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

Preparation for a New Power Plant in the Hengill Geothermal Area, Iceland

Einar Gunnlaugsson and Gestur Gíslason

Reykjavik Energy, Baejarhals 1, 110 Reykjavik, Iceland

einar.gunnlaugsson@or.is; gestur.gislason@or.is

Keywords: Iceland, Hengill, power plant, Hellisheidi

ABSTRACT

Reykjavík Energy is developing a new combined heat and power geothermal plant in the Hengill region of SW-Iceland. The objective of the project is to meet the increasing demand for electricity and hot water for space heating in both the industrial and domestic sectors. The capacity of the completed power plant is projected to be 120 MWe and 400 MWt power. In all preparations environmental issues have been given great importance in accordance with the policy of the company. The conclusion of an Environmental Impact Assessment was that the power plant will not have a significant impact on the environment.

1. INTRODUCTION

The main geothermal utilization in Iceland until recently was the direct uses, with space heating being by far the most important of these. In recent years there has been a growing interest in electric energy production from geothermal energy, and currently about 18% of the electricity generated in Iceland is of geothermal origin, the rest being from hydro resources.

Reykjavik Energy is the largest developer of geothermal energy in Iceland, and operates the world's largest geothermal district heating utility, serving Reykjavik and neighbouring communities with thermal water. The installed capacity is about 750 MWt. Reykjavik Energy utilizes four low-temperature fields, located within or close to the city's limit, and one high-temperature field, Nesjavellir, located within the active Hengill volcanic complex.

As a consequence of the increased demand for thermal and electric power in the Reykjavik area, and an increase in the demand for electricity for industry, Reykjavik Energy has had to augment its production of both electricity and hot water. The favourable conditions observed in Nesjavellir stimulated a renewal of interest in the Hellisheidi field, to the south of the Hengill volcano.

2. HENGILL GEOTHERMAL AREA

The Hengill geothermal area lies in the middle of the western volcanic zone in Iceland, on the plate boundary between North America and the European crustal plates; this boundary runs from Reykjanes in a northeasterly direction towards Langjökull (Fig. 1). The plates are diverging at a relative rate of 2 cm/year. The rifting of the two plates has opened a NNE trending system of normal faults and frequent magma intrusions. This rift zone is also highly permeable and numerous fumaroles and hot springs emerge at the surface. The bedrock in the Hengill area consists mostly of palagonite formed by volcanic eruptions below glaciers during the last ice ages. It is one of the most extensive geothermal areas in the country. Surface measurements, heat distribution and subsurface measurements indicate an area of around 110 km^2.

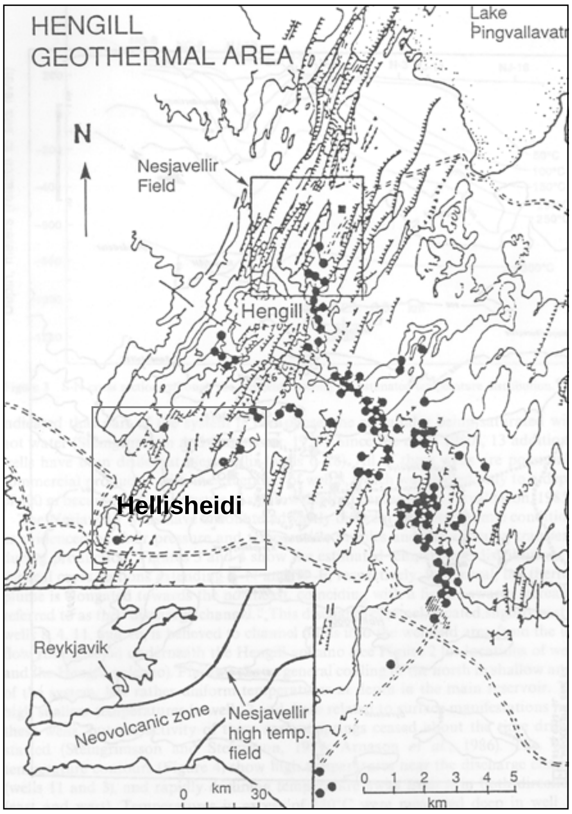

Figure 1. Location of the Hengill geothermal field. Hot springs and fumaroles are indicated by dots (•) and major faults by tagged lines (modified from Bodvarsson et al., 1990a).

Geothermal activity is associated with three volcanic systems of different age within the complex (Fig. 2). The geothermal heat source in Reykjadalur and Hveragerði is related to Grensdalur, the oldest of the three volcanoes. North of Grensdalur lies Hrómundartindur, which last erupted about 10,000 years ago, and which provides the heat for geothermal activity around Ölkelduháls. West of these volcanic systems is the Hengill system, with volcanic features and faults stretching from south-west to north-east through Hellisheiði, Nesjavellir and Lake Þingvallavatn.

Several potential geothermal fields can be distinguished within the Hengill complex. Only two of these areas have been developed, one for space heating, industrial use and greenhouse heating in the town of Hveragerdi, and at Nesjavellir, where Orkuveita Reykjavikur operates a geothermal power plant with 90 MWe of installed capacity and a 200 MWt plant for hot water used in space heating. A fault zone associated with the Hengill Volcano cuts through the volcanic zone from southwest to northeast. The most interesting geothermal prospects are those associated with this fault zone, Nesjavellir farthest to the north, and Hellisheidi on the southern side.

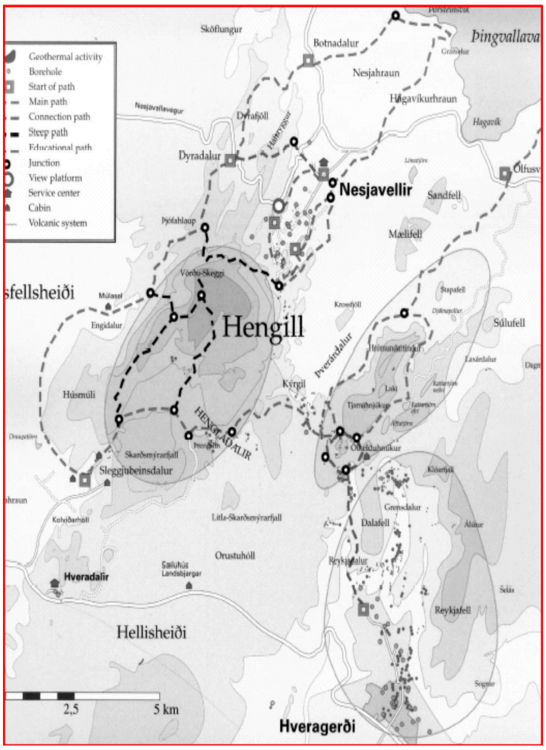

Figure 2. Volcanic systems of the Hengill complex

Three volcanic eruptions are known to have occurred over the last 11,000 years, the most recent eruption having taken place 2000 years ago. The last eruption in the vicinity occurred in the year 1000 on a fissure west of Hengill, forming the Svínafellsbruni lava field.

Reykjavík Energy has for some time planed to utilize Hellisheiði field, which is only about 25 km east of Reykjavík. It has accordingly bought up the land and conducted extensive research in the area. In 2001 the company's board of directors decided to start preparations for building a combined heat and power plant at Hellisheiði. Initial estimates are for an installed capacity of 120 MWe and 400 MWt. The first stage of this new plant will be commissioned in 2006.

2.1 Surface exploration

The Hengill volcano has been studied extensively from as early as 1947. Initial work focused on geological, geophysical and geochemical studies, which led to the drilling of a few shallow exploratory wells. Based on these, a 30 MWe unit was proposed in the Hveragerdi region, although pumping hot water to Reykjavik was considered uneconomical at the time (Bodvarsson, 1951). More wells were, however, drilled at Hveragerdi as a spin-off from the initial exploration phase. These wells have been used for space heating as well as for heating greenhouses.

Extensive geological, geophysical and geochemical surveys have been carried out throughout the Hengill area in conjunction with the Nesjavellir and Hellisheiði projects. The pioneering work of Saemundsson (1967) became the foundation of the present full-size map database, including all major geological units, location of hot springs and fumaroles, fault lines and thermally altered grounds. Aeromagnetic, gravity and DC-resistivity surveys were carried out between 1975 and 1986. These delineated a 110 km^2 low-resistivity area at 200 m b.s.l., and showed a negative and transverse magnetic anomaly coherent with the most thermally active grounds (Bjornsson et al., 1986). Transient electromagnetic soundings (TEM) were carried out at 186 sites (Fig. 3) between 1986 and 2000 to revise the resistivity map. The results of this study suggested that the resistivity anomaly is complex and affected by processes such as faulting, shearing and spreading (Arnason and Magnusson, 2001).

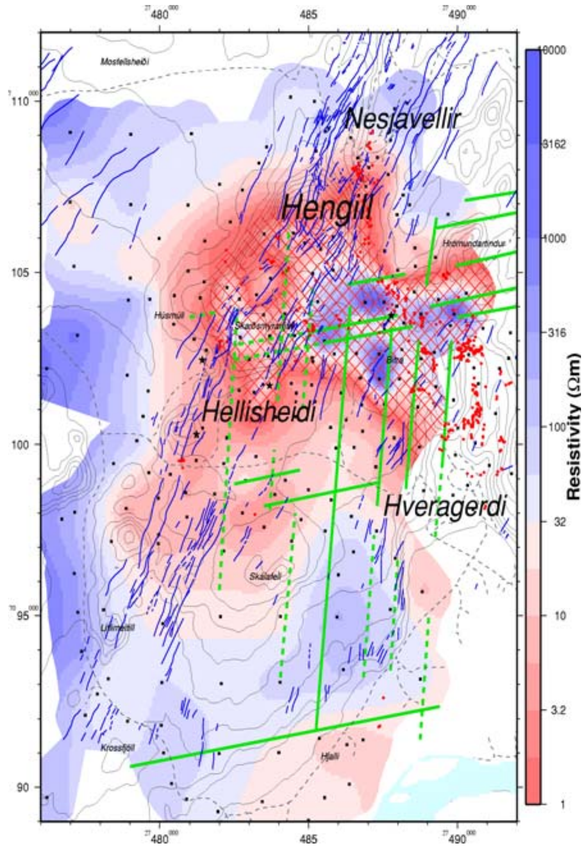

Figure 3. Resistivity at 100 m b.s.l. according to a recent TEM survey. Also shown in blue are visible fault lines and, in green, faults as defined by earthquake locations (from Arnason and Magnusson, 2001).

Approximately 100,000 micro-earthquakes vibrated the Hengill area between 1994 and 2000. Most quakes were located at 5 ± 3 km depth, reflecting the locally very thin and hot crust. The quakes group together on lines striking either E-W or N-S, but surprisingly not to the NNE, as seen in the surface geology (Arnason and Magnusson, 2001).

An intensive geochemical study was carried out using gas chemistry from fumaroles to predict temperature and to distinguish between different sub-fields (Ívasson 1998). The concentration of various gases in the fumarole steam is considered to be in equilibrium with mineral buffers at different temperatures. Five gas geothermometers were used in the study, showing a temperature decrease towards the east (Fig. 4).

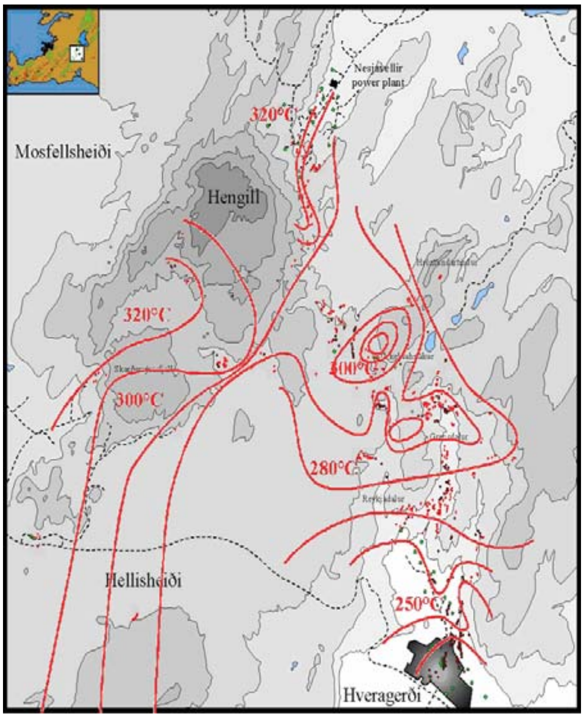

Figure 4. Distribution of temperature based on the concentration of CO_2 gas.

The geochemical study indicates the existence of three different centers with higher temperature, coinciding with the volcanic centers.

3. HELLISHEIDI PROJECT

The geothermal power plant proposed for Hellisheiði will be a co-generation plant. The capacity of the power plant when completed will be 120 MWe and 400 MWt. The power plant will be built in modular units and units will be added as the market demand increases. The production capacity of each electrical unit will be 40 MWe and 133 MWt for each thermal unit.

The Hengill area is one of the main scenic nature sites of South Iceland. On the southern side of the mountain stretches some volcanic fissures with crater rows from eruptions over the last 10,000 years. Material from many of these craters was used during construction of nearby roads. This part of the area is therefore disturbed and damaged by previous activity. The concept during the preparation phase of the power plant in this area is to work in harmony with nature. Therefore the first approach was to select which area had to be covered to supply geothermal fluid for the power plant. The area lies between the lines in Fig. 5 and runs in a SW-NE direction. Within these lines are the main volcanic fissures. The next step was to map the area, which already had been damaged by previous activity. By locating the drillsites within this area all the selected drill targets could by reached by directional drilling. Furthermore, the drillsites were grouped together to minimize their effect on the environment. Up to 5 wells can be drilled on each of the 11 sites shown in Fig. 5.

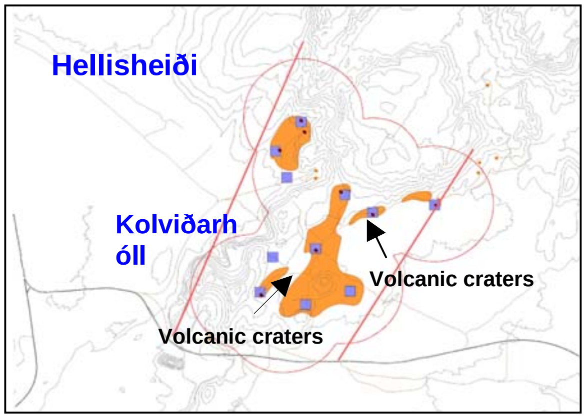

Figure 5. Location of well fields. Between the red lines is the selected production field. The orangey-brown area shows where drillholes can be located with minimum impact on the environment. Blue squares indicate the location of well platforms.

3.1 Drilling

Following on surface exploration, drilling started in 2001, although one well had already been drilled in 1986. By the end of 2003 seven deep exploration wells had been drilled. The drilling targets were the young faults traversing the field, especially the faults that acted as magma feeders during the latest eruptions.

All these wells are productive and have been thoroughly tested in order to characterize the Hellisheidi resource. A few boreholes were drilled vertically but to minimize the effects on the environment more emphasis has been laid on directional drilling. The length of the boreholes is in the range of 1800-2300 m. Four of the boreholes were deviated, and intercept the faults at 1000-1300 m depth, where the main aquifers have been found, with total loss of circulation fluid. Up to 1000 m have been drilled without any return of drilling fluid and rock cuttings. Downhole measurements show that the temperature range in the aquifer zone is 255-275°C, but lower temperatures are commonly found at deeper levels.

Figure 4. Distribution of temperature based on the concentration of CO_2 gas.

A flow test has been completed for the wells. The enthalpy during the tests was 1175-1400 kJ/kg and the total flow ranges from 30 to 70 kg/s. Well outputs range between 3-9 MWe and 30-60 MWt. The geothermal fluid is relatively dilute, as is common in high-temperature fields in Iceland, with total dissolved solids of <1000 ppm and quite low nn-condensable gas in the steam (<0.5 %).

Special emphasis is laid on recording pressure transients, which are induced by temporary production from new wells. These data are considered extremely valuable by providing permeability constraints for the numerical reservoir model that is currently under calibration.

Ten production wells will be drilled in the years 2004 and 2005. Another eight production wells will be added before commissioning the second stage of the electric power plant planned for 2012. The seven exploration wells in the area have been drilled as possible production wells and will be connected as such to the plant's steam supply system if profitable.

3.2 Numerical modelling

Reservoir simulation models have formed an integral part of reservoir assessment and management in the Hengill area since 1986. Initially the modeling effort focused on the Nesjavellir site. The first model was developed between 1984 and 1986 (Bodvarsson et al., 1990a, 1990b). It was one of the key indicators when it was decided to build the first unit of the Nesjavellir power plant. An intense field-monitoring program was set up in order to gather data for future maintenance and recalibration of the numerical model. In 1992 the model was recalibrated (Bodvarsson, 1993) and the second update of the Nesjavellir model was carried out in 1998 (Bodvarsson, 1998). Drilling of new wells in the Hellisheidi field, together with surface exploration activities, indicate that the Nesjavellir and the Hellisheidi fields can be regarded as belonging to the same system, joined by a common upflow zone midway between the two. It was then decided to recalibrate the numerical model once more and extend the model over all the Hengill geothermal field (Bjornsson et al., 2000, 2003).

For Hellisheiði the numerical reservoir model predicts low financial risk in constructing a 40 MWe and 133 MWt plant. The financial risk increases with the size of the construction stages because of the uncertainty in the number of production wells that will be needed.

According to the model, discharge of separated geothermal water will not increase over the production period. The indications are that geothermal production in the Hellisheiði power plant will be sustainable. If the power plant is shut down after 30 years of operation the pressure and the volume of the geothermal fluid in the reservoir are predicted to recover quickly and return almost entirely to their original levels within a lifetime. The temperature of the reservoir will have dropped from 270°C to 260 °C during the 30-year production period, but the area will recover completely in 1000 years assuming there is no external heat injection as a result of volcanic activity. The environmental effect of the project on the geothermal reservoir is assumed to be reversible.

3.3 Groundwater

Groundwater research is important for all geothermal utilization in high-temperature areas, especially when the heat is going to be used for other than electric energy production. Firstly, geothermal water from high-temperature fields cannot be used directly for heating and large volumes of groundwater are needed; secondly, the groundwater flow has to be well-known for planning disposal or reinjection of the geothermal fluid.

The groundwater system in the Hengill and surrounding area is very complicated. Precipitation in this area is among the highest in Iceland but runoff on the surface is very limited. Most of the runoff has thus to take place underground. Concurrent with geothermal reconnaissance, an extensive study is also being carried out on groundwater flow, including the drilling of 23 research wells, 60 - 200 m deep.

The main characteristic of the groundwater system in the investigated area is that it is divided from southwest to northeast by a range of mountains formed by Hengill, and the mountain-range towards the south-west. On the eastern side, water flows from Hellisheiði to the east (Fig. 6). Hydrology is a little more complex on the western side, with a characteristic area of 15 km^2 west of Hengill where the level of the groundwater table is around 172 m above sea level. From there the ground water flows in three directions: west to Elliðaá catchment area, northeast to Þingvallavatn, and to the south until it reaches the sea at Selvogur.

On the basis of the results of this study a well field has been identified to supply cold water. It is estimated that the cold water consumption for the whole power plant will be 1700 l/s. The fresh water will be pumped from wells at 100-200 m depth about 5 km northwest of the power-house.

The discharge water will be reinjected into 1000-m deep boreholes about 3 km southwest of the power plant. It is estimated that 750 l/s of geothermal water and 150 l/s of condensate will be discharged from the power plant.

3.4 Design of the Hellisheiði power plant

The main power-house will be built near Kolviðarhóll in the lower part of the development area (Fig. 7). All the main equipment will be indoors due to weather conditions. The power harnessing cycle can be divided into three phases, i.e. the collection and processing of steam from drillholes, the generation of electricity and the supply and heating of cold water for space-heating. A simplified flow diagram of the geothermal heat and power plant is shown in Fig. 8.

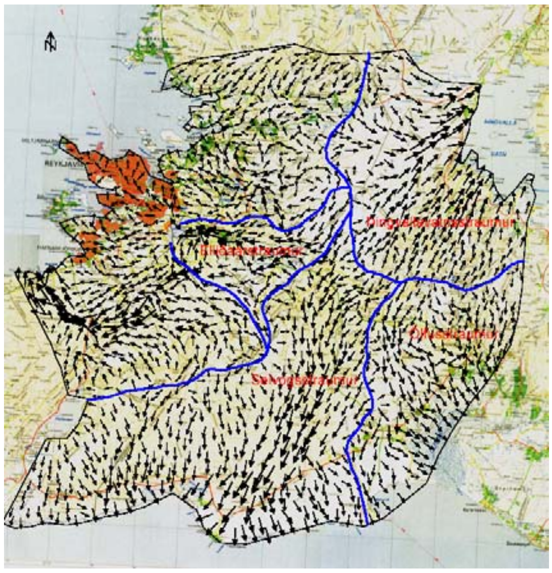

Figure 6. Flow of groundwater according to groundwater model of the area.

Steam and water from drillholes are transported to the separation station where the steam and water are separated. From there, the steam and water are then carried to the power station. A pressure-control station and two to three steam exhaust stacks will be constructed and located near to the main powerhouse.

The steam is conveyed to the steam turbines where electricity is generated. Each turbine has a rated capacity of 40 MWe. In the condenser the steam is utilized to preheat the cold water. Final heating of the water will be in tube heat exchangers in which the separated geothermal water is circulated for heating purposes. Cooling towers will be used when less heating is required.

The cold water is saturated with dissolved oxygen that corrodes steel after being heated. To remove the dissolved oxygen the water is passed through a de-aerator where boiling releases the oxygen and other gases from the water.

The power plant will be connected to the grid by a 220 kV overhead power line that runs through the development area.

An approximately 18-km long buried hot water transmission pipe will run from the power house through Kolviðarhóll to Reykjavík to connect the plant to the existing distribution system. The pipeline will be located along an existing road for the first 4 km and the rest of the distance a service road will be constructed beside the pipe, which runs along a power line most of the distance to Reykjavík.

4. ENVIRONMENT

One of the main missions of Reykjavík Energy is to work in harmony with nature in all issues. All preparations and designs for this new power plant have been planned with this mission in mind. A monitoring program for the power plant will include the geothermal reservoir as well as other environmental factors such as groundwater and its chemistry. An environmental impact assessment was made for the project. The conclusion was that the proposed power plant on Hellisheiði, with a capacity of 120 MWe and 400 MWt, will not have a significant impact on the environment.

REFERENCES

Arnason K. and I.Þ. Magnusson: Geothermal activity in the Hengill area. Results from resistivity mapping. Orkustofnun report, in Icelandic with English abstract, OS-2001/091, 250 p., (2001).

Bjornsson A., Hersir G.P. and G. Bjornsson: The Hengill High-Temperature Area in SW-Iceland. Regional Geophysical Survey. *Geothermal Resources Council Transactions,* Vol. 10, pp. 205-210, (1986).

Bjornsson, G., Sigurdsson O., Bodvarsson G.S. and B. Steingrimsson: Nesjavellir. Recalibration of a numerical reservoir model and estimated generating capacity. *Orkustofnun report*, in Icelandic, OS-2000/019, 40 p., (2000).

Bjornsson, G., Hjartarson A., Bodvarsson G.S. and Steingrimsson B.: Development of a 3-D Geothermal Reservoir Model for the Greater Hengill Volcano in SW-Iceland. *Proceedings*, Tough Symposium, Lawrence Berkeley National Laboratory, Berkeley, California, (2003).

Bodvarsson, G.: Report on the Hengill Thermal Area. Investigations carried out in the years 1947 to 1949. Section I.: *Yearbook*, Association of Chartered Engineers in Iceland, pp. 45-48, (1951).

Bodvarsson, G.S., Bjornsson S., Gunnarsson A., Gunnlaugsson E., Sigurdsson O., Stefansson V. and B. Steingrimsson: The Nesjavellir Geothermal Field, Iceland. Part 1. Field Characteristics and Development of a three-Dimensional Numerical Model. *Geotherm. Sci. & Tech.*, Vol. 2 (3), (1990a), pp. 189-228.

Bodvarsson, G.S., Bjornsson S., Gunnarsson A., Gunnlaugsson E., Sigurdsson O., Stefansson V. and B. Steingrimsson: The Nesjavellir Geothermal Field, Iceland. Part 2: Evaluation of the generating capacity of the system. *Geotherm. Sci. & Tech*., Vol. 2 (3), (1990b), pp. 229-261.

Bodvarsson, G.S.: Recalibration of the three-dimensional model of the Nesjavellir geothermal field. *Report* prepared for the Reykjavik District Heating, 111 p. (1993).

Bodvarsson, G.S.: Update of the three-dimensional model of the Nesjavellir geothermal field. *Report* prepared for Reykjavik District Heating. 1998

Ívasson, G.: Fumarole Gas Geochemistry in Estimating Subsurface Temperature at Hengill in Southwestern Iceland. *Proceedings* of the 9th International Symposium on Water-Rock Interaction – WRI-9, Taupo, New Zealand (1998), pp. 459-462.

Saemundsson, K.,: Vulkanismus und tectonic des Hengillgebietes in Sudwest-Island. *Acta Naturalia Islandica,* Vol II, no. 7, (1967).

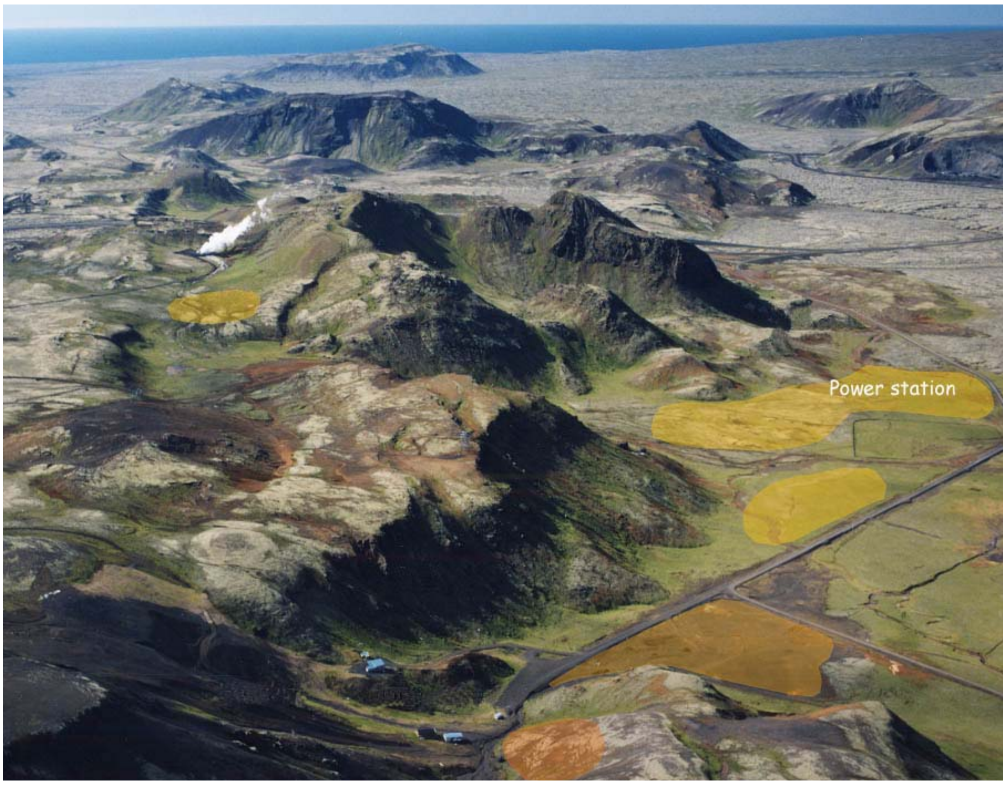

Figure 7. Photo of the area showing the location of the proposed power station.

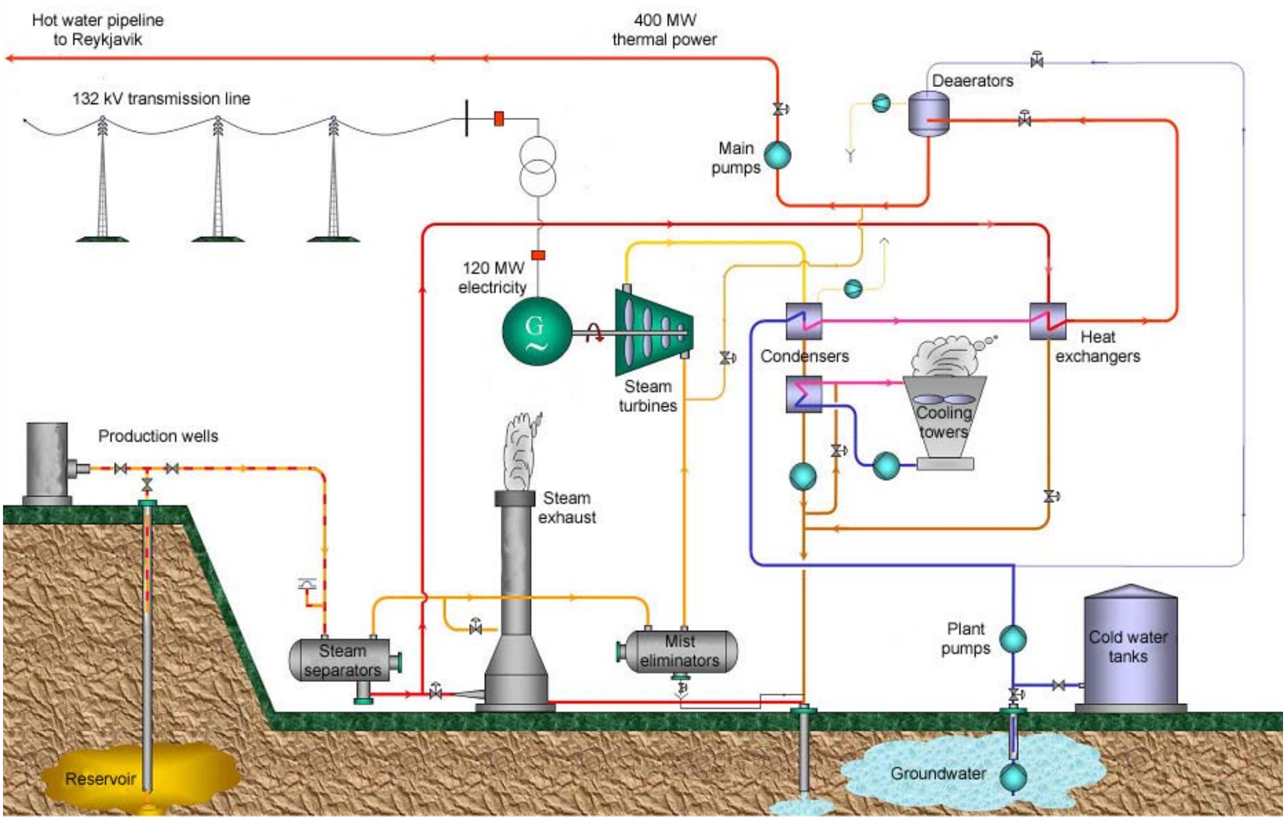

Figure 8. Simplified flow diagram of the geothermal heat and power plant.