow of thermal springs was estimated to be about 120 l/s of 70-83°C water. After drilling, the water from this area was piped to Reykjavík and by the end of 1943 about 200 l/s of 86°C water was available for heating houses in Reykjavík. After 1970, the deep rotary drilling of large diameter wells and installation of pumps redeveloped the Reykir field. The yield from these wells then increased to 2000 l/s of 85-100°C water.

The Reykir-Reykjahlíð geothermal field, which is about 5.5 km^2, is geographically divided into sub-areas, Reykir and Reykjahlíð. It is located between two calderas and the stratigraphy consists of lavas and hyaloclastite layers cut by numerous faults and fractures. Altogether, 34 exploitation wells are in the field. The temperature is in the range of 65-100°C.

At ***Nesjavelllir high-temperature field*** 300 MWt are installed, equivalent to about 1680 l/s. The temperature of this field is around 300°C. There cold water has to be heated in heat exchangers.

5.3 Chemistry of the geothermal water

In general, there are more dissolved solids in geothermal water than in cold water, sometimes so much that it is not considered healthy for consumption. Fortunately, the low-temperature geothermal fields utilized for district heating in Reykjavík are low in total dissolved solids (Table 2) and can be used directly for heating and even cooking and drinking. This water almost fulfils the requirements of drinking water codes. The sulphide concentration is higher than allowed in drinking water as well as the pH value.

The water from the high-temperature geothermal field cannot be used directly for house heating due to relatively high content of dissolved gases and dissolved solids. Therefore at Nesjavellir water and steam is used to heat up cold groundwater in heat exchangers. The groundwater is saturated with dissolved oxygen which has to be removed before it is pumped to Reykjavík.

TABLE 2: Chemical composition of geothermal water and heated groundwater. Concentration in mg/kg.

	Laugarnes	**Elliðaár**	**Reykir-Reykjahlíð**	**Nesjavellir geothermal water**	**Nesjavellir heated ground water**
°C	130	86	93	290	83
pH/°C	9.45/23	9.53/23	9.68/20	6.2	8.59/24
SiO_2	150.2	67.6	95.0	600	21.8
Na	70.3	46.2	47.9	106	9.8
K	3.5	1.0	1.0	22.1	0.8
Ca	3.7	2.2	1.5	0.1	8.7
Mg	0.00	0.01	0.02	0.00	5.1
CO_2	17.5	26.3	23.7	204	31.4
H_2S	0.3	0	0.9	279	0.3
SO_4	28.7	13.3	20.3	13.2	8.3
Cl	55.6	25.1	12.2	118	8.5
F	0.6	0.18	0.83	0.7	0.08
CO_2 - gas				8700	
H_2S - gas				3350	

5.4 Production and monitoring of the low-temperature geothermal fields

Geothermal energy is generally classified as renewable resource. This is based on the fact that geothermal resources are steadily renewed, although the renewals takes place at a different rate depending on the nature of the resources. Geothermal utilization involves energy extraction from geothermal reservoirs. The generating capacity of systems is often poorly known and they often respond unexpectedly to long-term utilization. Therefore, the management of geothermal resources can be highly complicated. Successful management relies on proper understanding of the geothermal system involved, which in turn relies on adequate information on the system. This knowledge is continuously gathered throughout the exploration and exploitation history of a geothermal reservoir through careful monitoring. The parameters that need to be monitored to quantify a reservoir’s response to production differ from one geothermal system to another. In addition, the methods of monitoring as well as monitoring frequency may differ. The basic parameters, which should be included in geothermal monitoring programs, are:

- Mass discharge history of production wells.
- Temperature of fluid produced.
- Water level of production wells.
- Chemical content of water produced.
- Reservoir pressure (water level) in observation wells.
- Reservoir temperature through temperature logs in observation wells.

The following chapters describe the monitoring of the low-temperature geothermal fields utilized by the Reykjavik Energy.

5.4.1 The Reykir - Reykjahlíð geothermal field

Aquifers in this field can be correlated to faults and fractures. Prior to drilling, the artesian flow of thermal water was estimated about 120 L/s of 70-83°C water. After redeveloping of the field and installation of downhole pumps, yield from the wells increased to 2000 L/s of 85-100°C water. Figures 4 and 5 show the production (in Gigaliters) and water level in observation wells from 1983 to 2006. The water level was steadily decreasing until 1990 when it became possible to reduce pumping from the field when the new power plant at Nesjavellir started operation. Immediately after the reduction of production, the pressure built up and the water level rose again. Changes in chemistry and temperature of the fluid were only observed at the south-eastern boundary of the field (Gunnlaugsson et al., 2000).

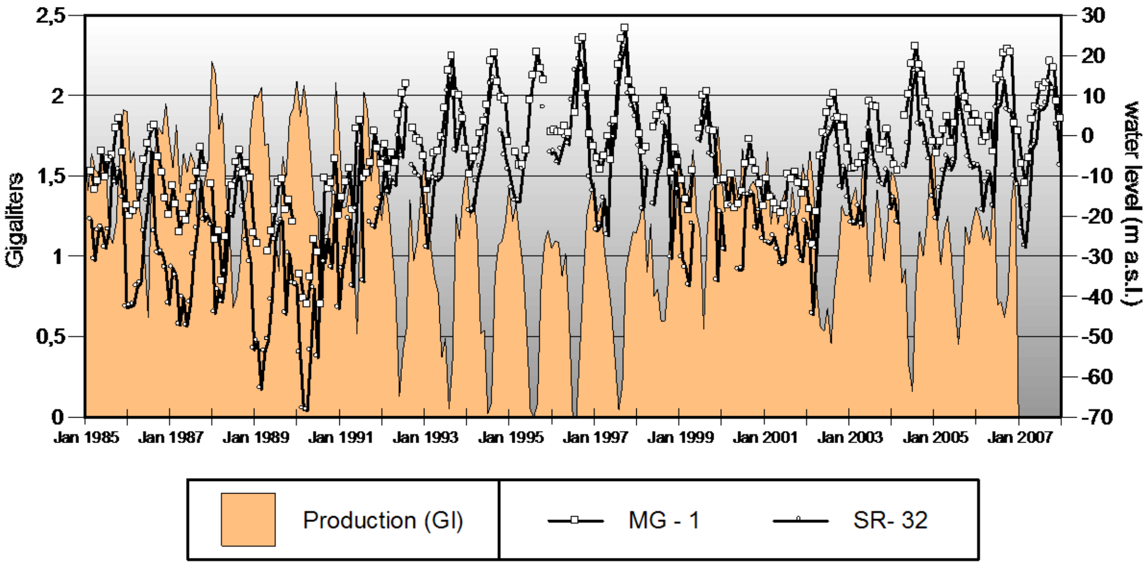

FIGURE 4: Production (in Gigaliters) from the Reykir field and the water level in observation well from 1983 to 2007

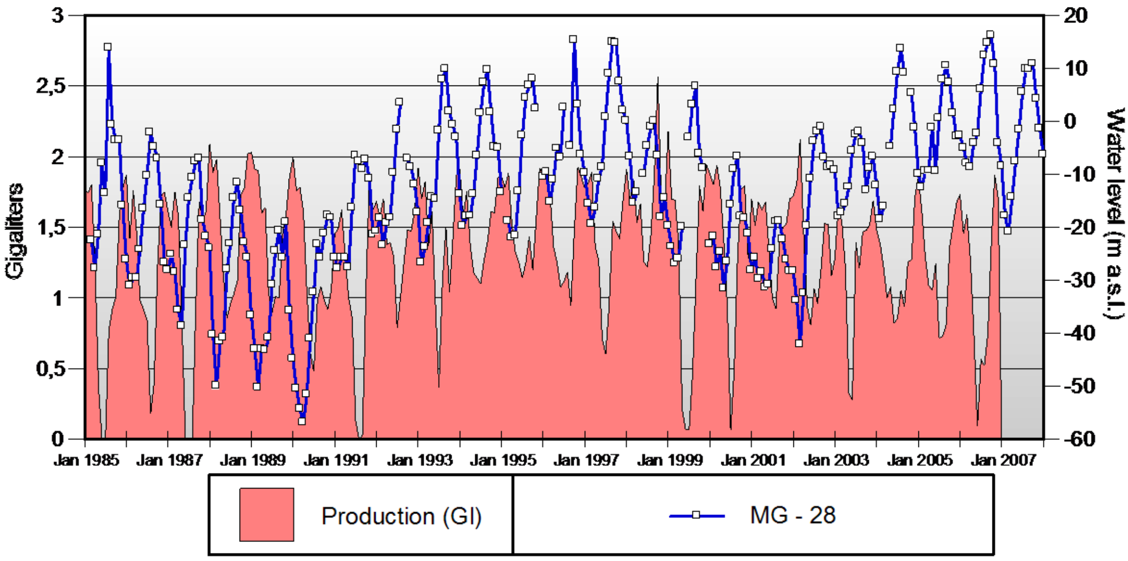

FIGURE 5: Production (in Gigaliters) from the Reykjahlíð field and the water level in observation well from 1983 to 2007

5.4.2 The Laugarnes geothermal field

Prior to exploitation, the hydrostatic pressure at the surface in the Laugarnes geothermal field was 6-7 bars, corresponding to a free water level of 60-70 m above the land surface. Exploitation has caused a pressure drop in the field, and the water level has fallen (Figure 6). Consequently, fresh and slightly saline groundwater has flowed into the pressure depression and mixed with the geothermal water. A slight decrease in silica and fluoride, and in some wells also an increase in chloride concentration, were noticed but without changes in the fluid temperature. The mixing of different water types resulted in disequilibria of calcite and formation of that mineral. Reduced pumping after 1990 has reduced the pressure drop and the mixing of groundwater (Gunnlaugsson et al., 2000).

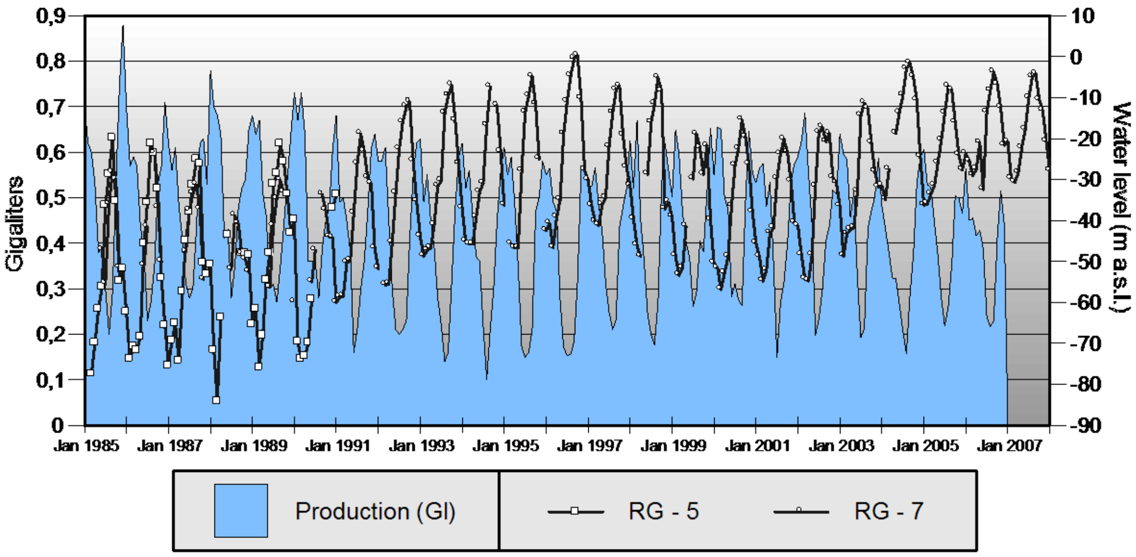

FIGURE 6: Production (in Gigalitres) from the Laugarnes field and the water level in observation well from 1983 to 2007

5.4.3 The Ellidaár geothermal field

When exploitation started in this area, the temperature was in the range of 95-110°C. Production from the field caused a pressure drop and consequent cooling of the field. Cold groundwater from the surroundings mixed with the thermal water, reduced the temperature, and affected the chemistry of the water by diluting the silica and the fluoride concentrations. Chemical changes can often be seen before noticeable changes in temperature are observed. Reduction of production in 1990 resulted immediately in higher water levels in the area (Figure 7) and a decrease in the mixing with cold water (Gunnlaugsson et al., 2000).

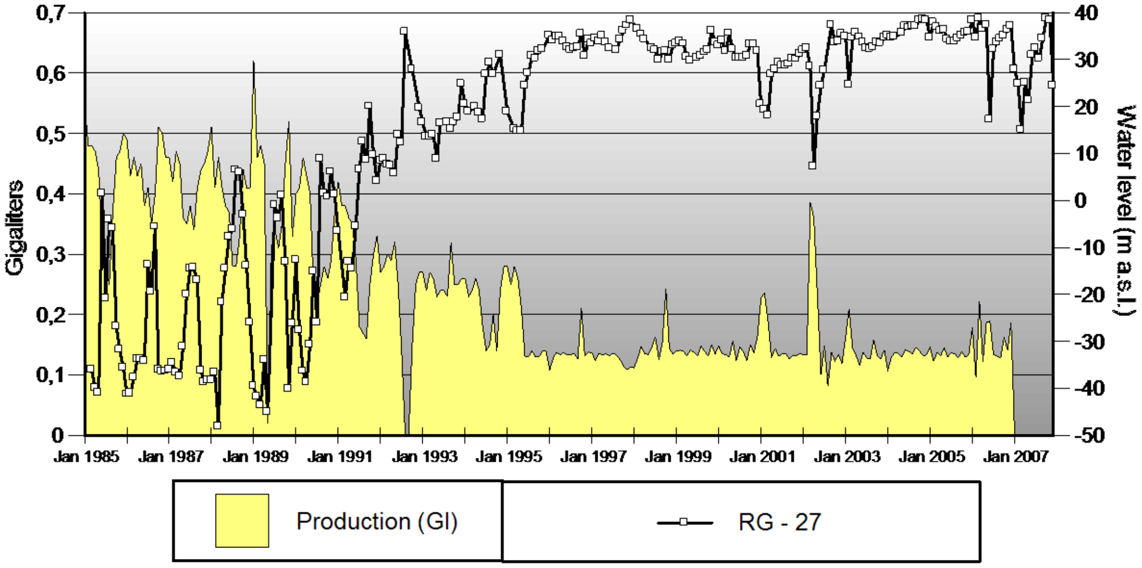

FIGURE 7: Production (in Gigalitres) from the Elliðaár field and the water level in observation well from 1983 to 2007

5.5 The distribution system

Reykjavík District Heating uses either a single or a double distribution system (Figure 8). In the double system, the return flow from the consumer runs back to the pumping stations. There it is mixed with hotter geothermal water and serves to cool that water to the proper 80°C, before being re-circulated. In the single system, the backflow drains directly into the sewer system. During the coldest period of the year the consumers use about 18,400 m^3/hour of water for space heating. When production from the fields is not quite sufficient, the water in the storage tanks usually meets the demand because the cold spells do not last very long.

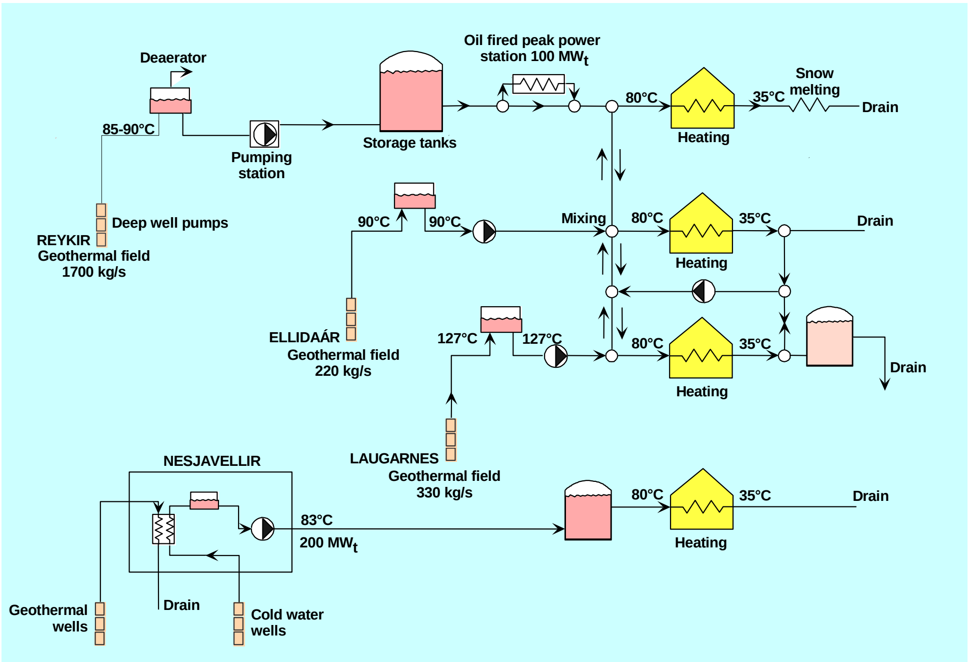

FIGURE 8: Simplified diagram of the district heating system in Reykjavík, Iceland

The geothermal water from Reykir-Reyjahlíð field flows through a main pipeline to six tanks just outside Reykjavík that hold 54 million litres. From there, the water flows to six storage tanks on Öskjuhlíð in mid-Reykjavík, holding 24 million litres. Nine pumping stations distributed throughout the servicing area pump the water to the consumers. The water from Nesjavellir flows to two tanks on the way to Reykjavík that hold 18 million litres. From there, the heated water flows along a main pipeline to the southern part of the servicing area. The heated fresh water and the geothermal water are never mixed in the distribution system, but kept separated all the way to the consumer. The total length of the pipelines in the distribution system is about 2700 km. This includes all pipelines from the wells to the consumer. The new pipes are insulated with foam or rock wool.

After the hot water has been used in a building, it is 25-40°C. In recent years, it has become increasingly common to use this run-off water to melt snow of pavements and driveways. The use of geothermal water for melting snow has been increasing during the last two decades. The total area of snow melting systems installed in Iceland is around 835,000 m^2 and the energy consumption is approximately 360 GWh annually. Half of this energy comes from used return water from space heating systems.

The annual production from 1994 to 2006 is shown in figure 9. For the first years the production was below 10 million tonnes per year but from about 1960 to 1990 there was an increase in production as the system expanded to new areas. Then almost all houses had been connected and since 1990 the expansion is only new houses which are connected. In 2006 the annual water production was about 70 million cubic meters of hot water. The total power production of hot water in 2006 was equivalent to 392 MWt with about 60% of the water coming from the low-temperature fields. About 85% of the hot water is used for space heating and 15% being used for bathing and washing. The utility serves about 183,000 people living in about 30,660 houses. This is 58% of the total population in Iceland.

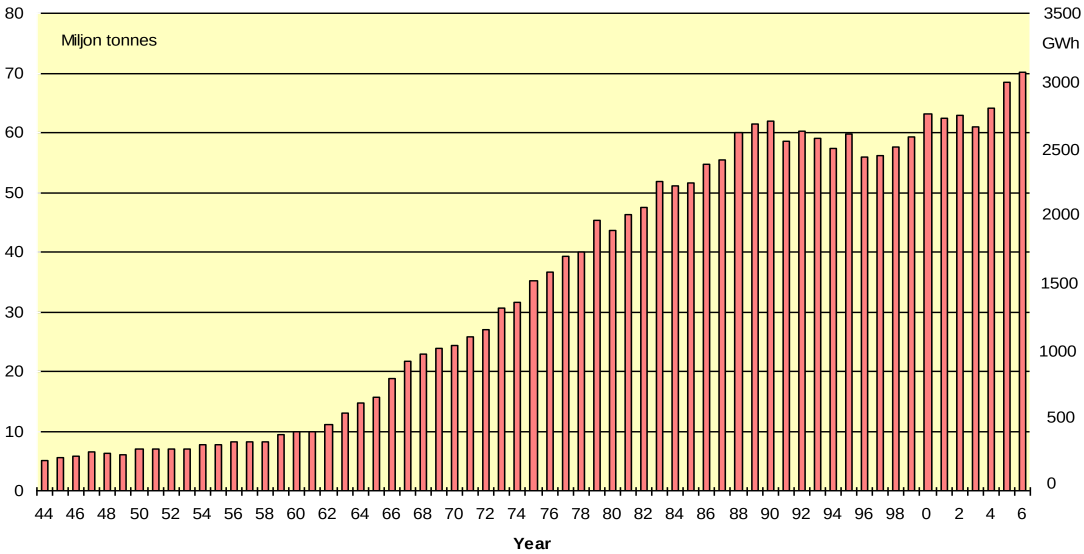

FIGURE 9: Water production from 1944 to 2006

The price of heating with geothermal water is different from one place to another. In Iceland it is very well compatible with other alternatives. The price of heating houses in Reykjavík is nearly ¼ of the price of using oil for heating. In 2000, the value of the total savings between 1970 and 2000 was estimated at $8,200 million or more than three times Iceland’s national budget in 2000. Figure 10 compare the energy prices for house heating using different energy sources.

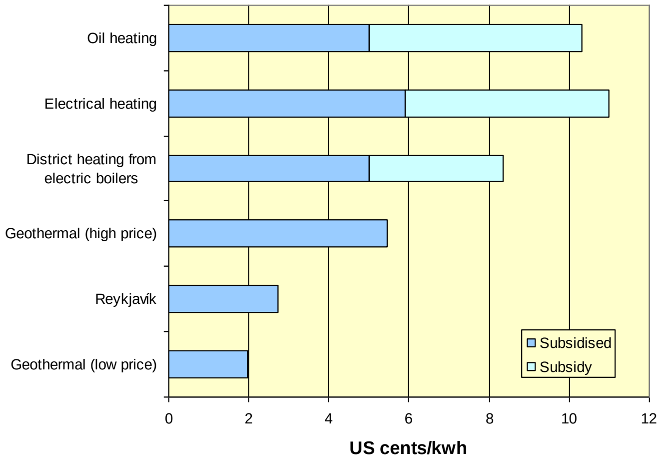

FIGURE 10: Comparison of the energy prices for heating houses in 2007

6. OTHER DISTICT HEATING UTILITIES IN ICELAND

Almost 90% of all houses in Iceland are currently heated by geothermal water, and the remainder is heated by electricity generated by hydro (83%) and geothermal (17%). The district heating utility in Reykjavík is far the largest and so far the largest in the world. District heating are in most populated areas where geothermal water can be found in the vicinity. The country's larger district heating services are owned by their respective municipalities. Some 200 smaller heating utilities have been established in rural areas. Recently, district heating is also becoming popular for holiday homes (Friðriksson 2003). Figure 11 show the distribution of district heating services in Iceland.

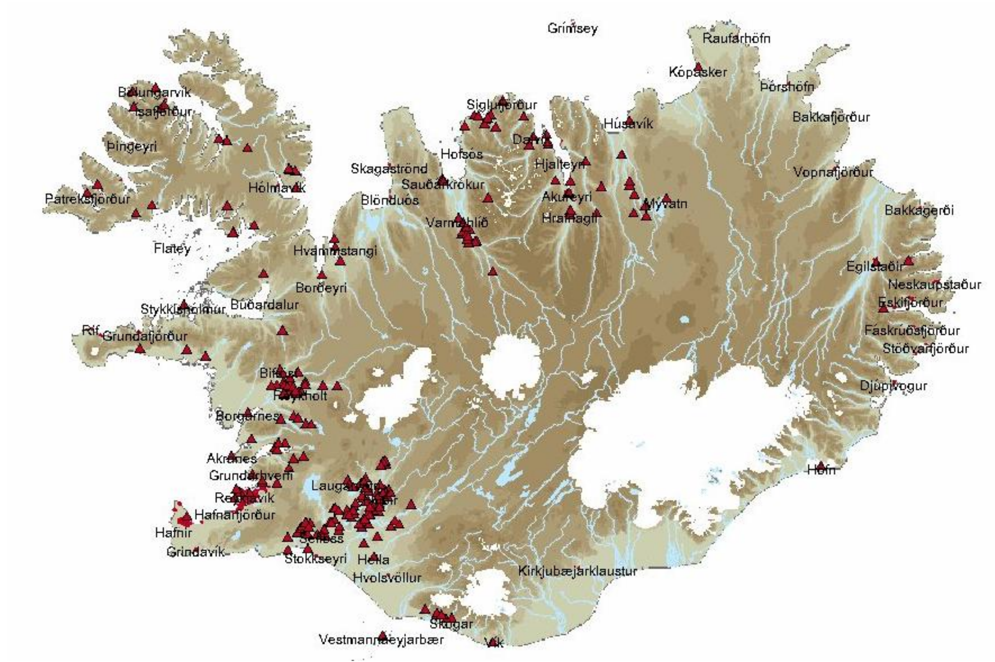

FIGURE 11: District heating utilities serving about 90% of all houses in Iceland

Figure 12 shows the 15 largest district heating services in Iceland in the year 2000 ranked according to the water production. The largest is in the capital, Reykjavík and the second largest produces about one third of the production in Reykjavík.

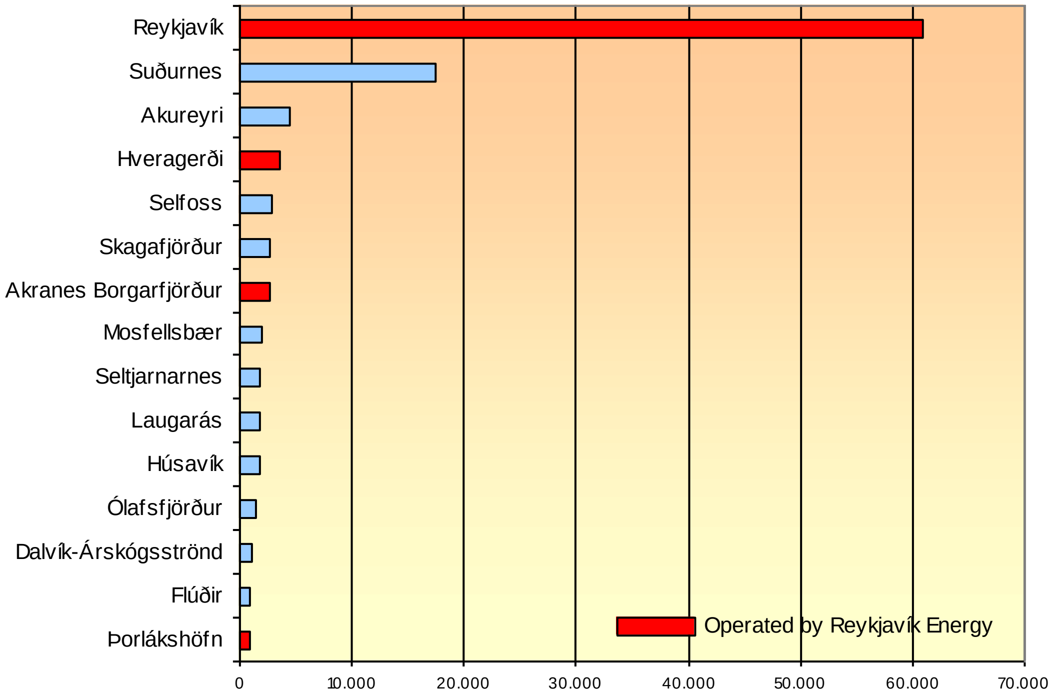

FIGURE 12: Water production of the 15 largest district heating services in Iceland. Data from the year 2000

7. BENEFITS OF DISTRICT HEATING

Reykjavik is one of the cleanest capitals in the world, thanks to geothermal district heating. There is no smoke from chimneys. In the 1940s the majority of houses were heated by burning coal but today they are heated with geothermal water. The gray grime is long gone and the sky is bright blue. Heating with polluting fossil fuels has been eliminated, and about 100 million tonnes of CO_2 emissions have been avoided by replacing coal and oil heating by geothermal (Figure 13). Geothermal utilisation has reduced CO_2 emissions in Iceland by some 2-4 million tonnes annually compared to the burning of fossil fuels. The total release of CO_2 in Iceland in 2004 was 2.8 million tonnes. The reduction has significantly improved Iceland's position globally in this respect. Iceland has therefore reduced its greenhouse gas emission dramatically, decades before the international community began contemplating such actions.

Many countries could reduce their emissions significantly through the use of geothermal energy. The gas emissions from low-temperature geothermal resources are normally only a fraction of the emissions from the high-temperature fields used for electricity production. The gas content of low-temperature water is in many cases minute, like in Reykjavik, where the CO_2 content is lower than or similar that of the cold groundwater or about 0.05 mg CO_2 /kWh (5 times 10-5 g CO_2/kWh). In sedimentary basins, such as the Paris basin, the gas content may cause scaling if it is released. In such cases the geothermal fluid is kept at pressure within a closed circuit (the geothermal doublet) and reinjected into the reservoir without any de-gassing taking place. Such systems have zero emission.

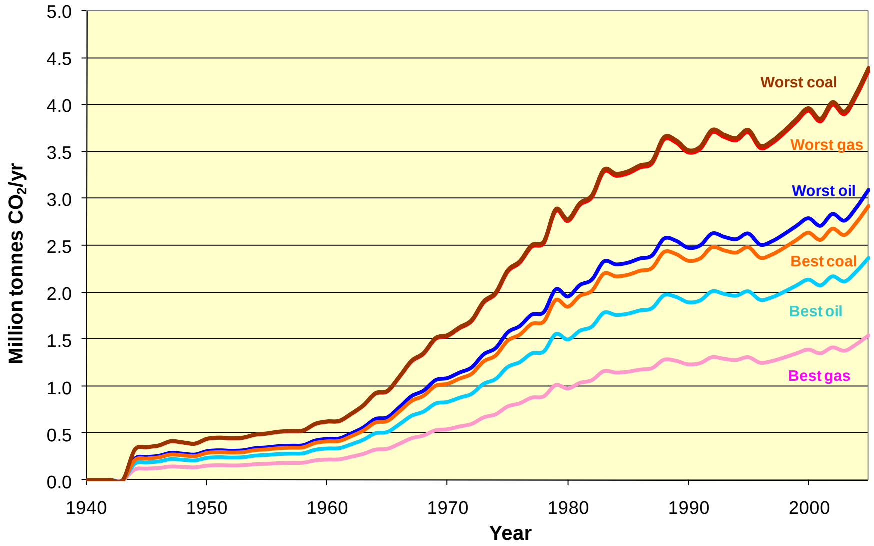

FIGURE 13: CO_2 savings using geothermal water in Reykjavik (Iceland) compared to other energy sources 1940-2006. Total avoidance 90 million to 110 million tonnes of CO_2 emissions depending on the type of fossil fuel(s) replaced by geothermal resources

No systematic collection has been made on CO_2 emission data from geothermal district heating systems in the world. The CO_2 emission from low-temperature geothermal water can be regarded negligible or in the range of 0-1 g CO_2 /kWh depending on the carbonate content of the water. Galanta in Slovakia is an example of replacing fossil fuels by geothermal water, although on a smaller scale. A district heating system using natural gas with about 9,000 GJ/yr heat production was modified. The natural gas was replaced as a heat source by carbonate rich geothermal water. The replacement resulted in the reduction of CO_2 emission by about 5,000 tonnes annually (Galantaterm, 2007). Although this geothermal water is rich in carbonate, its CO_2 emission is negligible (about 0.3 g CO_2/kWh).

The data from geothermal district heating systems in China (Beijing, Tianjin and Xianyang) is limited, but compared to the example from Galanta it can be assumed that the CO_2 emission would be similar if reinjection is not used.

8. SUMMARY OF OTHER DIRECT USES OF GEOTHERMAL ENERGY IN ICELAND

As mentioned at the beginning of this paper geothermal energy is 62% of all energy use in Iceland. It is mainly used for space heating as has been described in previous sections. Other direct uses of geothermal energy are summarized below and are based on Gunnlaugsson et al. 2001, Ragnarsson 2005 and Orkustofnun 2006.

8.1 Swimming pools

Heating of swimming pools accounts for 4% of the use of geothermal energy in Iceland. There are about 160 swimming pools in Iceland the majority or 130 are using geothermal water. While most of these pools are public, this figure also includes pools belonging to schools and other institutions. Most of the swimming pools or 76% are outdoor pools in constant use throughout the year. Swimming is very popular in Iceland and the swimming pool attendance has increased in recent years. In 2005, it was estimated that on average each Icelander went to a swimming pool 16 times per year. A new average size swimming pool uses similar amount of water as 80-100 private houses.

8.2 Snow melting

During the past two decades, geothermal energy has been increasingly used to melt snow. Spent water from heating of houses, about 35 °C, is commonly used for de-icing 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. Therefore during the winter months in Iceland, it is not uncommon to see pavement and walkways outside public or private buildings clear of snow. This is due to the snow melting systems installed underneath the sidewalks.

8.3 Greenhouses

The use of geothermal water for greenhouses accounts for 3% of the use of geothermal energy in Iceland. Heating of greenhouses started in Iceland 1924, but prior to that naturally warm soil had been used to grow potatoes and other vegetables. In 2005, there was a total of 175,000 m^2 of greenhouse area. Of this area, almost half is used for the production of flowers and plants, and the remainder for vegetables. Artificial lighting has increased considerably in the last years, doubled the crop yield and allowing year around production. Enrichment of CO_2 gas in greenhouses during the winter has increased last years.

8.4 Fish farming

In recent years, geothermal energy has been used to a considerable extent in aquaculture. The total production has been slowly increasing last years and is estimated to have been around 8,800 tons of round fish in 2005.

8.5 Industry

The seaweed processing plant at Reykhólar in West Iceland uses geothermal water directly for its production. The plant produces 2,000-4,000 tonnes of seaweed and kelp meal annually, using 28 l/s of 107°C hot water for its production.

In Southern Iceland, a plant for the commercial production of liquid carbon dioxide (CO_2) has been in operation since 1986. The plant uses 6 L/s of geothermal water at 160°C with high gas content. The annual production is about 2000 tonnes of CO_2, which is used in greenhouses, for manufacturing carbonated beverages and in other food industries.

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