Geothermal Country Update for Iceland

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ARGe-C6 conference, Addis Ababa, Ethiopia, 2\textsuperscript{nd} – 4\textsuperscript{th} November 2016
Outline

- Energy resources and consumption in Iceland
- Geothermal space heating
- Other direct utilization of geothermal energy
- Geothermal electricity generation
- New developments
Geothermal Resources in Iceland
Energy in Iceland - Highlights

- During the 20th century Iceland went from a poor country to a country with high standard of living.
- Harnessing indigenous renewable energy contributed to this development.
- The share of renewables (hydropower and geothermal) is among the highest in the world (85%).
- The consumption of primary energy and electricity per capita is among the highest in the world (750 GJ/capita, 53,000 kWh/capita).
- The policy of the government is to support further development of hydropower and geothermal energy in order to eliminate the present import of fossil fuel for transportation and fishing.
Primary energy consumption in Iceland 2015

- Primary energy consumption 750 GJ/capita
- 1 PJ = 1000 TJ = 1,000,000 GJ
- 1 kWh = 3,600 kJ
- 1 toe = 41,868 GJ

Source: Orkustofnun
Primary energy consumption in Iceland 1940-2015

Relative consumption

Hydro
Geothermal
Oil
Coal
Peat

PJ

0 50 100 150 200 250 300

Production and consumption of electricity in Iceland 2015

<table>
<thead>
<tr>
<th>Installed capacity</th>
<th>MW</th>
<th>%</th>
</tr>
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<tbody>
<tr>
<td>Hydro</td>
<td>1,986</td>
<td>71.7</td>
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<tr>
<td>Geothermal</td>
<td>663</td>
<td>24.0</td>
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<tr>
<td>Oil</td>
<td>117</td>
<td>4.2</td>
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<tr>
<td>Wind</td>
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<td>Total</td>
<td>2,769</td>
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<table>
<thead>
<tr>
<th>Electricity generation</th>
<th>GWh</th>
<th>%</th>
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<tbody>
<tr>
<td>Hydro</td>
<td>13,780</td>
<td>73.3</td>
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<tr>
<td>Geothermal</td>
<td>5,003</td>
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<tr>
<td>Oil</td>
<td>4</td>
<td>0.0</td>
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<tr>
<td>Wind</td>
<td>11</td>
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<tr>
<td>Total</td>
<td>18,798</td>
<td>100.0</td>
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<table>
<thead>
<tr>
<th>Electricity consumption</th>
<th>GWh</th>
<th>%</th>
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<td>3,449</td>
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<td>Energy intensive industry</td>
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<td>Transmission losses</td>
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<td>Total</td>
<td>18,798</td>
<td>100.0</td>
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</table>

Source: Orkustofnun
Geothermal utilization in Iceland 2014

- **Electricity generation**: 41.4%
- **Space heating**: 42.6%
- **Greenhouses**: 1.4%
- **Fish farming**: 4.9%
- **Industrial process heat**: 2.0%
- **Snow melting**: 4.2%
- **Swimming pools**: 3.5%

<table>
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<th></th>
<th>Installed power</th>
<th>Energy consumption</th>
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<tr>
<td></td>
<td>MW</td>
<td>TJ/year</td>
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<td>1,550</td>
<td>19,400</td>
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<td>Greenhouses</td>
<td>45</td>
<td>660</td>
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<td>85</td>
<td>2,230</td>
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<td>70</td>
<td>2,910</td>
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<td>195</td>
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<td>Direct uses total</td>
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<td>26,700</td>
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<td>Electricity generation</td>
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<td>Geothermal utilization total</td>
<td>2,698</td>
<td>45,582</td>
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GEOTHERMAL SPACE HEATING
Space heating in Iceland 1970-2015

- Geothermal: 90.0%
- Oil: 9.3%
- Electricity: 0.7%
Geothermal space heating

- **Reykjavík Energy** is the owner of the largest district heating system in Iceland. They supply hot water to the capital area and serve about 240,000 people, over 70% of the population of the country.
  - Total number of employees is 450, turnover in 2015 was about 300 million US$.
  - Utilize low-temperature areas within and in the vicinity of Reykjavík as well as high-temperature fields at Nesjavellir and Hellisheidi (co-generation plants).
  - Total installed capacity of the district heating system is 1,100 MW\(_t\) and annual hot water production was 83 million m\(^3\) in 2015.

- **HS Orka** operates a co-generation power plant in Svartsengi (190 MW\(_t\) and 74 MW\(_e\)). They serve about 20,000 inhabitants of the Reykjanes peninsula with hot water and electricity.

- **Nordurorka** is an energy company in North Iceland that serves about 23,000 people with hot water (103 MW\(_t\)) and electricity, mainly in the town Akureyri.

- Totally about 30 separate geothermal district heating systems and additionally some 200 small systems in rural areas.
OTHER DIRECT UTILIZATION OF GEOTHERMAL ENERGY
Greenhouses

- Low-temperatur water used for heating greenhouses since 1924. Total surface area now about 194,000 m²
  - 50% used for growing vegetables (tomatos, cucumbers, paprika).
  - 50% mainly for growing cut flowers and potted plants.

- Share of domestic production of the total consumption.
  - 75% for tomatoes.
  - 90% for cucumbers.

- Energy consumption:
  - 3.67 GJ/m² in greenhouses with artificial lighting.
  - 5.76 GJ/m² in greenhouses without artificial lighting.

- Artificial lighting and CO₂ enrichment (geothermally produced) is common.
Bathing and swimming - Spas

- Natural hot springs have been used for bathing in Iceland for centuries.
- Swimming is very popular in Iceland and swimming lessons are compulsory in schools.
- About 165 recreational swimming centers in the country, of that 140 geothermally heated pools, totally 34,000 m²
- Mostly outdoor pools, open to the public throughout the year with water temperature 28-30°C. Limited focus on balneological aspects.
- The largest pool is Laugardalslaug with 1,500 m² outdoor pools, 1,250 m² indoor pool and five hot tubs (35-42°C).
- Health centers: the Blue Lagoon, bathing facility at Mývatn, health facility in Hveragerði and others.
- A geothermal beach – Nauthólsvík - a small part of the North Atlantic Ocean is heated by effluent geothermal water from the Reykjavík district heating system.
The Blue Lagoon

- Effluent brine from the Svartsengi geothermal power plant is disposed of into a surface pond called the Blue Lagoon.
- Holds 6 million liters of 37-39°C seawater, which is renewed every 40 hours.
- Is used by people suffering from psoriasis and other forms for eczema, who seek therapeutic effects from the silica rich brine.
- Skin care products produced from the geothermal brine.
- One of Iceland’s most popular tourist attractions with almost 1 million visitors per year.
Aquaculture

- A slowly growing sector in Iceland for many years.
- About 60 farms in Iceland produced totally 8,300 tonnes in 2015, mainly arctic char and salmon.
- Of them 15-20 farms use geothermal energy.
- Geothermal energy used for smolt production (char, salmon) and production of trout in land-based plants.
Fish farming plant at Reykjaness peninsula

- The plant is breeding warm-water Senegalese sole by using effluent water from Reykjaness geothermal power plant.
- Indoor land-based plant, 22,500 m²
- The power plant uses a large amount of sea water for cooling and after the cooling process a part of the water at 35°C flows by gravity to the fish farming plant.
- There it is mixed with sea water that is pumped from wells and used in the farming at about 21°C.
- The fish is grown to about 400 g before it is slaughtered and transported fresh to markets in Europe.
- The production capacity is now 500 tons per year, but the planned production after reaching the final stage is 2,000 tons per year.
Industry - Thorverk seaweed processing plant at Reykhólar

- Since 1975 the plant has produced 4,000 tonnes of rockweed and kelp meal annually.
- Harvest seaweed in Breidafjordur Bay using specially designed harvester crafts.
- Uses 36 l/s of 112°C geothermal water to heat air to 85°C for drying on a belt dryer.
- The meal products are mainly used as fodder or fertilizer.
- The 70°C hot return water is partly used by a nearby salt factory.
Salt production from seawater – Nordursalt and Saltverk

- **Nordursalt** at Reykhólar has been in operation since 2013.
- Use 30 l/s of 70°C hot geothermal return water from Thorverk seaweed processing plant.
- Use also 115°C hot water from a geothermal well.

- **Saltverk** at Reykjanes in NW-Iceland has been in operation since 2011.
- Use 10 l/s of 90-95°C hot water from a geothermal well to produce 70-80 tonnes of salt annually.
Hæðarendi – CO₂ production

- Commercial liquid carbon dioxide (CO₂) has been produced at Hæðarendi, South Iceland, since 1986.
- Uses 6 l/s of 160°C geothermal fluid from two wells with high gas content (1.4% by weight).
- The gas discharged by the wells is nearly pure CO₂.
- Calcite scaling is prevented by a 250 m long downhole hat exchanger.
- Produces 3,000 tonnes CO₂ annually, which is a large share of the Icelandic market, for use in greenhouses and in food industry.
Drying of fish products

- Geothermal energy has been used for drying fish in Iceland for about 35 years.
- Drying of salted fish, cod heads, small fish, stockfish and other products.
- About 10 small companies are drying totally about 12,000 tonnes of codheads indoors using geothermal water.
- One of the largest producers, Haustak, buys 1.3 kg/s of steam from the nearby Reykjanes power plant to produce annually 2,500 tonnes of dried products from 12,000 tonnes of raw material.
- Dried cod heads are exported to Nigeria for human consumption.
The Icelandic-American company Carbon Recycling International (CRI) has since 2012 operated a plant for producing methanol from CO$_2$ emissions of the Svartsengi geothermal power plant. The plan is to use annually 4.5 thousand tonne CO$_2$, which others would be released to the atmosphere, to produce 5 million liters of methanol. Hydrogen used in the process is produced locally by electrolysis of water. The methanol is used to blend with gasoline to fuel cars. Plans for expanding the current production capacity of 1.7 million liters to 5 million liters per year.
Snow melting / de-icing

- Return water from district heating is to an increasing extent used to heat pavements, parking spaces and even streets for snow melting.
- Spent water at 35°C, sometimes mixed with 80°C hot water when the load is high.
- Total area covered 1,200,000 m², of that 70,000 m² in downtown Reykjavik.
- Common design conditions: Maximum output 180 W/m² and annual energy consumption 430 kWh/m²
- 67% of the energy comes from spent water, 33% from 80°C hot water.
- 100 m² house area can supply return water for 16 m² snow melting area.
GEOTHERMAL ELECTRICITY GENERATION
<table>
<thead>
<tr>
<th>Plant name</th>
<th>Plant size MW</th>
<th>Year</th>
<th>Unit size MW</th>
<th>No of units</th>
<th>Type</th>
<th>Temp. °C</th>
<th>Press. bar</th>
<th>Flow rate t/h</th>
<th>Estimated production GWh/yr</th>
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<tr>
<td>Krafla</td>
<td>60</td>
<td>1978</td>
<td>30</td>
<td>1</td>
<td>DF</td>
<td>172/122</td>
<td>7.2/1.1</td>
<td>400/130</td>
<td>480</td>
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<td></td>
<td></td>
<td>1997</td>
<td>30</td>
<td>1</td>
<td>DF</td>
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<td></td>
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<td>6</td>
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<td>4.5</td>
<td>124</td>
<td>611</td>
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<td>7</td>
<td>B</td>
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<td></td>
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<td>1.05</td>
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<td>SF</td>
<td>178</td>
<td>8.5</td>
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<td>Total</td>
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<td>4,418</td>
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SF: Single flash; DF: Double flash; DS: Dry steam; B: Binary
Geothermal power plants

- Bjarnarflag 1969
  - 3 MW
- Krafla 1978-97
  - 60 MW
- Þeistareykir
  - 200 MW
- Under development
- Húsavík – Kalina 2000
  - 2 MW
- Peiðareykir
  - 200 MW
  - Under development
- Nesjavellir 1998 - 2005
  - 120 MW
- Hellisheiði 2006 - 2011
  - 303 MW
- Svartsengi 1976 - 2007
  - 74 MW
- Reykjanes 2006
  - 100 MW
- Reykjanes 2006
  - 100 MW
- Nesjavellir 1998 - 2005
  - 120 MW
- Hellisheiði 2006 - 2011
  - 303 MW
- Svartsengi 1976 - 2007
  - 74 MW
- Reykjanes 2006
  - 100 MW
- Nesjavellir 1998 - 2005
  - 120 MW
- Hellisheiði 2006 - 2011
  - 303 MW
- Svartsengi 1976 - 2007
  - 74 MW
- Reykjanes 2006
  - 100 MW
- Nesjavellir 1998 - 2005
  - 120 MW
- Hellisheiði 2006 - 2011
  - 303 MW
- Svartsengi 1976 - 2007
  - 74 MW
- Reykjanes 2006
  - 100 MW
Geothermal electricity generation 1970-2015

- Svartsengi 74.4 MW
- Krafla 60 MW
- Nesjavellir 120 MW
- Húsavík 2 MW
- Hellisheiði 303 MW
- Reykjanes 100 MW

GWh/year

New geothermal power plant at Theistareykir – North Iceland

- The most developed new geothermal project in Iceland is the Theistareykir geothermal field in North Iceland. It has been under exploration since 1999.
- Landsvirkjun (National Power Company) started the construction work of a 90 MW_e power plant in 2015. Commissioning 1st 45 MW in October 2017 and 2nd 45 MW in April 2018.
- 12 wells have already been drilled in the area. Drilling for the second phase is ongoing.
- The power will go to a planned production plant for silicon metal in the nearby town Húsavík, with an initial production capacity of 33,000 tonnes per year.
- Geothermal drilling made by Iceland Drilling Ltd (Jarðboranir hf).
- Turbine, generator and cold end equipment come from Fuji Electric and Balcke Dürr.
- EIA has been made for a fully developed 200 MW plant.
Peistareykir Geothermal Power Plant 90 MW

Source: Landsvirkjun
Iceland Deep Drilling Project (IDDP)

- Iceland Deep Drilling Project (IDDP) was founded in the year 2000 by a consortium of three Icelandic energy companies.
- International research and cooperation project with participation of over 100 scientists worldwide.
- Funded by Icelandic energy companies and international companies and funds.
- The idea is to drill down to 4-5 km depth for geothermal fluid at supercritical state and temperature 400-500°C in order to significantly increase the power output of geothermal wells.
- Investigate the feasibility of utilizing the geothermal fluid. The output could possibly be 5-10 times the output from a conventional geothermal high-temperature well.
A well (IDDP-1) was drilled in the Krafla field 2008-2009. Drilling was terminated at about 2.1 km depth when drilling penetrated molten rock.

The well was very powerful. During testing in 2010 it gave about 30 kg/s of 330°C superheated steam at 17 bar.

Several scientific papers have been written based on the testing of IDDP-1.

The well was sealed and abandoned in October 2015.

Further information is on the IDDP web: http://iddp.is.
Drilling of IDDP-2 started at Reykjanes in mid August 2016.
- Deepening of an existing 2500 deep well (RN-15) drilled in 2004
- During drilling from 2500 to 3000 m there was a total loss of circulation and no cuttings were retrieved at the surface.
- Directional drilling started at about 2750 m.
- One permeable zone was detected at 2775 m. Formations are relative hard.
- A production casing was inserted down to 2941 m.
- A core sample has just been taken at a depth of about 3650 m.
- Completing IDDP-2 to 5000 m is estimated to take about 150 days.
THANK YOU

Photo: Hreinn Hjartarson