Utilization of geothermal energy in Iceland

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Based on slides from Árni Ragnarsson, Iceland GeoSurvey
Outline

- Energy resources and consumption in Iceland
- Geothermal space heating
- Other direct utilizations of geothermal energy
- Geothermal electricity generation
- New developments
Iceland is rich in Energy Sources

- **Geothermal**: Due to volcanism, as the Mid-Atlantic Ridge crosses the country
- **Hydro**: Due to mountainous terrain and humid climate. (the glaciers act as water storage)
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 (730 GJ/capita, 55,000 kWh/capita/year).
- 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 2017

| Source: Orkustofnun |

<table>
<thead>
<tr>
<th>Energy Source</th>
<th>PJ</th>
<th>Ktoe</th>
<th>%</th>
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<tbody>
<tr>
<td>Hydropower</td>
<td>50.6</td>
<td>1,209</td>
<td>20.3</td>
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<tr>
<td>Geothermal</td>
<td>152.2</td>
<td>3,635</td>
<td>60.9</td>
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<tr>
<td>Oil</td>
<td>42.2</td>
<td>1008</td>
<td>16.9</td>
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<tr>
<td>Coal</td>
<td>4.8</td>
<td>115</td>
<td>1.9</td>
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<tr>
<td><strong>Total</strong></td>
<td>249.8</td>
<td>5,966</td>
<td>100</td>
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</tbody>
</table>

Primary energy consumption 730 GJ/capita
1 PJ = 1000 TJ = 1,000,000 GJ
1kWh = 3,600 kJ
1 toe = 41.868 GJ
Primary energy consumption in Iceland 1940-2017

Source: Orkustofnun
Power generation in Iceland

- About 40 hydropower plants supply power to the national grid, the largest one 690 MW
- 8 geothermal plants up to 303 MW
- Total annual generation 19,239 GWh, of that 77% goes to energy intensive industry
- Total consumption 55,000 kWh/capita/year
Production and consumption of electricity in Iceland 2017

<table>
<thead>
<tr>
<th>Installed capacity</th>
<th>MW</th>
<th>%</th>
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<tbody>
<tr>
<td>Hydro</td>
<td>1,984</td>
<td>71.7</td>
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<tr>
<td>Geothermal</td>
<td>708</td>
<td>25.6</td>
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<tr>
<td>Oil</td>
<td>72</td>
<td>2.6</td>
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<tr>
<td>Wind</td>
<td>3</td>
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<td>Total</td>
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<table>
<thead>
<tr>
<th>Electricity generation</th>
<th>GWh</th>
<th>%</th>
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</thead>
<tbody>
<tr>
<td>Hydro</td>
<td>14,059</td>
<td>73.1</td>
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<tr>
<td>Geothermal</td>
<td>5,170</td>
<td>26.9</td>
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<tr>
<td>Oil</td>
<td>2</td>
<td>0.01</td>
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<td>Wind</td>
<td>8</td>
<td>0.04</td>
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<tr>
<td>Total</td>
<td>19,239</td>
<td>100.0</td>
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</table>

<table>
<thead>
<tr>
<th>Electricity consumption</th>
<th>GWh</th>
<th>%</th>
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<tbody>
<tr>
<td>General consumption</td>
<td>3,397</td>
<td>17.7</td>
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<td>Energy intensive industry</td>
<td>14,870</td>
<td>77.3</td>
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<td>Plant consumption</td>
<td>375</td>
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<td>Distribution losses</td>
<td>223</td>
<td>1.2</td>
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<tr>
<td>Transmission losses</td>
<td>373</td>
<td>1.9</td>
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<tr>
<td>Total</td>
<td>19,239</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Source: Orkustofnun
Electricity consumption 1965-2015

Source: Orkustofnun
Oil consumption in Iceland 1982-2017

Automobiles
Fishing Vessels
Cars
Airplanes
Construction
Ocean Vessels
Other Industry
Space heating and swimming pools
Energy production
Other Industry

Orkustofnun Data Repository: OS-2018-T007-01
Geothermal map of Iceland

- High temperature area
- Low temperature area

Installed electrical capacity 2017
Planned expansion

Base map: Geothermal map of Iceland by Hallur Jóhannesson and Kristján Sæmundsson 1999, Iceland. 1:1,000,000. Icelandic Institute of Natural History.
Geothermal utilization in Iceland 2017

| Source: Orkustofnun |

<table>
<thead>
<tr>
<th></th>
<th>MW</th>
<th>TJ/year</th>
<th>GWh/year</th>
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<tr>
<td><strong>Installed power</strong></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Electricity generation</td>
<td>708</td>
<td>18.611</td>
<td>5.170</td>
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<tr>
<td>Geothermal utilization total</td>
<td>3.322</td>
<td>52.911</td>
<td>14.697</td>
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<tr>
<td><strong>Energy consumption</strong></td>
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<tr>
<td>Space heating</td>
<td>2.000</td>
<td>25.204</td>
<td>7.001</td>
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<tr>
<td>Greenhouses</td>
<td>37</td>
<td>518</td>
<td>144</td>
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<tr>
<td>Fish farming</td>
<td>85</td>
<td>2.135</td>
<td>593</td>
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<tr>
<td>Industrial process heat</td>
<td>80</td>
<td>1.012</td>
<td>281</td>
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<tr>
<td>Snow melting</td>
<td>218</td>
<td>2.065</td>
<td>574</td>
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<tr>
<td>Swimming pools</td>
<td>194</td>
<td>3.367</td>
<td>935</td>
</tr>
<tr>
<td>Direct uses total</td>
<td>2.614</td>
<td>34.300</td>
<td>9.528</td>
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GEOTHERMAL SPACE HEATING
Space heating in Iceland 1970-2017
From fossil fuel to geothermal - The environmental benefit

Before geothermal space heating:
Reykjavik in 1933 covered with smoke from coal heatings,

With geothermal space heating:
Reykjavik in 2008, almost same view but without visible air pollution
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 MWₜ and annual hot water production was 83 million m³ in 2015.

- **HS Orka** operates a co-generation power plant in Svartsengi (190 MWₜ and 74 MWₑ). 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 MWₜ) and electricity, mainly in the town Akureyri.

- Totally about 30 separate geothermal district heating systems and additionally some 200 small systems in rural areas.
Comparison of energy prices for residential heating 2016

Source: Orkustofnun
Energy cost/yr of homes in the Nordic countries - comparison 2016

Source: Samorka
Savings of CO₂ emissions in Reykjavik by geothermal heating
OTHER DIRECT UTILIZATION OF GEOTHERMAL ENERGY
- Low-temperature water used for heating greenhouses since 1924. Total surface area now about 194,000 m² = 19.4 ha
  - 50% used for growing vegetables (tomatos, cucumbers, paprika).
  - 50% mainly for growing cut flowers and potted plants.
- 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 140 geothermally heated swimming centers in the country, mostly outdoor pools, open to the public throughout the year with water temperature 28-30°C.
- Health centers: the Blue Lagoon and a few others.
- A geothermal beach – Nauthólsvík - a small part of the North Atlantic Ocean is heated during summer by effluent geothermal water from the Reykjavik district heating system.
Aquaculture

- A slowly growing sector in Iceland for many years.
- About 60 farms in Iceland produced totally 8,300 tons 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, Iceland

- 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 geothermal 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.
Production of methanol in Svartsengi

- 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 tons CO$_2$, which otherwise 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.
Diatomite plant at Myvatn

- Kísilidjan, a diatomite plant employing 50 people was operated in Iceland from 1967 to 2004
- Diatomaceous earth was dredged from the bottom of Lake Myvatn by a suction dredger and the slurry transmitted by pumping through a 3 km pipeline to the plant site
- Up to 45 tonnes/h of steam at 180°C (10 bar) were transmitted from wells 600 m away and used in a rotary steam tube dryer as well as to keep the reservoirs containing settled diatomaceous earth ice-free.
- The plant produced about 28,000 tonnes of filter aids for export annually
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.
- 100 m² house area can supply return water for 16 m² snow melting area.
GEOTHERMAL ELECTRICITY GENERATION
Geothermal power plants

Bjarnarflag 1969
3 MW

Krafla 1978-97
60 MW

Þeistareykir
90 MW

Húsavík – Kalina 2000
2 MW

Reykjanes 2006
100 MW

Svartsengi 1976-2007
74 MW

Hellisheiði 2006-2011
303 MW

Nesjavellir 1998-2005
120 MW

Nesjavellir 1998-2005
120 MW

Nesjavellir 1998-2005
120 MW

Nesjavellir 1998-2005
120 MW

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120 MW

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120 MW

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120 MW

Nesjavellir 1998-2005
120 MW

Nesjavellir 1998-2005
120 MW

Nesjavellir 1998-2005
120 MW
Geothermal electricity generation 1970-2017

Source: Orkustofnun
- 30 MWe double flash condensing unit started operation in 1977
- Second 30 MWe unit installed in 1997
- Further expansion by 40 MWe under preparation
- Plans for building a new plant in the area
Svartsengi

- Co-generation power-plant producing hot water and electricity since 1977
- 30 MW sub superindex e unit installed in 1999
- A new 30 MW unit installed in 2007
- Total capacity 150 MW sub superindex t and 74 MW sub superindex e, of that 8.4 MW sub superindex e from binary units
- 50-75% of the geothermal fluid is reinjected.
- The effluent water goes to the Blue Lagoon.
Reykjanes power plant

- HS-Orka started electricity production for energy intensive industry in a new 100 MW$_e$ power plant at Reykjanes in May 2006
- Plans for additional 80 MW$_e$
Nesjavellir

- Co-generation power-plant started in 1990 with production of hot water
- Electricity generation by two 30 MW_e units started in 1998
- Third 30 MWe unit installed in 2001
- Further expansion to 120 MW_e was completed in 2005
- Hot water production 300 MW_t
Reykjavik Energy operates a co-generation power plant at Hellisheiði (Hengill area)

First stage, 90 MWₑ, started production for energy intensive industry in October 2006

A 33 MWₑ low pressure unit was installed in 2007

Two 45 MWₑ units were installed in late 2008

Hot water production started in 2010

90 MWₑ added in 2011
The Theistareykir geothermal field in North Iceland has been under exploration since 1999.

Landsvirkjun (National Power Company) started the construction work of a 90 MW<sub>e</sub> power plant in 2015. Commissioned 1<sup>st</sup> 45 MW in November 2017 and 2<sup>nd</sup> 45 MW in April 2018.

- 18 wells have been drilled in the area, in the average 2700 m deep.

- The power will mainly go to a new 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).
Iceland Deep Drilling Project (IDDP-1)

- Iceland Deep Drilling Project (IDDP) was founded in the year 2000. It is an international research and cooperation project with participation of over 100 scientists worldwide.
- 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, possibly by a factor of 5-10.
- A well (IDDP-1) was drilled in the Krafla field, North-Iceland, in 2008-2009. Drilling was terminated at about 2.1 km depth when drilling penetrated molten rock.
- After testing the well, which was very powerful, was sealed and abandoned in 2015.
Drilling of the 4650 m deep IDDP-2 well at Reykjanes was completed in January 2017 after 176 days of drilling.

- Temperature at the bottom of the well was measured at 426°C, with fluid pressure of 340 bars.

- Potential utilization will be known when all research, including substantial well stimulation and flow testing, have been finished.

- Further information is on the IDDP web: http://iddp.is.