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DISTRICT HEATING IN REYKJAVIK
PAST – PRESENT – FUTURE

Einar Gunnlaugsson
Orkuveita Reykjavikur
Baejarhals 1
110 Reykjavik
ICELAND
einar.gunnlaugsson@or.is

ABSTRACT

The principal use of geothermal energy in Iceland 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. The district heating utility in Reykjavik is the largest municipal geothermal district heating service in the world. It started on a small scale in 1930 but has expanded considerably and is now serving 61% of the total population of Iceland with hot water. For the first 60 years only geothermal water from low-temperature fields were used for heating but since 1990 geothermal energy from the high-temperature field at Nesjavellir has increasingly been used for heating. The pumping from the low-temperature fields has lowered the water level and geothermal surface manifestations have disappeared. With reduced pumping after 1990 the water level rose again and equilibrium has been attained indicating that the geothermal fields are utilized in a sustainable manner. Geothermal energy is one of the cleanest energy sources available. In the case of Reykjavik the use of geothermal water has reduced CO_2 emission by 100 million tonnes or 3-4 million tonnes annually.

1. INTRODUCTION

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. The geothermal energy is mainly used for space heating but electrical generation is increasing (Figure 1).

For centuries, the utilization of geothermal heat was primarily limited to cooking, bathing and laundering. In the Icelandic sagas which were written in the 12th – 13th century A.D. bathing in hot springs is often mentioned. The bathing pools seem to have been rather primitive. Commonly bath was taken in brooks 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 13th 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 (Sveinbjarnardottir, 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, 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 came up. Experiments proved that it was technologically possible and could be advantageous (Jonasson and Thordarson, 2007). A farmer at Sudurreykir, close to

Reykjavik, piped water from a geothermal spring to his house in 1908, and in 1911 a farmer at Sturlureykir in Borgarfjordur, West Iceland, and 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 wool factory who led hot water from a 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.

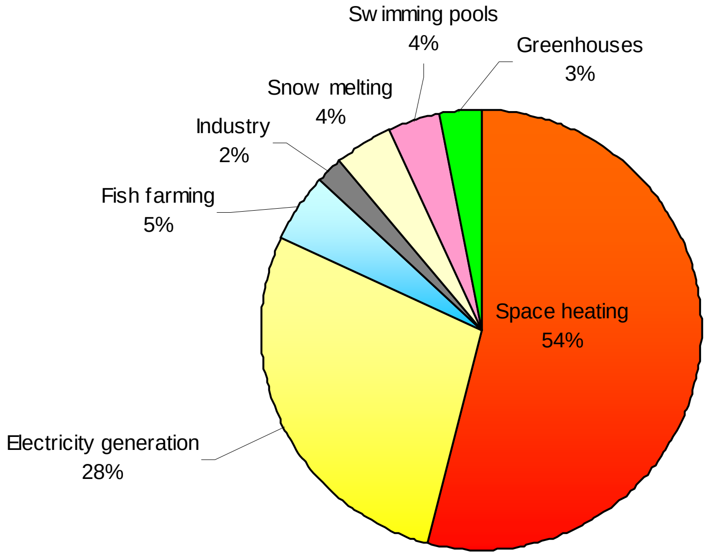

FIGURE 1: Utilization of geothermal energy in Iceland 2006 (Orkustofnun, 2007).

2. DISTRICT HEATING IN REYKJAVIK

2.1 Historical development

For hundreds of years, the residents of Reykjavik used the thermal springs in Reykjavik to wash their laundries. District heating in Reykjavik began in 1930, utilizing water from boreholes in the Laugarnes field close 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 Reykjavik, which thereby became the first building in Reykjavik 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 Reykjavik. A large geothermal area 17 km east of Reykjavik, the Reykir-Reykjahlid field, was considered to be ideal both relatively close and capable of producing large quantities of geothermal water. Shallow drillholes were drilled in this area and a pipeline build to Reykjavik. 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 Reykjavik 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 Reykjavik. 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 Ellidaar River, within the city limits of Reykjavik. It was also necessary to re-drill older boreholes in Reykir-Reykjahlid 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.

2.2 The geothermal fields today

Three low-temperature geothermal areas are utilized for district heating in Reykjavik 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 Reykjavik

Field	Temperature (°C)	Capacity (l/s)	MWt	No. of exploitation wells
Laugarnes	125-130	340	125	10
Ellidaar	85-95	260	50	8
Reykir-Reykjahlid	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 Thvottalaugar 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 125-130°C water.

Now there are 10 production wells in the field, which covers 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 1,000-2,000 m depth.

The *Ellidaar 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-Reykjahlid 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 Reykjavik and by the end of 1943 about 200 l/s of 86°C water was available for heating houses in Reykjavik. 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-Reykjahlid geothermal field, which is about 5.5 km^2, is geographically divided into sub-areas, Reykir and Reykjahlid. 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 MW_t 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.

2.3 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 Reykjavik 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 Reykjavik.

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	

2.4 Production and monitoring of the low-temperature geothermal fields

Geothermal energy is generally classified as a renewable resource. This is based on the fact that geothermal resources are steadily renewed, although the renewals takes place at 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 Reykjavik Energy.

2.4.1 The Reykir - Reykjahlid 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 2 and 3 show the production (in Gigalitres) 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).

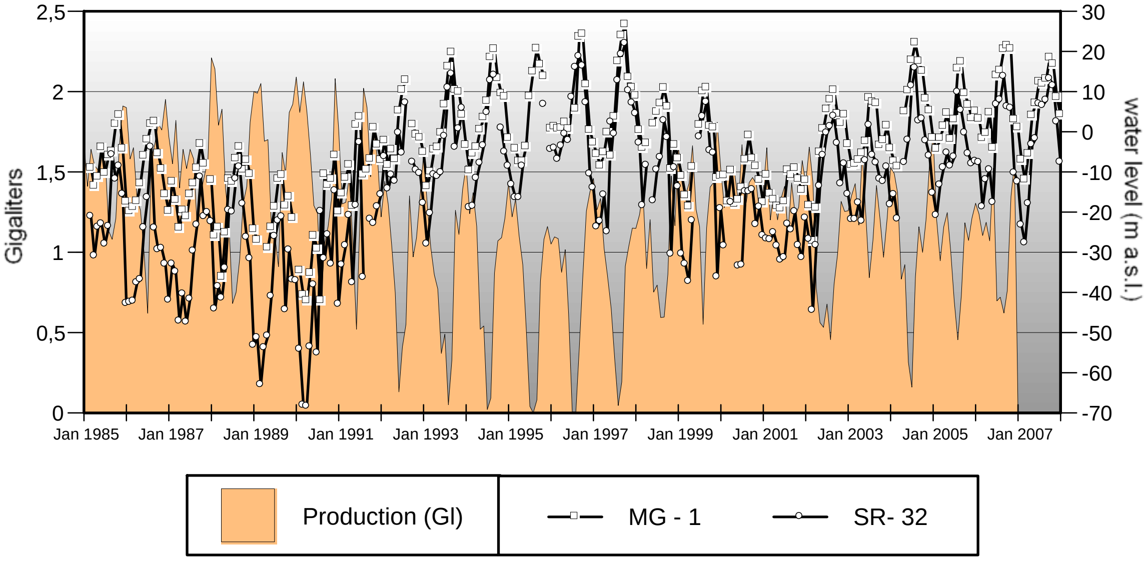

FIGURE 2: Production (in Gigalitres) from the Reykir field
and the water level in an observation well from 1983 to 2007

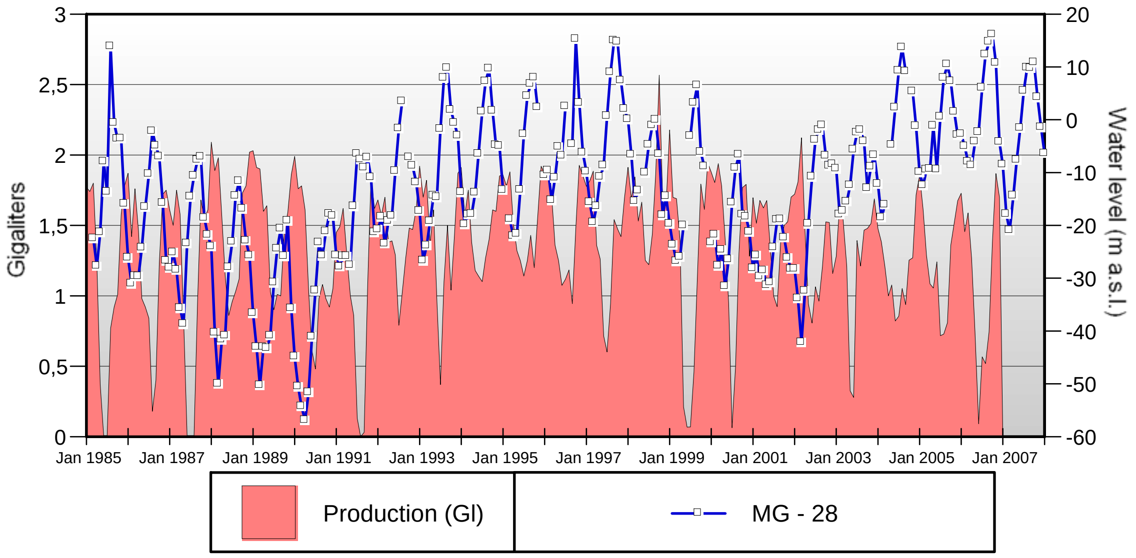

FIGURE 3: Production (in Gigalitres) from the Reykjahlid field
and the water level in an observation well from 1983 to 2007

2.4.2 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 4). Consequently, fresh and slightly saline groundwater have 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).

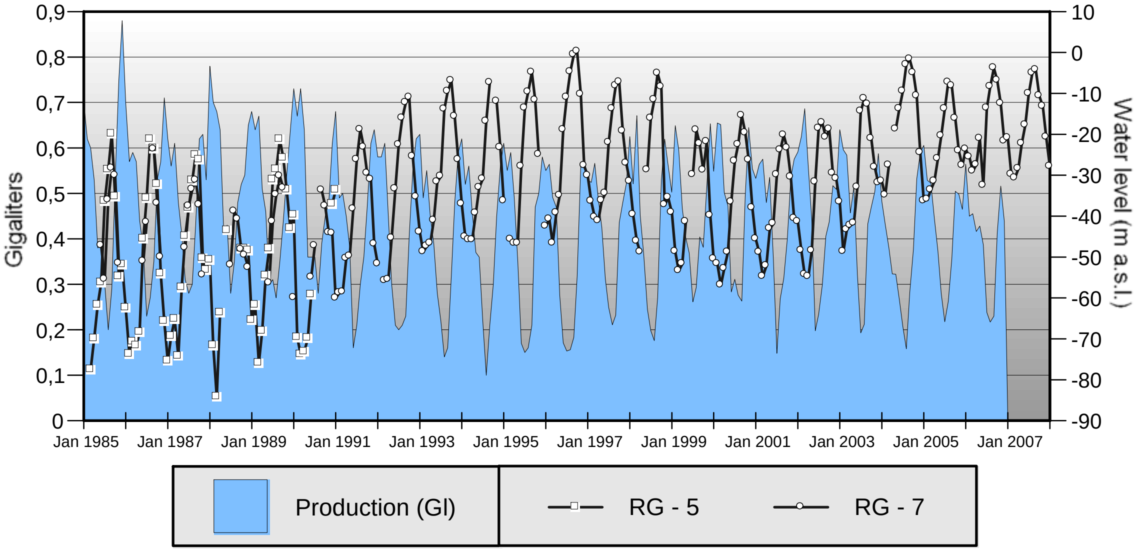

FIGURE 4: Production (in Gigalitres) from the Laugarnes field and the water level in an observation well from 1983 to 2007

2.4.3 The Ellidaar 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 5) and a decrease in the mixing with cold water (Gunnlaugsson et al., 2000).

2.5 The distribution system

Reykjavik District Heating uses either a single or a double distribution system (Figure 6). 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.

The geothermal water from Reykir-Reyjahlid field flows through a main pipeline to six tanks just outside Reykjavik that hold 54 million litres. From there, the water flows to six storage tanks on Oskjuhlid in mid-Reykjavik, holding 24 million litres. Nine pumping stations distributed throughout

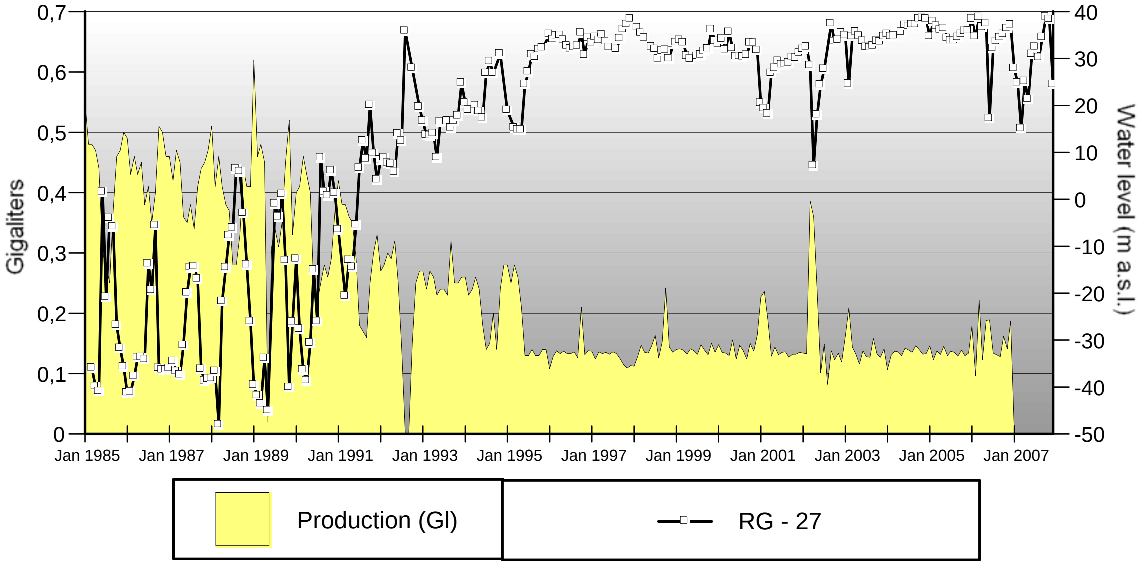

FIGURE 5: Production (in Gigalitres) from the Ellidaar field and the water level in an observation well from 1983 to 2007

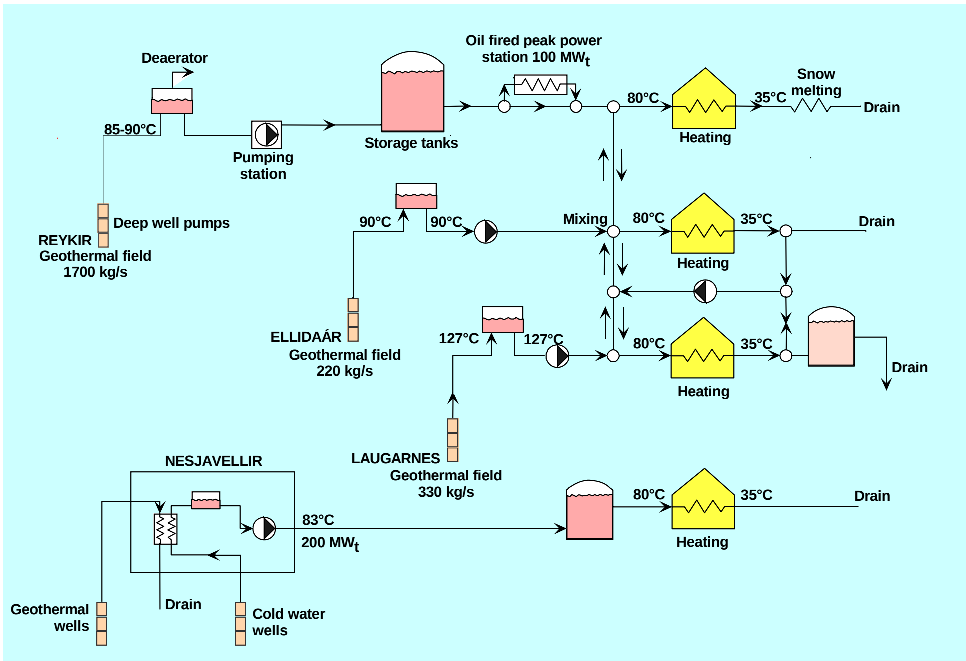

FIGURE 6: Simplified diagram of the district heating system in Reykjavik, Iceland

the servicing area pump the water to the consumers. The water from Nesjavellir flows to two tanks on the way to Reykjavik 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.

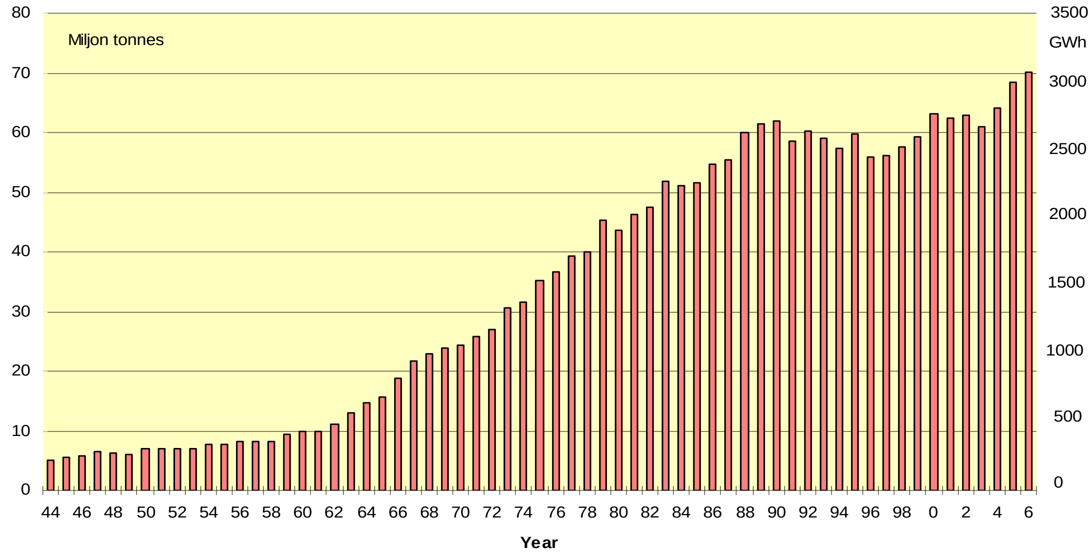

FIGURE 7: Water production from 1944 to 2006

The annual production from 1994 to 2006 is shown in Figure 7. 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 MW_t 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.

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 Reykjavik has been nearly ¼ of the price of using oil for heating. With increasing price of oil last months the heating with geothermal is more favourable than ever. 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 8 compares the energy prices for house heating using different energy sources.

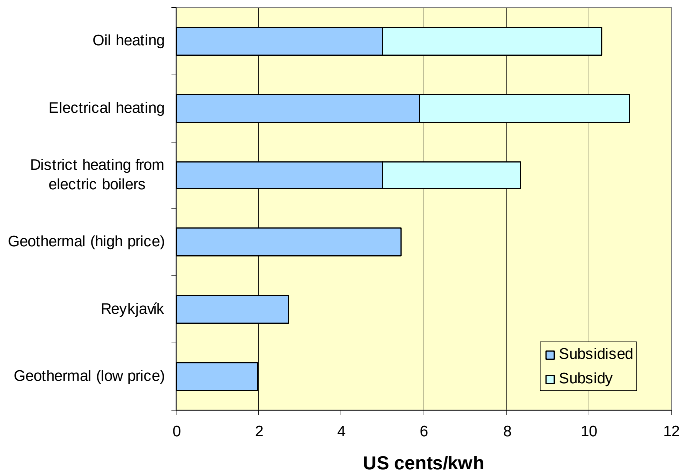

FIGURE 8: Comparison of the energy prices for heating houses in 2007

3. EXPANSION OF ORKUVEITA REYKJAVIKUR

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 Reykjavik is far the largest and so far the largest in the world. District heating systems are in most populated areas in Iceland 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 (Fridriksson 2003).

In recent years Orkuveita Reykjavikur has been taking over smaller district heating utilities in Iceland. Now the company is operating 12 heating utilities outside the capital area serving towns and rural areas (Figure 9). The towns are Akranes, Borgarnes and Stykkisholmur in the west and Hveragerdi, Thorlakshofn, Hella and Hvolsvollur in South Iceland.

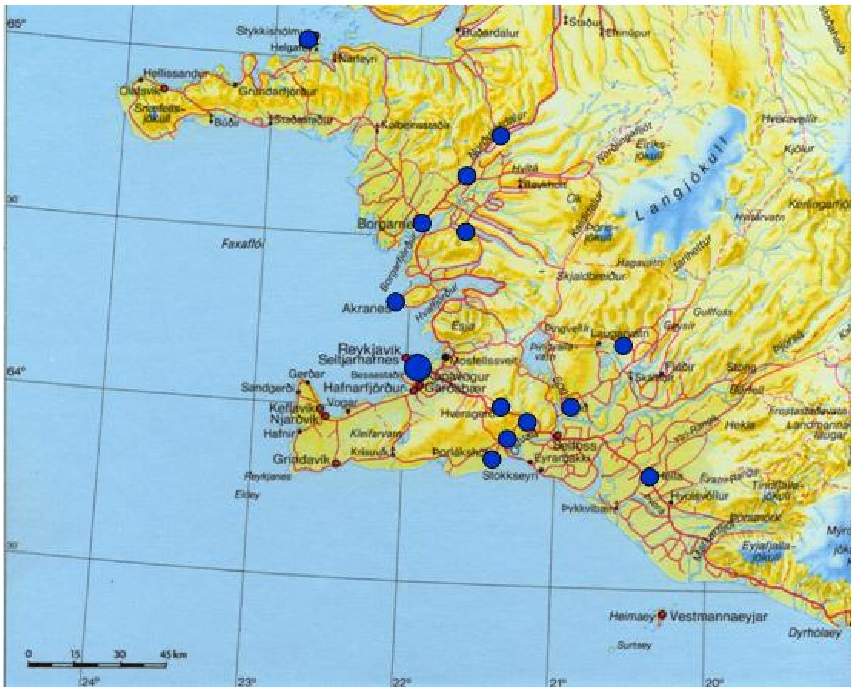

FIGURE 9: Location of district heating utilities operated by Orkuveita Reykjavikur

Figure 10 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, Reykjavik, and the second largest produces about one third of the production in Reykjavik.

4. 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 it is heated with geothermal water. The grey 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 11). 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.

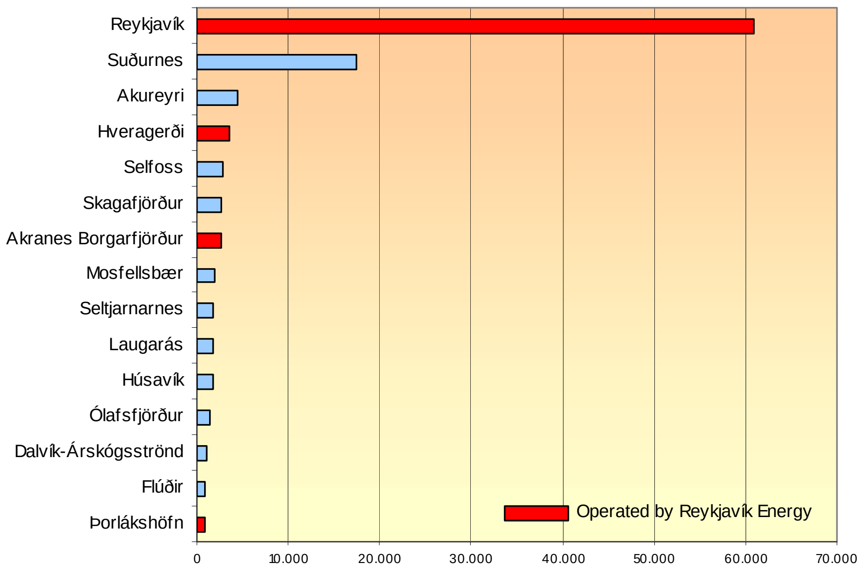

FIGURE 10: Water production of the 15 largest district heating services in Iceland; data from the year 2000

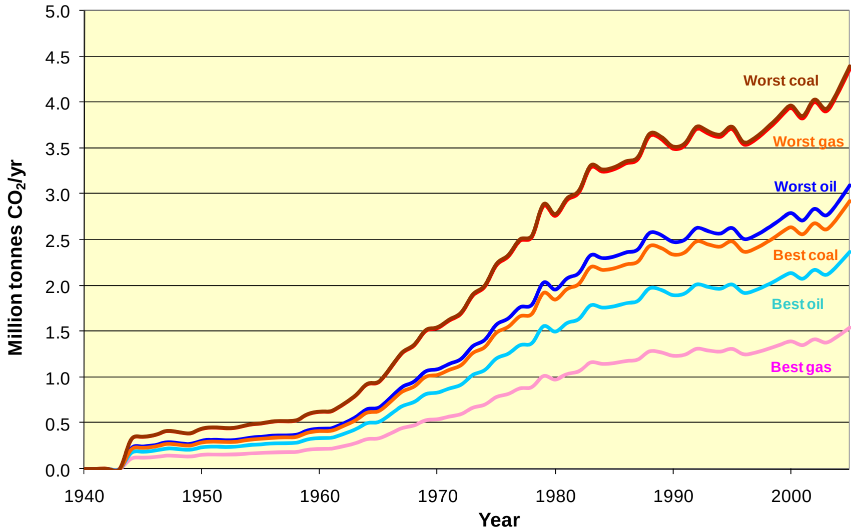

FIGURE 11: CO_2 savings using geothermal water in Reykjavik (Iceland) compared to other energy sources 1940-2006. Total avoidance 90 million to 110 million tonnes of CO_2 emissions depending on the type of fossil fuel(s) replaced by geothermal resources

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 to that of the cold groundwater or about 0.05 mg CO_2 /kWh (5 times 10-5 g CO_2/kWh).

5. HARNESSING OF GEOTHERMAL STEAM TO GENERATE ELECTRICITY

As mentioned earlier in this paper geothermal energy in Iceland is mainly used for space heating as has been described in previous sections. Production of electricity by using geothermal steam has increased considerably in recent years.

Orkuveita Reykjavikur has research permission in the Hengill high-temperature area which is one of the largest high-temperature areas in Iceland. The geothermal activity is connected with three volcanic systems. The oldest volcanic system is the so-called Grensdalur system and the geothermal heat in Hveragerdi belongs to that system. North of it is a volcanic system named after Hromundartindur. The last eruption in this system was about 10,000 years ago.

West of these volcanic systems lies the Hengill system, with volcanic fissures and faults from Nesjavellir in the north, through the Mt. Hengill and to Hellisheidi on the southern side of the mountain. Orkuveita Reykjavikur operates two geothermal power plants in this area, the Nesjavellir and the Hellisheidi geothermal plants.

5.1 The Nesjavellir power plant

The construction of the Nesjavellir power plant started in 1987. In the beginning the plant utilized steam and separated water from four drillholes, to heat up fresh ground water for district heating in the Reykjavik area. This first stage was completed in 1990 with 100 MW_t power, equivalent to about 560 l/s of 80°C water.

Production of electricity with steam turbines began in fall 1998 with production of 60 MW_e in two 30 MW turbines. In June 2001, the third turbine was added and the fourth in 2005 bringing the capacity to 120 MW_e. The modular development of the Nesjavellir power plant is an example of the

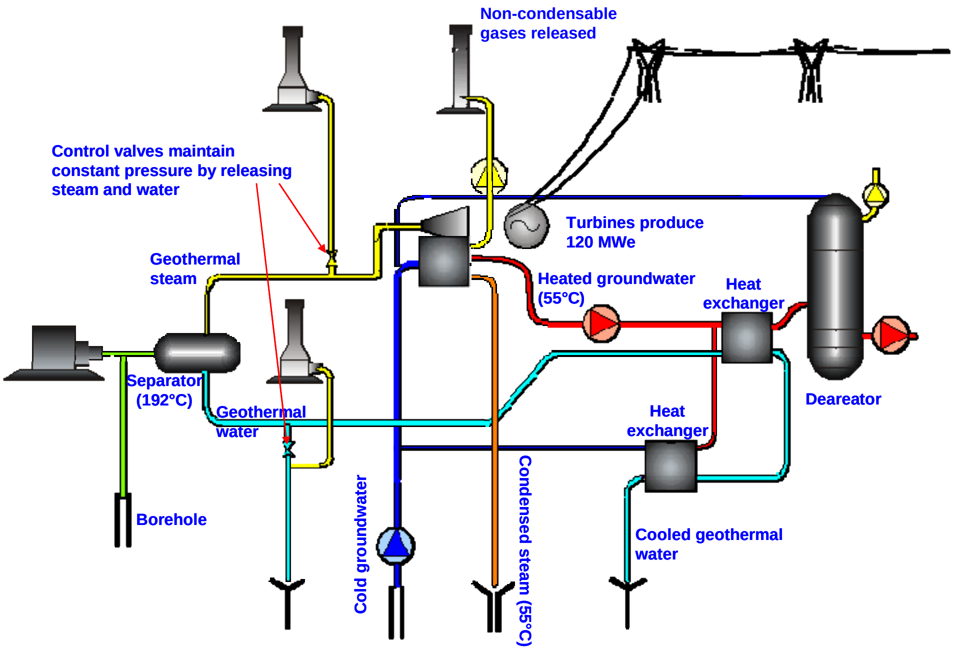

FIGURE 12: Simplified diagram of the Nesjavellir power plant.

development of geothermal resource with increased production in line with the known potential of the field (Gislason et al., 2005). Figure 12 shows a simplified diagram of the Nesjavellir plant.

5.2 The Hellisheidi power plant

The Hellisheidi field is located on the southern side of the Hengill Mountain and associated with the same fault zone as at Nesjavellir on the northern side of the mountain (Figure 13). Reykjavik Energy has for some time planned to utilize the Hellisheidi field, which is only about 25 km east of Reykjavik. It has accordingly bought up the land and conducted extensive research in the area (Gunnlaugsson and Gislason, 2005). In 2001, the company's board of directors decided to start preparations for building a combined heat and power plant at Hellisheidi. The first stage of this new plant was commissioned in 2006 with two 45 MW_e turbines. In 2007 a low-pressure bottom unit was installed with 33 MW_e. Later this year, 2008, two additional 45 MW units will be commissioned bringing the output up to 210 MW_e. In the fall of 2009, the first stage of the heating plant will be ready delivering 133 MW_t of hot water for space heating in Reykjavik.

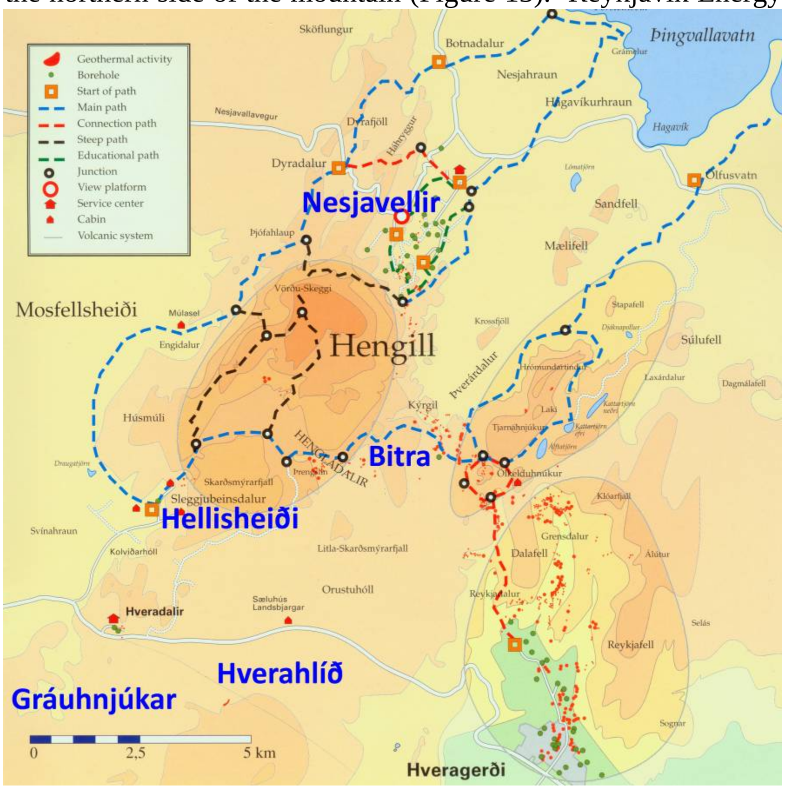

FIGURE 13: The Hengill geothermal field showing present power plants (Nesjavellir, Hellisheidi) and possible future sites

6. NEAR FUTURE OF ORKUVEITA REYKJAVIKUR

Almost all houses in Reykjavik and surrounding communities are now heated with water from geothermal fields. The increase in the population in this area is around 3-4% per year. The low-temperature fields utilized for district heating in Reykjavik are now fully utilized. Further heat demand in this area will therefore come from the high-temperature fields in the Hengill area.

Figure 13 shows the Hengill geothermal area. Power plants are now operated at Nesjavellir and Hellisheidi producing heat and power at Nesjavellir and so far only power at Hellisheidi. In 2009 water will also be heated up there and piped to Reykjavik. There are also other fields under development. Three research drillholes have been drilled at the Bitra field as well as the Hverahlid field. Environmental Impact Assessments have been made for power plants in these areas. Drilling in Hverahlid will continue this year and with positive results a power plant can be on line in 2011 or 2012.

Re-injection of geothermal water from the Hellisheidi power plant has been in the vicinity of Grauhnjukar. There temperature up to 300°C has been found. If the geothermal water can be injected safely elsewhere, energy from Grauhnjukar can be used for further power production in this area. It is therefore likely that in the near future more power plants will be built in the Hengill area increasing considerably the power production.

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