Nesjavellir

POWER PLANT

Owner

Orkuveita Reykjavíkur (Reykjavík Energy)

Geothermal development, coordination to existing heating system, experimental preparation and tests, financing, etc

Consultants

VGK Consulting Engineers Ltd.

Project management, mechanical engineering, design of pressure vessels and HVAC systems

Fjarhitun Ltd.

Civic engineering, main consultant of pipeline to Reykjavík

Rafteikning Ltd.

Electrical engineering in general

Rafhönnun Ltd.

Electrical engineering, control system

Teiknistofan Ltd.

Architects

Landmark RV & ÞH

Landscape architects

Orkustofnun (National Energy Authority)

Geothermal research

Suppliers of material and equipments are from these countries:

Sweden, Finland, Denmark, Holland, USA, England, France, Germany, Austria, Portugal, Israel, Japan, Belgium, Croatia, Czech republic, Italy

Investment costs for Nesjavellir

(end of year 2005)

Research and drilling	69	MUS$
Power Plant	109	MUS$
Main transmission pipeline to Reykjavík	41	MUS$
Geothermal Power Plant	110	MUS$
High voltage transmission line to Reykjavík	8.9	MUS$

Reykjavík Energy was launched on January 1, 1999. It was founded on the merger of two established companies, Reykjavík District Heating and Reykjavík Electric Company. Reykjavík Water Works joined the company January 1, 2000.

Orkuveita Reykjavíkur

Bæjarhálsi 1, 110 Reykjavík
Tel.: +(354) 516-6000
www.or.is

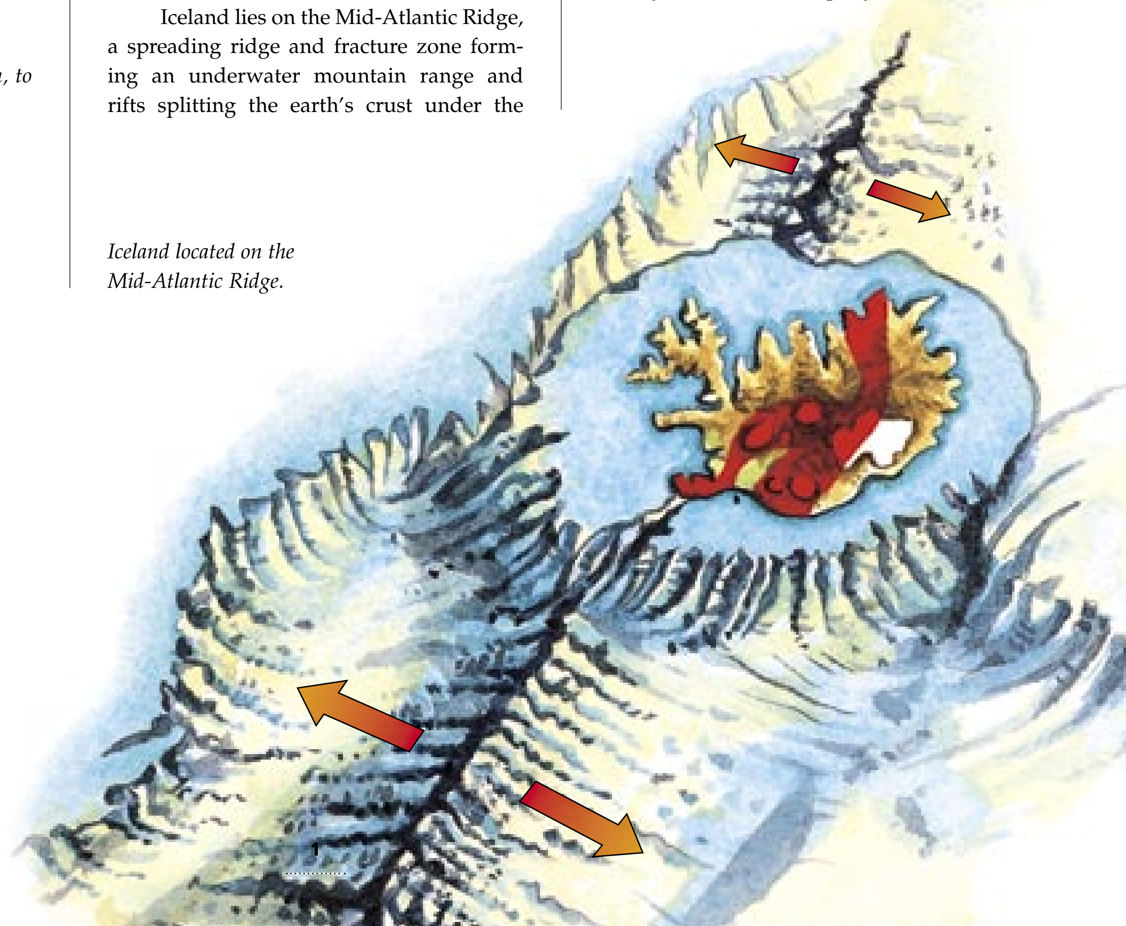
Photography:
Emil Þór, Ragnar Th. Sigurðsson, Snorri P. Snorrason, Grétar Eiríksson, The Reykjavík Museum of Photography, Reykjavík District Heating.
Illustrations on page 1,2, 7 and 9: Logi Halldórsson.
Design/Printing: Oddi Ltd.

Introduction

Plate boundaries. To the left deep-sea trench, to the right oceanic ridge.

The earth is divided into layers with the crust, or lithosphere, being outermost, the mantle in the middle and the core innermost. Together the lithosphere and mantle form separate plates that move relative to each other. Because of streams of material beneath the mantle, the plates are moved either away from or toward each other. Where they move apart, magma flows upward forming new material in the earth's crust, but where the plates move together, they thicken and form fold-mountains. If one plate moves under another, a deep-sea trench is formed.

Iceland lies on the Mid-Atlantic Ridge, a spreading ridge and fracture zone forming an underwater mountain range and rifts splitting the earth's crust under the Atlantic Ocean from North to South. A belt of volcanic fractures cuts across Iceland from Reykjanes (the Reykjanes Ridge) in the South north-east to Langjökull Glacier. From there, the belt turns eastward where, at Vatnajökull Glacier, it merges with the eastern belt and then heads north, re-entering the ocean at Öxarfjördur. From this point, the belt is called Kolbein's Island Ridge. The middle of this belt of fractures corresponds fairly well to the interface between the American and European tectonic plates that are diverging at the average rate of approximately two centimetres per year.

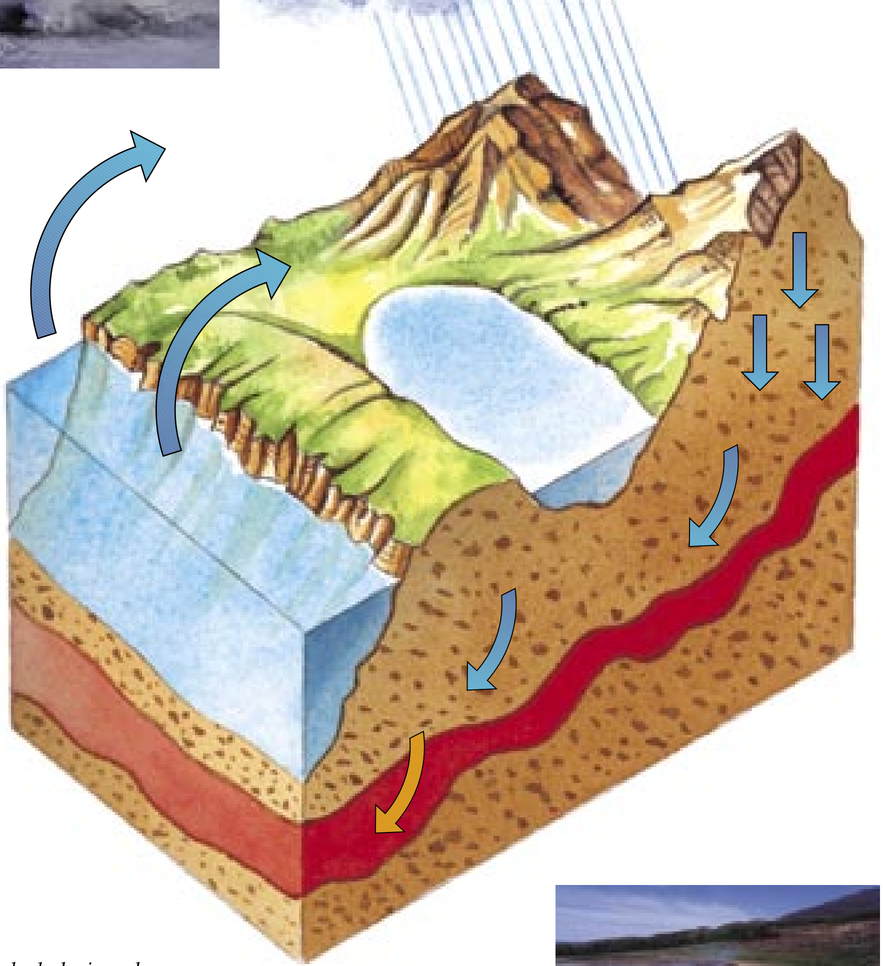


Iceland located on the Mid-Atlantic Ridge.

Geothermal heat

Geothermal water, like cold water, starts as precipitation. After falling to earth, it sinks deep beneath the earth's surface, forming ground water. Hot substrata and magma intrusions heat the ground water, which then rises toward the surface. Colder ground water then streams in from the sides or from above and seeps down to the substrata. This constitutes the bedrock water cycle. In this way, heat is conducted from hot substrata in the earth to upper layers, and geothermal areas are formed.

When water is heated underground, it dissolves various minerals that mix with the water. This is how, for example, the characteristic smell of hot water is formed; it comes from dissolved hydrogen sulphide. Substances dissolved in geothermal hot water are well utilised in research on geothermal energy. By measuring the concentration of materials in the water from boreholes and pools, inferences can be made about the temperature of water in the earth, thus making an assessment possible of the potential uses of the area involved. There are two types of geothermal areas, that is, low-temperature and high-temperatures areas. This division is based on geological characteristics and the lay of the areas.



The hydrologic cycle.

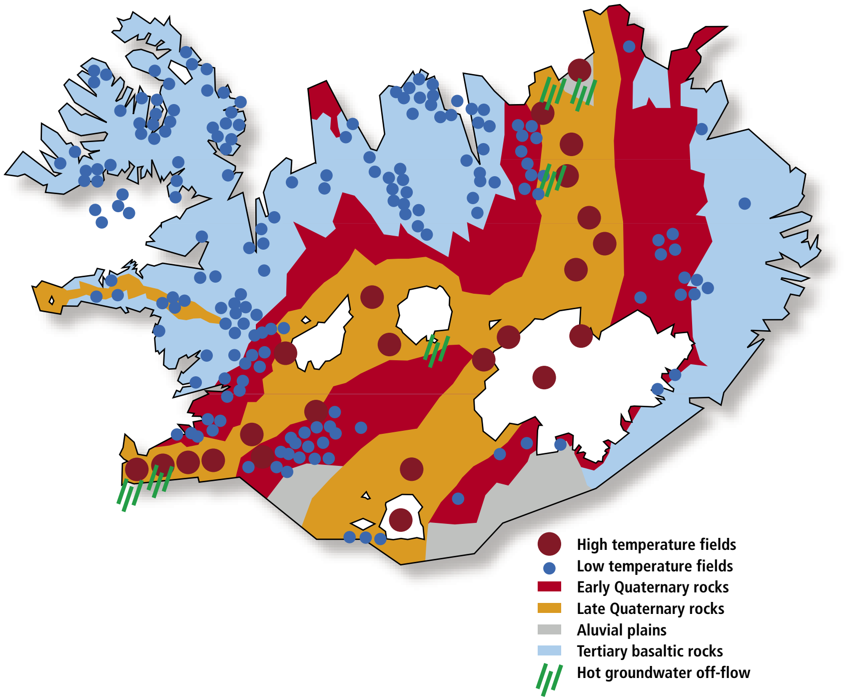
Low- and high-temperature areas

Low-temperature areas

Low-temperature areas in Iceland, which number about 250, are found all over the country, except perhaps in the East and South-east, outside the active fracture belt. The largest low-temperature areas lie in southern and western Iceland, for example, the largest area Reykir is in Mosfellssveit near the capital Reykjavík and the Reykholt Area in Borgarfjördur (W-Iceland).

The general definition of a low-temperature area is that its temperature is less than 150° C at a depth of approximately 1000 metres. The temperature is highest in low-temperature areas lying closest to the volcanic belt, but decreases going away from it. In low-temperature areas, geothermal heat on the surface is characterised by little or no alleration around pools and hot springs, and vegetation often reaches up to the banks.

Because of the low concentration of minerals in the water in low-temperature areas, the water can be used directly for hot water supply, and it is generally deemed safe to drink. In being heated, the water dissolves various substances from bedrock that mix with the water, for example, silica and the hydrogen sulphide that gives the water its peculiar smell.



Location of high- and low-temperature areas in Iceland.

High-temperature areas

High-temperature areas are only found on active volcanic belts or along their periphery. These areas number between 20 and 30 in Iceland. The volcanic belts lie in a broad area, stretching from the south-western corner of the country diagonally to the Northeast. There, the water temperature is not less than 200° C at a depth of 1000 metres. High-temperature areas are believed capable of developing into low-temperature areas as they extend outward from the centre of the volcanic belt because of continental drift. The surface activity of these areas is much more diverse than that of low-temperature areas. Fumaroles are found there along with boiling hot springs, mud pots and geysers. Generally, the soil is very acidic, making it inhospitable to vegetation. The main high-temperature areas in Iceland are on the Reykjanes Peninsula, Krísuvík, Hengill (all in SW-Iceland), the Torfajökull area and Grímsvötn (S-Iceland) and Námaskarð and Krafla (N-Iceland).

The water in high-temperature areas heats up when it comes into contact with hot bedrock, which is in turn heated by its proximity to magma. Because of the high temperature, much more minerals and gases are dissolved in the water in high-temperature areas. For this reason, this water is not utilised directly for heating. The high steam pressure and great thermal power are, on the other hand, well suited for heating up fresh water as a hot water supply and for generating electricity.

Harnessing of geothermal heat

In previous centuries, the utilisation of geothermal heat was primarily limited to bathing and laundering. The Icelandic Book of Settlement, the Bishops' Sagas and the Sturlunga saga cycle mention the use of hot pools for bathing, the most famous instance of which is certainly the Pool of Snorri Sturluson in Reykholt. For hundreds of years, the residents of Reykjavík used the Laugardalur pools (Þvottalaugar) to wash their laundry.

Little is known about the utilisation of hot water for heating in previous centuries, but it is possible that houses in Reykholt were heated using steam conveyed from the Skrifla hot spring. In 1907, in Mosfellssveit (the area lying just outside Reykjavík today), hot water from the Amsterdam Hot Spring was conveyed to the house of Stefán B. Jónsson in Reykir. Jónsson is generally deemed to be the first Icelander to heat his house with water from a hot spring. Later, water from this hot spring was conveyed to a wool factory.

The Reykjavík District Heating began operations in 1930, utilising the water from boreholes in Laugardalur. They provided 14 litres/second of water at 87° C. This was piped 3 kilometres to Austurbær Primary School in the eastern part of Reykjavík, which thereby became the first structure in Reykjavík to be supplied with hot water by the Utility. This hot water utility proved so successful that people began looking for geothermal areas near the city. Drilling was successful at Reykir and Reykjahlíd in Mosfellsveit, along the city street of Laugavegur and next to the Ellidaár River. After the low-temperature areas in Reykjavík and neighbouring areas were fully utilised, planning began for harnessing the geothermal heat at Nesjavellir (not far from Thingvellir National Park) for a hot water supply, and a power station was opened there in September 1990

Snorralaug at Reykholt.

Þvottalaugar hot springs in Laugardalur, Reykjavík. Picture taken around 1900.

Pumpingstation at Reykir Mosfellsbær.

The Reykjavík Energy now services an area from Kjalarnes north-west of Reykjavík south to Hafnarfjördur, with the exception of Seltjarnarnes. In this area, more than half the nation's population lives in approximately 26,000 houses. The harnessed power of the geothermal areas, including Nesjavellir, is about 700 MWt. Annually, about 60 million cubic metres of hot water flow through the Utility's distribution system.

Snorralaug at Reykholt.

The swimmingpool in Laugardalur.

View over city of Reykjavík.

Geothermal activity in the Hengill area

Nesjavellir and Hengill mountain.

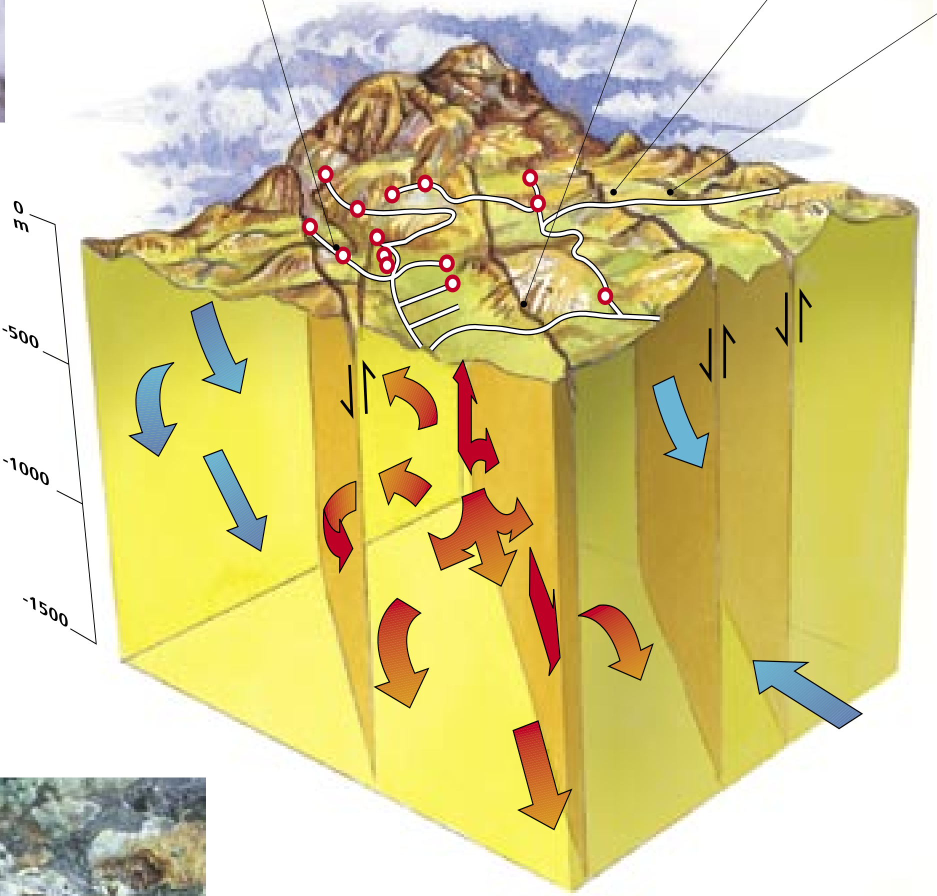
The Hengill area east of Reykjavík is one of the largest high-temperature areas in Iceland. The geothermal activity is connected with three volcanic systems in this area. The geothermal heat in Reykjadalur Hveragerði belongs to the oldest system, called the Grensdalur system. North of this is a volcanic area named after Hrómundartindur, which last erupted about 10,000 years ago. The geothermal heat in Öldukelsháls is connected with this volcanic site.

West of these volcanic systems lies the Hengill system, and volcanic fractures and faults stretch to the Southwest through Innstidalur, Kolviðarhóll and Hveradalur (Hot Spring Valley) and to the Northeast through Nesjavellir and Lake Þingvallavatn.

Research shows that precipitation falling on the highlands north of Lake Thingvellir seeps deep beneath the bedrock and flows onward underground to lower areas, depending on faults and cracks in the bedrock. Water coming into contact with bedrock heats up and is forced boiling up through cracks and faults under Hengill. The flow of hot water is generally deemed to be at a depth of from one to three kilometres.

The Hengill system has erupted several times since glaciation. Two thousand years ago, the Nesjahraun lava field flowed from the Kýrdalur fracture near Nesjavellir, and Sandey Island emerged from the waters of Lake Thingvellir. At Nesjavellir, as elsewhere in this area, people notice a lot of earthquakes. Nearly 24,000 earthquakes exceeding 0.5 on the Richter scale were measured in the Hengill area in an earthquakes period from the year 1993 to 1997. 12,000 of these occurred in 1997. The largest quake in this period registered 5.3 on the Richter scale in June 1998.

Geothermal activity in the Hengill area.



Model of the Nesjavellir geothermal field.

Geothermal activity at Nesjavellir

The power plant at Nesjavellir.

In 1926, Jón Thorláksson, an engineer who later became the Mayor of Reykjavík and the Prime Minister of Iceland, gave an address before the Association of Chartered Engineers in Iceland that he titled "The Reykjavík District Heating". Among other things, he pointed out three, vast geothermal areas near Reykjavík. One of them was the Hengill area. However, he doubted whether a sufficient quantity of water was obtainable there to heat buildings in Reykjavík. In addition, the hot water would cool down on its way to Reykjavík considerably more than, for example, hot water brought from Reykir in Mosfellssveit.

The harnessing of geothermal heat in the Hengill area has therefore been discussed for a long time. In 1948, the Town Council of Reykjavík approved participation in research on the Hengill area, whose area is 50 square kilometres. In co-operation with the Ministry of Communications and the market town of Hafnarfjörður, the area was researched from 1947 to 1949.

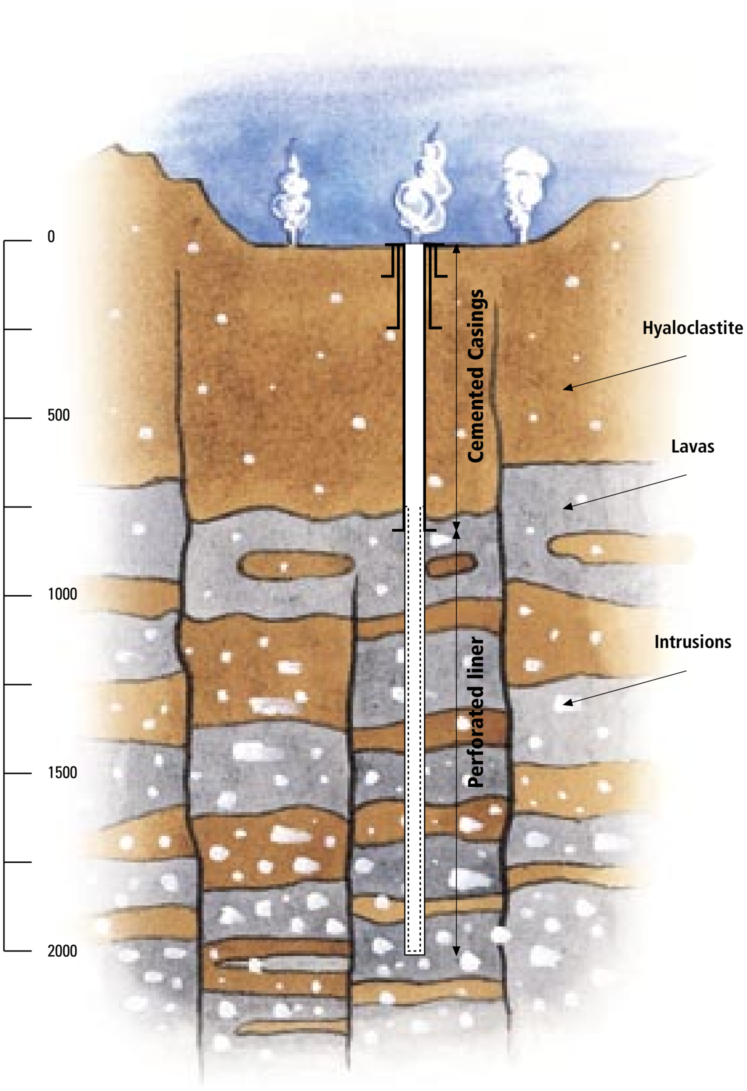
However, it was not until 1965 that further test drilling began at Nesjavellir. This continued, with several pauses, until 1986. The greatest geothermal activity on the surface is in the area south of Nesjavellir, and this became the focal point. The distribution of geothermal activity at a depth of one to two kilometres to the East, West and North was also checked, and exhaustive research was carried out on Nesjavellir and the surrounding area's geology, geochemistry and geophysics.

Drilling at Nesjavellir.

The findings of this research can be assembled into a model of the geothermal system showing a stream of boiling-hot water coming from beneath Hengill along the Kýrdalur Ridge to Nesjavellir. Between Kýrdalur Ridge and Köldulaugagil, geothermal heat lies at a depth of one to two kilometres, but the heat in Kýrdalur west of the Kýrdalur Ridge lies deeper.

View over Nesjavellir.

Strata and aquifers



Section through the Nesjavellir geothermal field.

Because of high volcanic activity, the strata of rock under Nesjavellir are relatively young. In the uppermost 500 metres, hyaloclastite is predominant, but below this lie strata of basaltic lava. Magma intrusions become more common with increasing depth, and at a depth of 1400 to 1600 metres and below, they are the prevailing type of rock.

Aquifers are often found on the peripheries of intrusions. There is a fault along the Kýrdalur Ridge. It cannot be seen on the surface, but boreholes show clearly that the floor of the valley has subsided.

Rock temperature is highest next to volcanic fractures. At sea level, the temperature there is approximately 100 °C. It increases with depth, and at two kilometres down, exceeds 350 °C.

Drill core from a borehole.

Power harnessing cycle

Mist eliminators.

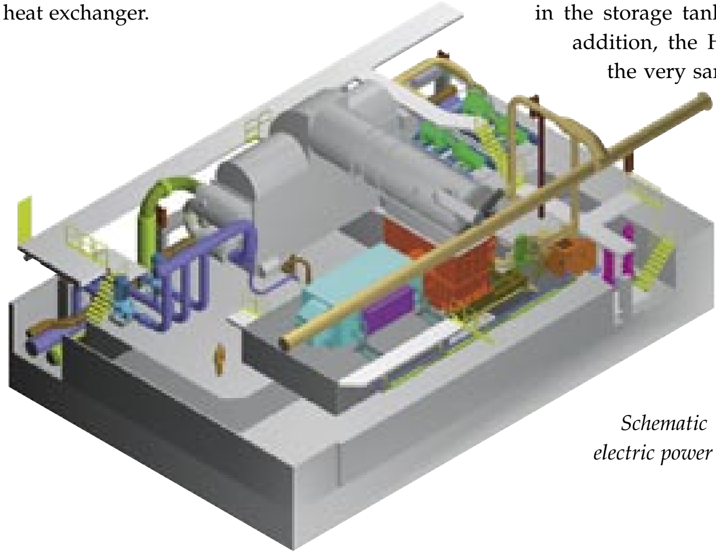
The power harnessing cycle may be divided into three phases, that is, the collection and processing of steam from boreholes, the procurement and heating of cold water and the production of electricity.

Steam mixed with water is conveyed from boreholes through collection pipes to the separation station where the water is separated from the steam. Excess steam and unutilised water go into a steam exhaust outside the separation station. From the separation station, steam and water proceed by separate pipes to the power plant at a pressure of about 12 bars and a temperature of 190° C. The steam is conveyed to steam turbines where electricity is generated. Each turbine produces 30 MWe of electricity. In the condenser the steam is utilised to preheat cold water. In the first tube heat exchangers the seperatedseparated water is utilised to heat cold water. The heated water is then mixed with preheated water before final heating occurs in the second tube heat exchanger.

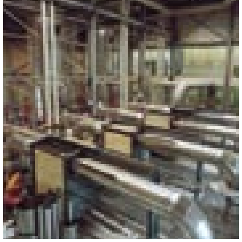
The cold water is taken from five boreholes near Grámelur at nearby Lake Thingvellir. It is pumped to water tanks next to the power plant. From there it goes to be heated in the condensers and heat exchangers mentioned above. The water is heated up to 85-90 °C.

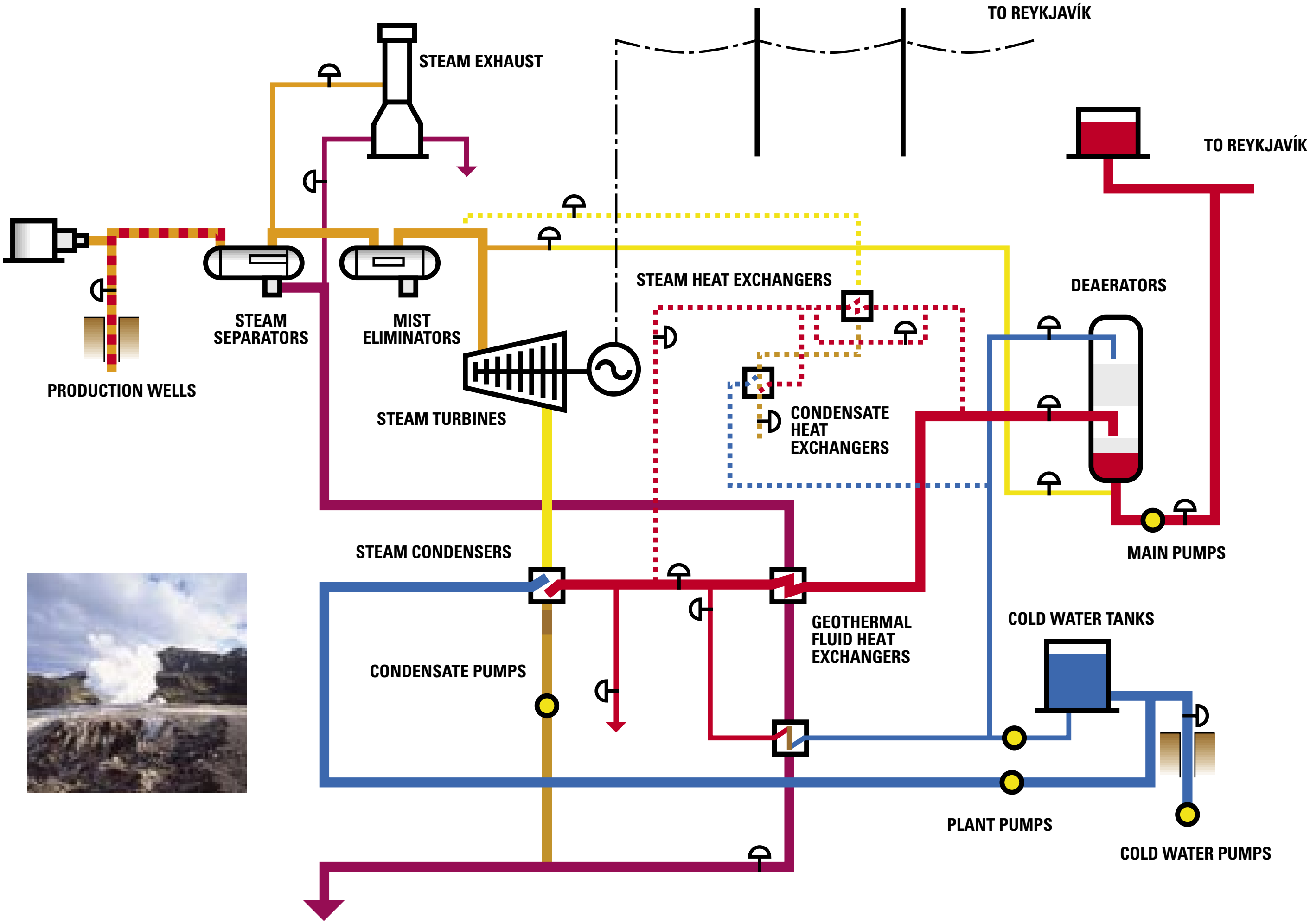
The cold water is saturated with dissolved oxygen that corrodes steel after being heated. To get rid of the oxygen, the water is sent to a deaerator where boiling under low pressure releases the dissolved oxygen and other gases from the water. During this process, the water temperature cools to 82-85 degrees.

Finally, a very small quantity of steam containing acid gases is mixed with the water to eliminate the last traces of dissolved oxygen and lower the pH of the water in order to prevent precipitation in the distribution system. Small quantities of hydrogen sulphide (H2S) ensures that dissolved oxygen that could get into the water in the storage tanks, is eliminated. In addition, the H2S gives the water the very same “good smell” for which the water from the hot water supply system in Reykjavík is known today.



Schematic drawings of electric power unit.





A flow diagram of the geothermal heat and power plant.

Drilling and harnessing geothermal energy at Nesjavellir

At Nesjavellir, drilling began in 1946 under the auspices of the landowner, Óli Metúsalemsson. Up to 1949, five holes were drilled, and the water obtained was utilised for heating a house and greenhouse at the site. From 1947-1949, as mentioned before, research was conducted on the Nesjavellir area, and holes were drilled although not at Nesjavellir. The Reykjavík District Heating bought Nesjavellir in 1964 and began research the next year. Up to 1972, holes were drilled for research, but later, they were designed as exploitations drillholes. The results have been very good. On average, each borehole provides about 60 MWt of thermal power, of which about 30 MWt are utilisable. This geothermal power suffices to heat a settlement of 7500 people.

At Nesjavellir 26 holes has been drilled, but 5 of them have been permanently closed.

The depth of the holes ranges from 1000 to 2000 metres, and temperatures of up to 380° C have been measured.

Construction of the Nesjavellir Power Plant began in early 1987, with the first stage being completed when the cornerstone of the power station building was laid May 13th 1990. The station was formally consecrated and put into operation on September 29th that same year. Four holes, generating about 100 MWt, were then connected to the processing cycle, making the station's productive capacity about 560 litres per second.

The next stage of power harnessing was brought online in 1995 when the fifth hole was connected; heat exchangers and a deaerator were added; and the production capacity was increased to 840 litres per second. This corresponds to 150 MWt of geothermal power. The power station is designed so that it can be extended to until the maximum production of geothermal energy is reached. From the beginning, the production of electricity with steam turbines has been planned. In fall 1998, the first steam turbine was put into operation and the second in end of the year. Five additional holes were put online, increasing the total processing power of the power station to 200 MWt, with the water production reaching more than 1100 litres per second. The current total production of the power plant is 120 MWe electricity and 300 MWth hot water.

The geothermal area at Nesjavellir is estimated to sustain hot water production of about 400 MWt. Assuming an average production of 400 MWt, forecasts indicate that viable production in the current processing area will continue for the next 30 years. After this time, one can expect that the influx of water will not suffice for such great utilisation.

Environmental impact of power harnessing

For centuries, the natural run-off from the geothermal area at Nesjavellir has gone into brook at Nesjavellir and from there into the lava Nesjahraun. The geothermal water can be found in Lake Thingvellir, especially in the Varmagjá in Þorsteinsvík.

In the beginning, people thought that a great quantity of run-off water from the power plant could affect the biosphere. Extensive research on Lake Thingvellir confirms that the portion of geothermal water flowing into the lake does not cause any environmental damage. It is therefore assumed that the disposal of run-off water from the plant into the brook of Nesjavellir has no deleterious effects. However, attempts will continue to inject the run-off water back down into the geothermal system or deep into the ground water system under Nesjavellir, which have no direct links with Lake Thingvellir. The chemical composition of the ground water flowing

Planting trees at Nesjavellir.

along with the lake's biosphere. The greatest scrutiny is given to substances like hydrogen sulphide, arsenic, boron and mercury.

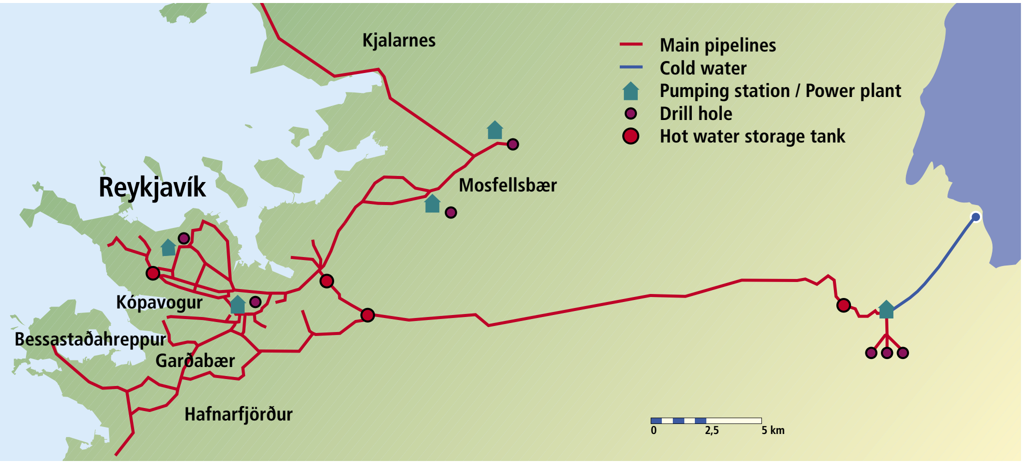
The steam of geothermal areas contains dissolved gases that go into the atmosphere. The main air pollutants are carbon dioxide (CO2), which is a greenhouse gas, and hydrogen sulphide (H2S). About 7500 tonnes of carbon dioxide are released into the air each year from the Nesjavellir Power Plant. In comparison with the emissions coming from the burning of fossil fuels, such as oil, the emission of carbon dioxide due the utilisation of geothermal areas is small. In addition, a net addition is not involved, as is the case with the burning of fossil fuels.

The emission of hydrogen sulphide is somewhat less or about 1700 tonnes per year. The combustion of fossil fuel produces sulphur emissions in the form of sulphur dioxide (SO2), which is very polluting and, among other things, can cause acid rain. Emissions from geothermal power stations, on the other hand, are mostly in the form of hydrogen sulphide (H2S), as mentioned before. Hydrogen sulphide can, with time, change into sulphur dioxide, but there are no signs of this happening in Iceland. Not everyone agrees what the fate of hydrogen sulphide is. Some experts believe that hydrogen sulphide changes into sulphur (S), which then falls to earth with precipitation and collects as harmless salts. Others think that it changes into sulphur dioxide. Research findings indicate that the former applies, that is, that hydrogren sulphide changes into sulphur in geothermal areas in Iceland. Further research, focused on both geothermal areas and other areas, is being conducted.

Varmagjá at Þorsteinsvík.

Other geothermal gases are nitrogen, methane, which is a greenhouse gas, mercury, ammoniac, arsenic, boron (harmful to vegetation) and radon. These substances, however, are in such small quantities that they are not deemed to be a threat to the biosphere.

Supply conduit to Reykjavík

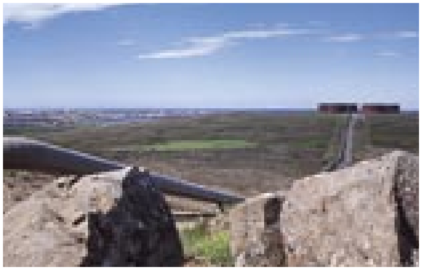


The power station at Nesjavellir is at 177 metres above sea level. The hot water is pumped from there through a pipe 90 centimetres in diameter into a tank on Háhryggur near Hengill. The ridge is at 406 metres above sea level. The first stage of the pipeline to Reykjavík is 90 centimetres in diameter; it then becomes 80 centimetres and feeds into tanks on the Reynisvatn. These tanks are at 140 metres above sea level. There is gravity feed between Háhryggur and Reynisvatn, where control valves manage the flow through the supply line and keep the water level in the Háhryggur tanks constant.

From the tanks at Reynisvatn, the pipeline runs south, supplying water from Nesjavellir to the towns Kópavogur, Gardabær, Bessastaðahreppur and Hafnarfjörður.

The supply line from Nesjavellir to Reynisvatn is 23 kilometres long. It is designed for water of up to 100°C in temperature and can convey 1870 litres per second. In the first stage of the project, the pipeline conveyed 560 litres per second. At this flowrate, the water took less than seven hours to flow from Nesjavellir to Reynisvatnheiði, with temperature decrease less than two degrees. Good insulation and a large quantity of water are the main factors in how little loss of heat there is. In the second stage of the project, the maximum flow increased to 840 litres per second, and in the third stage to about 1100 litres per second. As more water is produced the flow rate increases thereby decreasing the loss of heat and shortening the transport time.

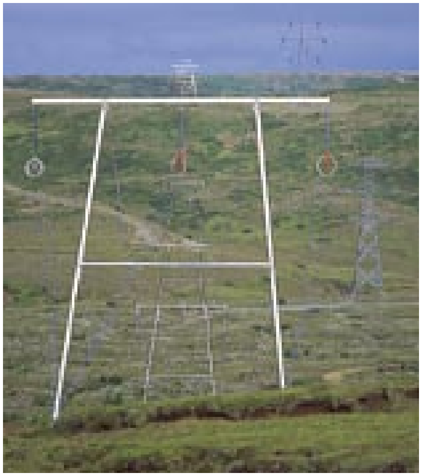
The pipeline is made of steel, insulated with rock wool covered with plastic and aluminium on the outside where the pipeline lies aboveground, but with urethane insulation, covered with plastic, where it runs underground. As an indication of the pipeline's insulation value, it can be mentioned that where the pipeline lies aboveground, snow does not melt off it. In order to facilitate traffic and for environmental reasons, about five kilometres of the pipeline are laid underground. In addition, at twelve sites where it lies aboveground, it is possible to drive over the pipeline. These sites are well marked. Because of temperature changes, the steel in the pipeline can either expand or contract. When hot water was run for the first time through the pipeline, the expansion was about 24 metres from Nesjavellir to Grafarholt (on the outskirts of Reykjavík). To accommodate these changes, the pipeline rests on special supports and apparatuses with wheels. In addition, at regular intervals, there are expansion joints that operate like springs.



Hot water storage tanks at Grafarholt near Reykjavík.

Transmission line to Korpa

The transmission line from Nesjavellir Power Plant runs to the Mosfellsheiði through the Mosfellsdalur to Korpa, a total of about 31 kilometres. From the power plant, the line runs underground to the Selklettar, about two to three kilometres north of Nesjavellir, where it continues on towers across Mosfellsheiði. The line runs parallel with Sog Line 3 from the Selklettar and west by Sköflungur, where it goes north-west over Mosfellsheiði toward the spot where the line from Hvalfjörður and Sog Line 1 intersect. From this point, it follows Sog Line 1 toward the deserted farm Bringur, where it goes underground along the road to the substation at Korpa. Of these 31 kilometres, about 13 kilometres are underground for environmental reasons. The visual impact of the line on Mosfellsheiði will be almost nil from a distance of two kilometres.



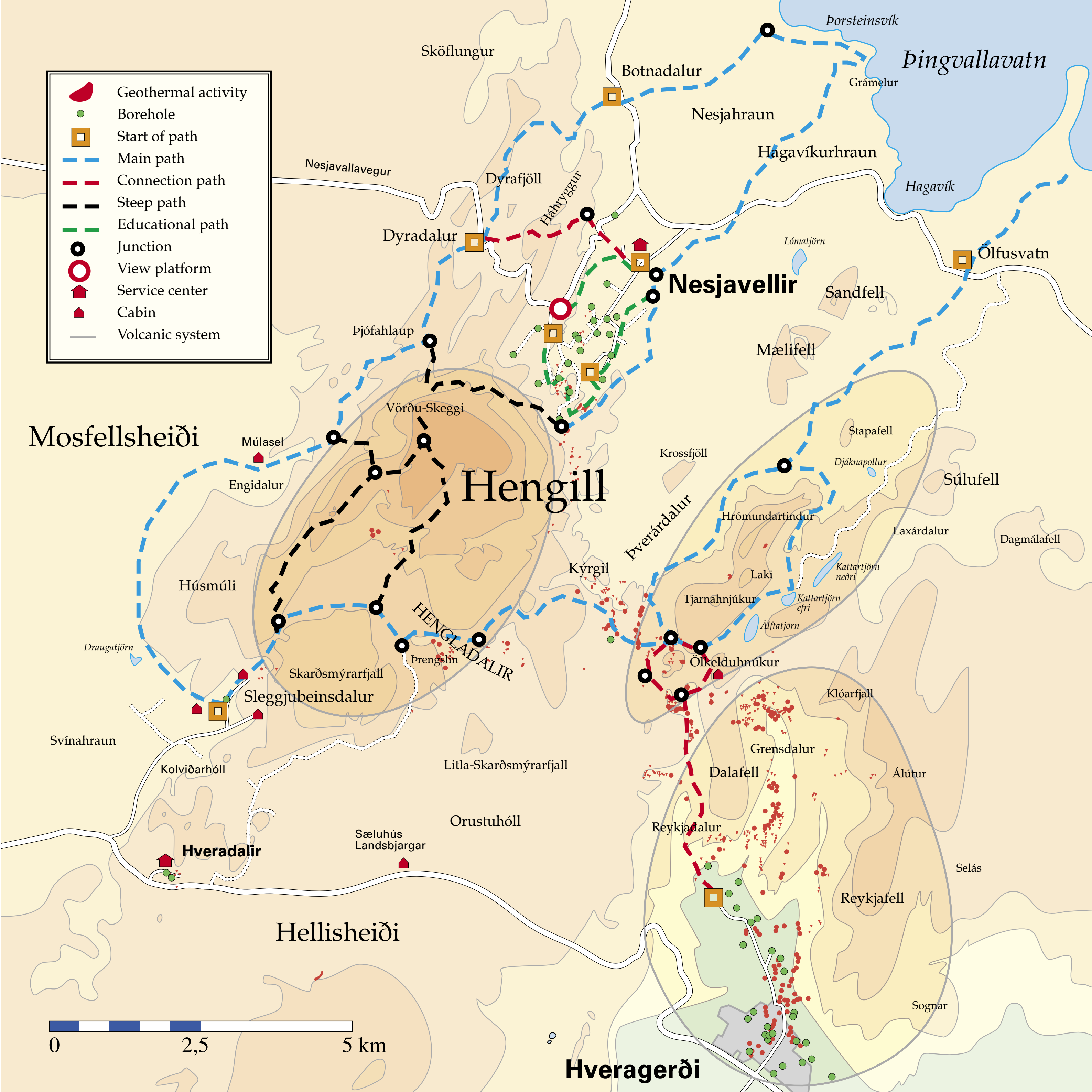
The transmission line.

Environmental and outdoor affairs

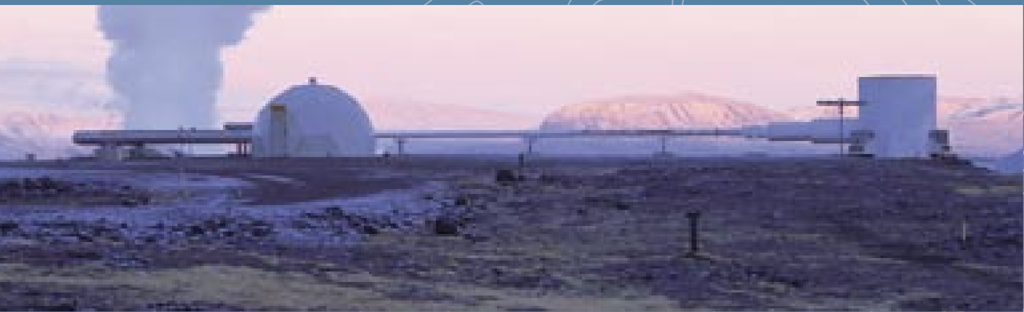
The Reykjavík Energy has organised the outdoor areas of its lands in Grafningur and Ölfus, that is to say, Nesjavellir, Ölfusvatn and Kolviðarhóll. There, hiking and riding trails have been marked, and archaeological finds and other historical cultural artefacts have been registered. A total of 375 historical sites have been recorded at Nesjavellir and Ölfusvatn. Regarding hiking trails in the Hengill area, two hikers' shelters have been built, Múlasel in the Engidalur and Dalasel in the Reykjadalur. They are open to everyone. A map of the Hengill area has also been published. It shows the marked hiking trails and locations of the hikers' shelters along with various information about the area. Since 1989, there has been a project to revegetate protruding erosion remnants of the landscape, and since 1990, a forestation project for Nesjavellir. On the lands of the Reykjavík Energy and the City of Reykjavík in Grafningur, over half a million forest seedlings of various types have been planted since 1990. Under the auspices of the Reykjavík Summer Youth Work Program, students in upper primary school have been planting and caring for plants and working on revegetation. Under the auspices of the Reykjavík Energy, secondary school and university students have worked on diverse projects on the lands of the City of Reykjavík in the Hengill area. Well over 2,000 students have thus got summer jobs in the outdoor areas in Grafningur and the Hengill area since 1989.

Students making hiking trails.

Tourists at Köldulaugargil.



Geothermal activity
Borehole
Start of path
Main path
Connection path
Steep path
Educational path
Junction
View platform
Service center
Cabin
Volcanic system
Þorsteinsvík
Þingvallavatn
Grámelur
Sköflungur
Botnadalur
Nesjahraun
Hagavíkurhraun
Hagavík
Nesjavallavegur
Dyrafjöll
Háhryggur
Dyradalur
Lómatjörn
Ölfusvatn
Nesjavellir
Sandfell
Þjófahlaup
Mælifell
Vörðu-Skeggi
Mosfellsheiði
Múlasel
Engidalur
Hengill
Krossfjöll
Stapafell
Djáknapollur
Súlufell
Hrómundartindur
Laxárdalur
Dagmálafell
Þverárdalur
Kýrgil
Laki
Kattartjörn neðri
Húsmúli
Tjarnahnjúkur
Kattartjörn efri
Álftatjörn
Draugatjörn
HENGLADALIR
Þrengslin
Ölkelduhnúkur
Skarðsmýrarfjall
Sleggjubeinsdalur
Klóarfjall
Svínahraun
Grensdalur
Kolviðarhóll
Litla-Skarðsmýrarfjall
Dalafell
Álútur
Orustuhóll
Reykjadalur
Hveradalir
Sæluhús Landsbjargar
Selás
Reykjafell
Hellisheiði
Sognar
0
2,5
5 km
Hveragerði



Orkuveita
Reykjavíkur