Hydro- and geothermal power in Iceland

A study trip

Ltu and Vattenfall visit Landsvirkjun
May 1-5, 2007

Isabel Jantzer
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Iceland is currently constructing the largest hydropower dam in Europe, Kárahnjúkar. There are not many possibilities to visit such construction sites, as the opportunity to expand hydropower is often restricted because of environmental or regional regulations limitations. However, the study trip, which was primarily designed for the visitors from Vattenfall, gave a broad insight in the countries geology, energy resources and production, as well as industrial development in general.

This report gives an overview of the trip, summarizes information and presents pictures and images. I want to thank Vattenfall as organization, as well as a large number of individuals at Vattenfall, for giving me the opportunity for participation.

Further, I want to express my sincere gratitude to the Swedish Hydropower Center, i.e. Svensk Vattenkraft Centrum SVC, Luleå University of Technology, and individuals at Elforsk for providing me the possibility to take part in this excursion. It has been of great value for me as a young person with deep interest in dam design and construction and provided me with invaluable insights.

Luleå, May 2007
Isabel Jantzer
Agenda

During three days we had the possibility to travel over the country: After the first day in Reykjavik, we flew to Egilsstadir in the north eastern part of the country, from where we drove to the Kárahnjúkar dam site and visited the Alcoa aluminium smelter at Reydarfjördur Fjarðaál afterwards. The next day we drove to the Krafla geothermal power plant, took a bath in Mývatn nature bath, and stopped at the Laxá power plants on the way to Akureyri, from where we flew back to Reykjavik in the evening.

Wednesday - May 2nd
09:00-11:00 Meeting in Landsnet’s Dispatch Center in Reykjavik.
   Introduction by Landsvirkjun on ongoing and planned projects and the power situation in Iceland in general.
   Introduction by Luleå University of Technology
11:00-12:00 Tour in Landsnet’s Dispatch Center
13:00-16:00 B2B meeting between Vattenfall and Landsvirkjun
16:00-20:30 Visit to Svartsengi geothermal powerplant (www.hs.is).
16:30-17:30 Tour in Svartsengi Power Station
17:30-18:30 Dip into the Blue Lagoon (bring swim suit) –
19:00-20:30 Dinner in the Blue Lagoon Restaurant.

Thursday - May 3rd
08:00-09:00 Flight from Reykjavik to Egilsstadir.
09:45 Végarður info center
11:30 Kárahnjúkar dam site/inspection of the Kárahnjúkar area.
13:00 Drive to the powerhouse
14:00-16:00 Inspection of the powerhouse in Fljótsdal and other buildings.
16:00-16:15 Coffee break at the canteen in Fljótshulur
16:15-17:15 Drive to Reydarfjördur.
17:15-18:30 Visit to the new Alcoa aluminium smelter in Reyðarfjörður Fjarðaál
19:30-20:30 Dinner in Hotel Herad at the invitation of Alcoa.

Friday - May 4th
08:00-10:00 Drive to Lake Mývatn from Egilsstadir.
10:00-12:00 Inspection Krafla power station
13:00-15:30 Visit Víti, Bjarnarflag, Myvatn Nature Bath (bring swim suit)
15:30-18:00 Drive to Akureyri via the Laxá power plants
18:40 – 19:25 Flight from Akureyri to Reykjavik
20:30 Dinner at Restaurant Perlan in Reykjavik at the invitation of Landsvirkjun.

Saturday - May 5th
07:50 Flight back to Sweden from Keflavík
Tuesday, May 1, 2007:  
**Flight to Reykjavik**

The first impression upon arrival is that the country is plain, almost no trees or vegetation. I learn that the time difference is two hours instead of the expected one: Iceland does not change to daylight saving time. I also learn that Iceland has an agreement with the European Community, but is not part of it because of the fishing rights which Iceland is not willing to give up (similar to Norway). In 2003, it was allowed to hunt 38 whales each year during a period of 6 weeks in August and September, which resulted in a Greenpeace protest action. The fishing industry stands for the major export product; besides that, aluminium production and tourism are the largest branches. Most of the 290 000 inhabitants of Iceland live in or around the capital. About the same number of tourists visits the country annually.

Wednesday, May 2, 2007:  
**Visit at Landsvirkjuns office and Svartengi geothermal powerplant**

Landsvirkjun is Iceland’s power company, corresponding to Vattenfall in Sweden. Landsvirkjun is jointly owned by the Icelandic state (50 %), City of Reykjavik (45 %), and the Town of Akureyri (5 %). We meet Bjarni Már (all men in Iceland are called Bjarni) who, having studied geology, explains Iceland’s geology and natural resources:

Iceland is located on the Mid-Atlantic ridge, a plate boundary which runs through the Atlantic Ocean from north to south. Because of the movement of the plates, the Atlantic Ocean is becoming approximately 2 to 4 cm wider each year. The island was created by volcanic eruptions and plate movements, which explains that there is a volcanic active terrain running diagonal over the country, with lava flows and geothermal activity, see the red marked areas in Figure 1.

![Geothermal fields](image)

*Figure 1. Volcanic active terrain which is located on the Mid-Atlantic ridge*
Iceland’s energy consumption per capita is four times higher compared to Sweden, and almost five times compared to Germany. It is one of the highest numbers per capita in the world. This is due on the high amount of energy needed in aluminium production. However, the consumption comprises approximately 70 % renewable, domestic resources, i.e. geothermal (about 55 %) and hydro power (about 17 %). The remaining 30 % are fossil fuels mainly used for transport (i.e. cars, fishing boats, airplanes). Almost 100 % of the electricity consumed is produced by geothermal energy or hydropower. Heating for houses and warm water supply is almost completely covered by geothermal heat. Iceland’s vision is to become the first country to become completely independent from fossil fuels by utilization of hydrogen.

In order to get a picture of how a geothermal power plant works we visit Svartsengi Power-Plant. This is a power plant with combined heat- and electricity production. Heat exchangers are used to warm up cold groundwater for heating purposes. The brine coming from the wells has about 2/3 of the salinity of saltwater. Steam is used for electricity production. The principle is shown in Figure 2.

![Figure 2. Svartsengi power plant – heat and electricity production (Thorolfsson, 2005)](image)

Afterwards we take a bath in the Blue Lagoon, which actually is process water from the power station which was pumped out in order to let it percolate back into the ground. But as the water is rich in silicates, the pores in the ground got clogged and a surface pond -or natural bath- was created. The water has a temperature of about 40 - 42°C and one has to be careful not to come to close to the outlet, as the water is still close to the boiling point.
Figure 3. Svartsengi Power plant

Figure 4. Blue Lagoon

Figure 5. Silicate accumulation
Thursday, May 2, 2007: Flight to Egilstadir, Visit at Kárahnjúkar and aluminium smelter at Reydalfjórdur

We flew to Egilstadir, a small town with approximately 1600 inhabitants in northwest Iceland, where we get picked up and drive to Kárahnjúkar. The controversial project was approved in February 2003, after an extensive Environmental Impact Assessment EIA. The complete energy production will be transmitted to the Alcoa aluminium smelter in Reydalfjórdur. A contract with the US based company Alcoa was signed in 2003, where Alcoa signed to receive all produced energy. The construction permit was issued in February 2003.

Kárahnjúkar dam site

Two glacial rivers are dammed, Jökulsá á Dal and Jökulsá í Fljótsdal, by three dams: Saudáralsstífla, Kárahnjúkar, and Desjarárstífla, creating the Hálsón reservoir with an area of 57 km² and a length of 25 km, see Figure 6. During the construction, the rivers have been led through tunnels under the western bank of the Kárahnjúkar dam which have been constructed in 2002.

Figure 6. Overview of the Kárahnjúkar dam site

The Kárahnjúkar dam is a concrete-faced rock fill dam, 193 m high and 730 m long, see Figure 7. It is located at the upper end of the Hafrahvammar canyon. Both the Desjarárstífla dam and the Saudáralsstífla dam are rock fill dams with earth fill core (Figure 8); the Desjarárstífla dam in the east is 68 m high and 1100 m long, the Saudáralsstífla dam in the west is 29 m high and 1100 m long. Rock fill for construction has been quarried upstream of the dams in the reservoir area. The selection of a concrete-faced rock fill dam for the main dam is due to stability evaluation in case of an earthquake (even though the area is considered to be the active zone). As the area is covered with a layer of glacial moraine which could be used for construction, both the other dams were built as rock fill dams with central moraine core to reduce costs. The rock fill material of the Kárahnjúkar dam is provided with a layer of earth fill upstream (marked light pink in the left cross section, Figure 7) to supply for self-healing material when displacements and/or cracks occur upon filling of the reservoir.
The foundation has been sealed by a grout curtain. Drilling was carried out to a depth of 100 m and cement injected. The grout curtain is marked yellow in Figure 9. The concrete toe wall and the foundation can be inspected in the gallery below the dam. Additional grouting in the bedrock can be carried out from the inspection tunnel if necessary.
The spillway located on the west bank consists of an overflow to a 450 m long side channel, which discharges into Hafrahvammagljúfur canyon. The canyon is 50 m wide and the water will fall about 90 m down into the canyon. The rock formation canyon was created by volcanic eruption and the underlying bedrock consists of solid layers of old lava flows which have been compressed by ice pressure during glacial periods. However, it will be reinforced by concrete to withstand eroding forces.

Filling of the reservoir started in September 2006 and stayed at a constant level during winter. It is now filled at a rate of approximately 30 cm per day. Filling will be completed in fall 2007, when the reservoir has reached full supply level at 625 m. The minimum level is 575 m, the regulation height is 50 m. Settlements, leakage, movements of the fill material, the concrete face and the foundation, groundwater pressure and stresses in the concrete are monitored. The Kárahnjúkar dam is considered to be the highest dam in Europe and one of the highest of its kind in the world.

Figure 10. Kárahnjúkar, concrete facing upstream

Figure 11. Kárahnjúkar, rockfill downstream (front: construction of spillway)
Figure 12. Hafrahvammagljúfur canyon

Figure 13. Spillway construction
Figure 14. Spillway overflow

Figure 15. Kárahnjúkar, rockfill downstream
The installed capacity of the power station is 690 MW in six units (for comparison: Hårsprånget 830 MW). Two vertical shafts (penstocks) are constructed to lead the water to an underground powerhouse. The total head is 599 m. The office building is the only structure that is above ground, all other structures are located below. The total length of all tunnels is about 72 km. The following Figure 16 and 17 are taken from the folder on the Kárahnjúkar hydropower project which can be found on the internet. (http://www.karahnjukar.is/EN/)

Figure 16. Kárahnjúkar hydropower project powerhouse area
Figure 17. Map of the Kárahnjúkar hydropower project
Alcoa aluminium smelter in Reydarfjördur Fjördalaál

All electricity generated by the Kárahnjúkar hydropower plant will be transmitted to the aluminium smelter in Reydarfjördur Fjördalaál. The construction of both the hydropower plant and the aluminium smelter have been controversial, as the production of aluminium is extremely energy consuming. Two thirds of Iceland’s population have, however, been in favour of the project, and almost 75% of the population outside the Reyjavik area voted for the aluminium smelter. This is mainly due to relatively high unemployment rate outside the Reykjavik area. (The general unemployment rate in Iceland is about 3.4%.) Besides that, it is considered that the environmental impact is comparatively low in Iceland because of the possibility of energy production by renewable sources.

Aluminium is the most abundant metallic element in the earth’s crust (about 7.5 - 8.1 %). However, it is rarely found in free form. It is primarily found in bauxite ore, the most important aluminium ore. Bauxite ore contains about 30 – 50 % alumina, Al₂O₃. The ore for production in Iceland comes primarily from Australia; other bauxite mining can be found e.g. in Brazil or China.

Aluminium found as Al₂O₃, is refined in the Bayer process. To break up the bond between Al and O, energy and Carbon is needed: 2 Al₂O₃ + 3C -> 4 Al + 3 CO₂. This electrolysis is called Hall-Héroult process after the two scientists that discovered the process. To produce 1 kg of Aluminium, the energy of 15 kWh is needed.

Criticism on the CO₂ emission from the process has been expressed. Statistics have, however, shown that Iceland’s CO₂ emission is about 0.05 % of the total emissions. (For comparison: US 24.3 %, Germany 3.3 %, Sweden 0.2 %)
Friday, May 3, 2007

Drive to Lake Mývatn, inspection of the Krafla power station

The area is rich in volcanic and geothermal activity and lava flows, craters and rock formations. The idea to exploit geothermal heat at Krafla was conceived in 1973. In 1974 the works began with trial boreholes. The basic idea is to bore holes about 2 – 3 km deep in the ground. As the ground is permeable, rain water percolates, gets warmed up and rises in the bore hole. This natural circulation takes some time until it regulates itself. The water’s temperature from boreholes at around 2 km depth is approximately 250 - 340°C. (It is planned to bore up to a depth of 5 km, where a temperature of 450°C is expected.) Steam pressure varies from borehole to borehole, mainly dependent on the drilled depth. The steam has to be separated from free water before it can be used for driving turbines and producing energy because of cavitations. The first turbine started up in August 1977, but electricity production started first half a year later because of insufficient steam supply. Several initial difficulties were met during prospecting and drilling. The seismic activity in the field caused several eruptions. In December 1975, several eruptions occurred, both causing surface subsidence and destroying borehole linings by magma entering the geothermal system. This is the only case where an eruption actually occurred in a man-made structure.

Figure 18 shows the surface elevation before and after eruption in 1975. During eruption, when magma is flowing out of the subsurface chamber, the surface elevation dropped about two meters. Several eruptions have occurred until 1984, and the surface has moved up and down about 0,5 m. From 1984 until 1990 magma has been accumulated and the surface elevation has risen about three meters compared to 1975. Subsidence of about 5 to 2,5 cm per year has since then been observed.

![Figure 18. Picture of 'Surface elevation at Krafla power station'](image)
Figure 22. Geothermal borehole

Figure 23. Volcanic area at Mývatn

Figure 24. Volcanic area at Mývatn
Figure 25. Lava at Krafla power station

Figure 26. Námafjall
References and useful links

- Information on the Kárahnjúkar Hydroelectric Project:
  http://www.karahnjukar.is/EN/


- Renewable energy in Iceland:
  http://en.wikipedia.org/wiki/Renewable_energy_in_Iceland

- Geothermal power in Iceland:
  http://en.wikipedia.org/wiki/Geothermal_power_in_Iceland

- Energy statistics in Iceland:
  http://www.os.is/Apps/WebObjects/Orkustofnun.woa/swdocument/3879/Orkut%C3%B6lur+enska+2005.pdf