Working together for a green, competitive and inclusive Europe

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***" Innovative Teaching methods for tomorrow's Renewable Energy Specialists"***

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The project is a cooperation between two partners: the Faculty of Physics at the University of Bucharest and the Iceland School of Energy at Reykjavik University

# Geothermal Energy

A part of the course: Energy in Iceland

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# Content of the presentation

What is geothermal energy?

How and where can geothermal energy be accessed?

How is geothermal energy explored?

How is geothermal energy utilized?

- Electricity production
- Direct use

Overview of geothermal energy use

- Worldwide
- In Iceland

# What is geothermal energy?

## Geothermal energy comes from the earth's inner parts:

- Thermal energy because of cooling of the earth's core
- Radioactive decay

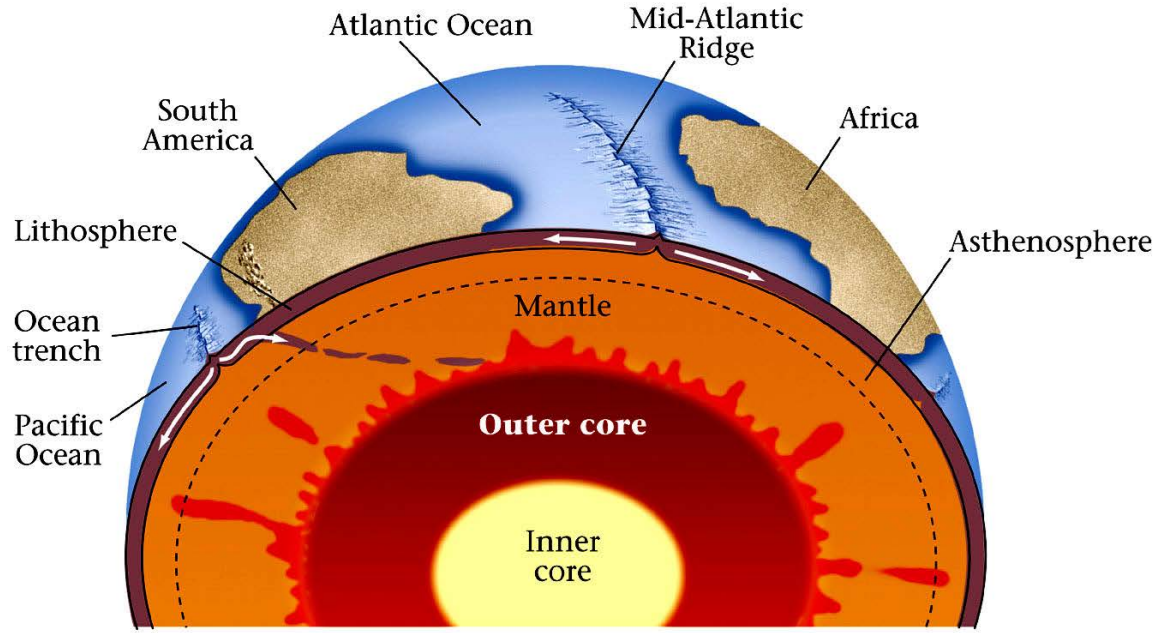



FIGURE 4.32

*Earth: Portrait of a Planet*, 2nd Edition

# How and where can geothermal energy be accessed?

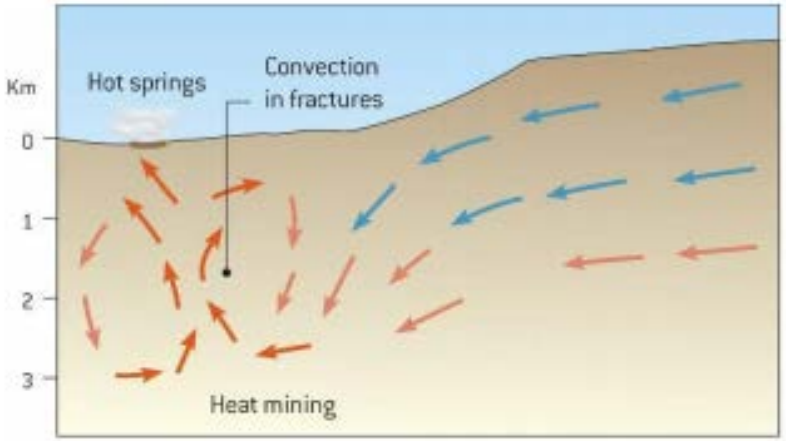
The earth is warmer in the inside than the outside.

Everywhere!

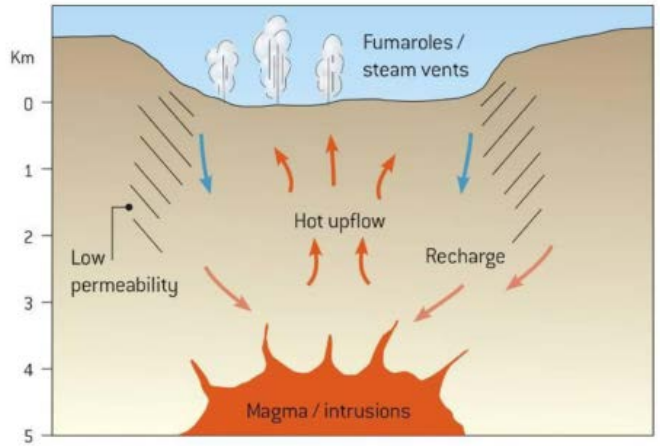
What we need for utilizing this heat is :

- A surrounding rock in the inside which allows flow (needs to be fractured, porous, permeable)
- A working fluid (water) to transport the heat to the surface

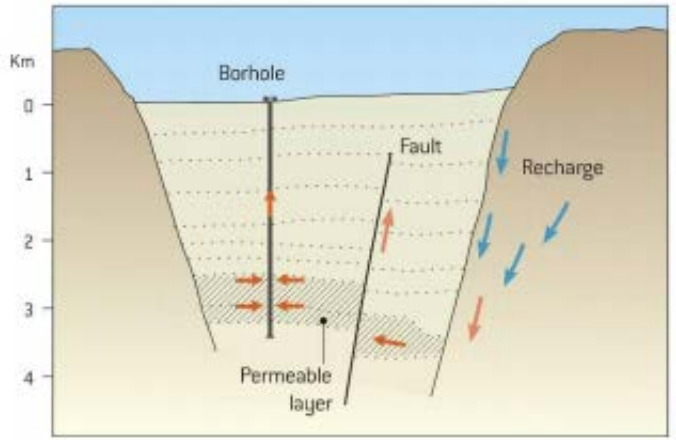
<u>Both</u> of these conditions have to be fulfilled in order to utilize the heat




Volcanic systems




Convective systems




Sedimentary systems

Figures: Axelsson, G. *Production capacity of geothermal systems.* Presented at the Workshop for Decision Makers on Direct Heating Use of Geothermal Resources in Asia, 2008

# Geothermal systems vs. geothermal reservoirs

Geothermal system is the overall underground system and its surroundings

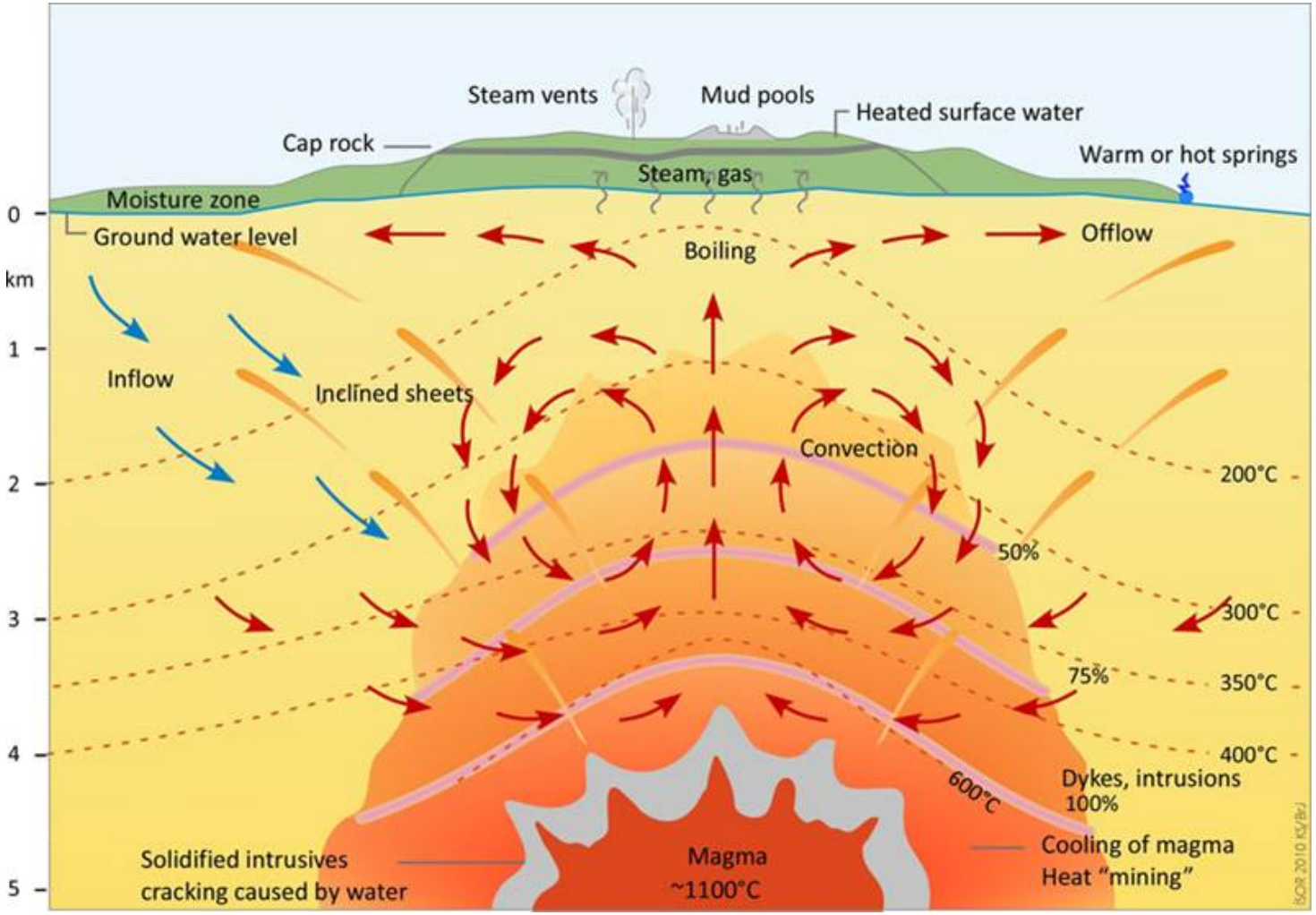
Geothermal reservoir is the part of the geothermal system that is accessible for utilization

Geothermal system > Geothermal reservoir

Classification of geothermal reservoirs

- High temperature
  - where the reservoir is > 200 ºC at 1 km depth
  - suitable for electricity production
- Low temperature
  - where the reservoir is < 150 ºC at 1 km depth
  - suitable for house heating, bathing etc.

# Geothermal system – high temperature reservoir



# Geothermal exploration

## Exploration of a geothermal field:

- Geological
- Hydrological
- Geochemical
- Geophysical (heat flux, el. resistivity, seismic, gravity, etc.)

## When all the data has been collected and analyzed:

- Geothermal drilling

# Geothermal wells

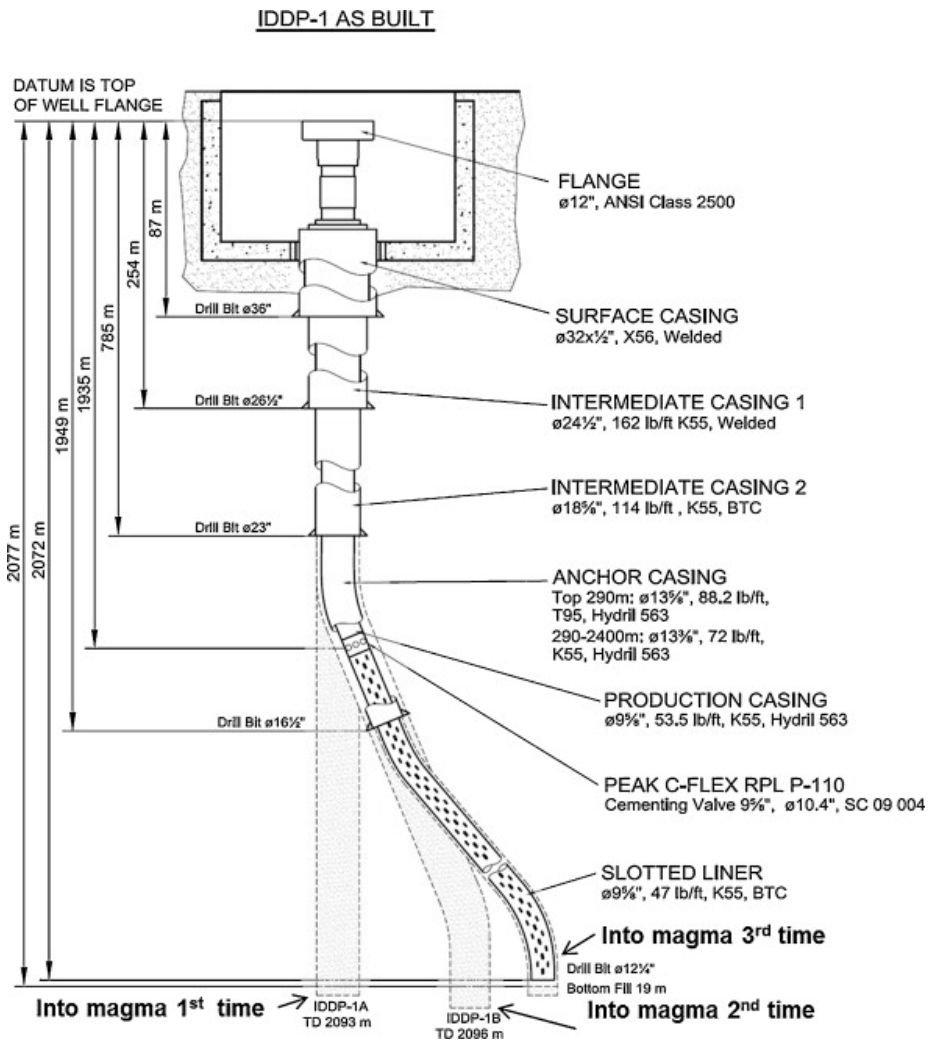



Fig. 5. “As-built” drawing of well IDDP-1.

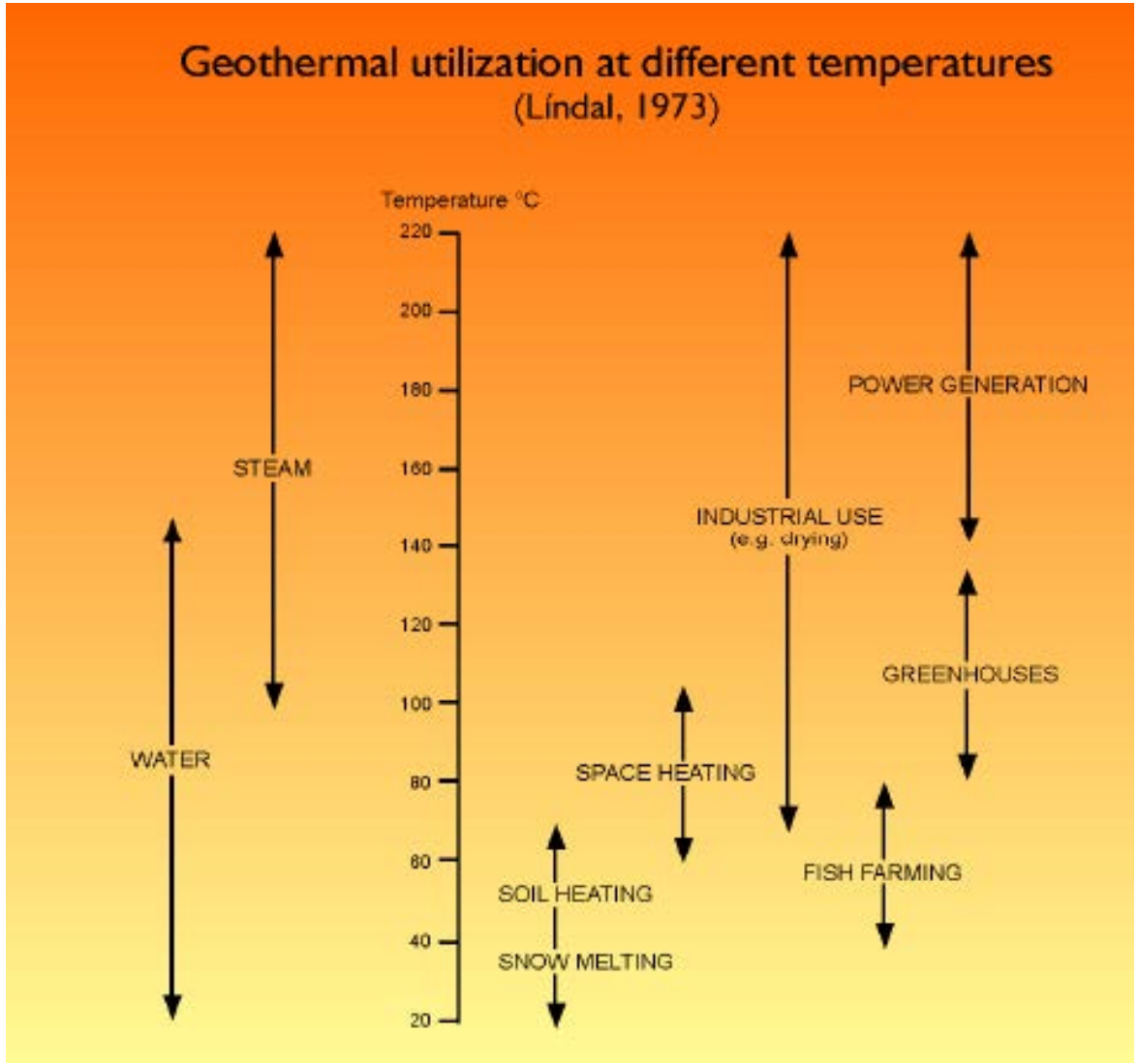

B. Pálsson, S. Hólmgeirsson, Á. Guðmundsson, H.Á. Bóasson, K. Ingason, H. Sverrisson, S. Thórhallsson

**Drilling of the well IDDP-1**

Geothermics, Volume 49, 2014, 23–30

http://dx.doi.org/10.1016/j.geothermics.2013.08.010

# Geothermal utilization – Líndal diagram



# Geothermal utilization

**Direct use** is when the fluid from the reservoir is used directly for:

- Bathing
- House heating
- Fish farming
- Greenhouses (house heating)
- Other

**Power production** is when the fluid is used in a power process to change the energy from thermal to electrical power

**Combined direct use and power production** when excess water (separated water) from the power production is used for hot water production

# Use of geothermal energy in Iceland

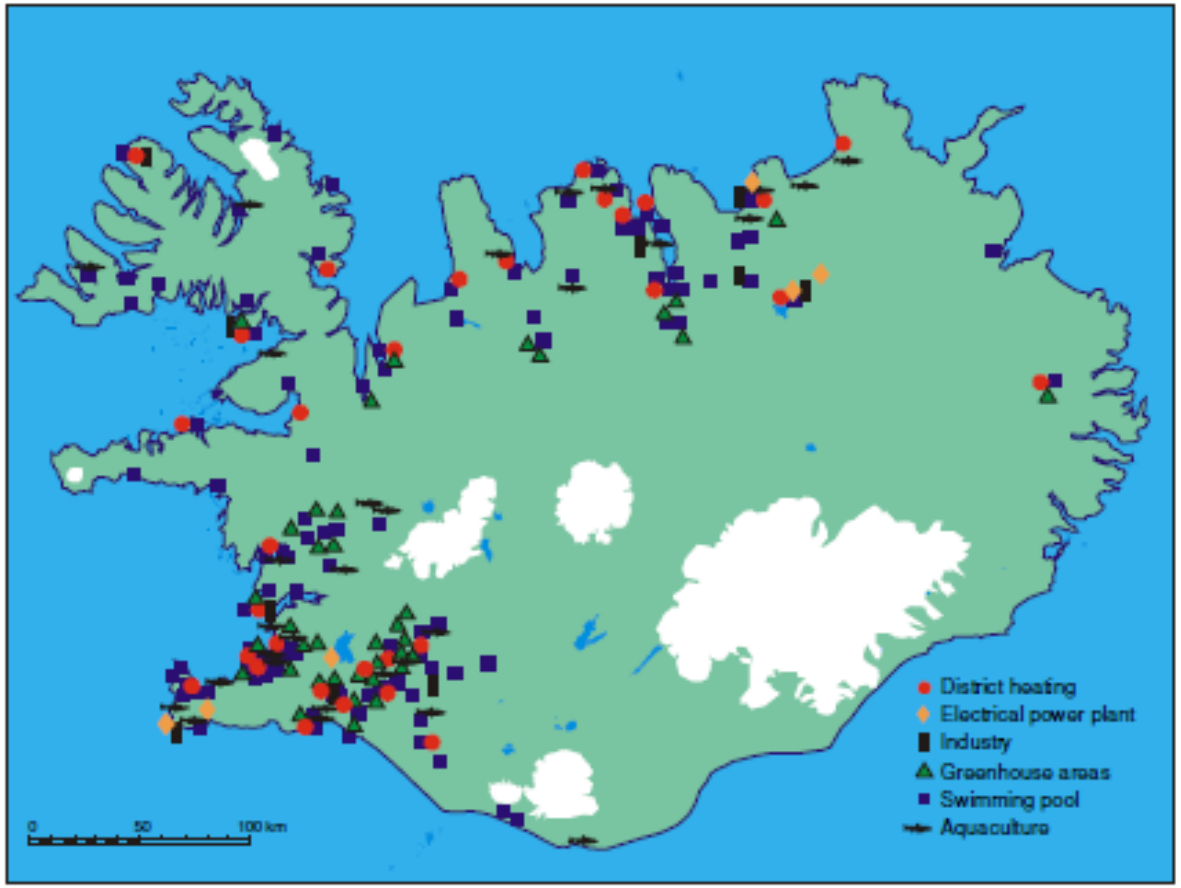
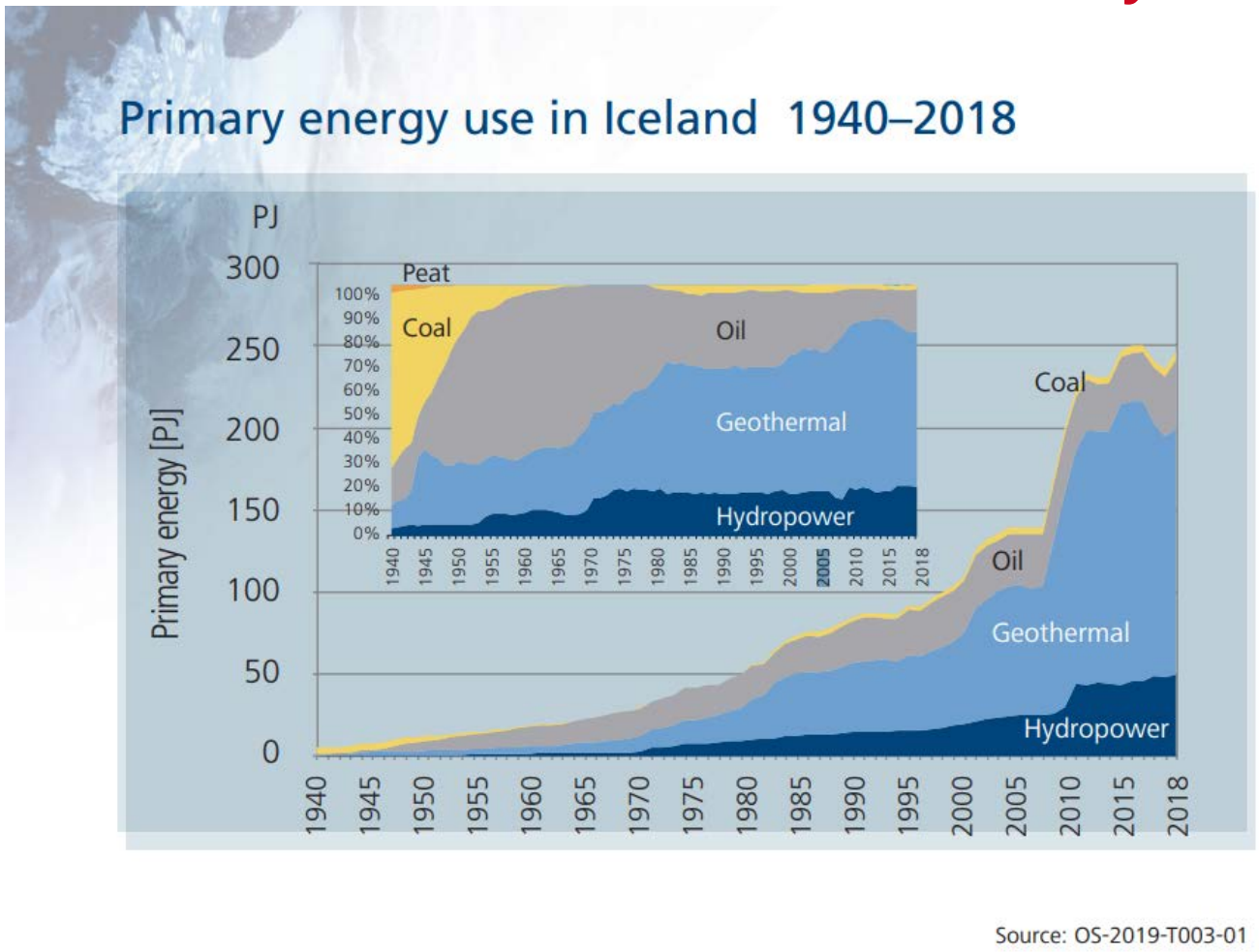



Figure: Árni Ragnarsson ÍSOR

# Primary energy use in Iceland

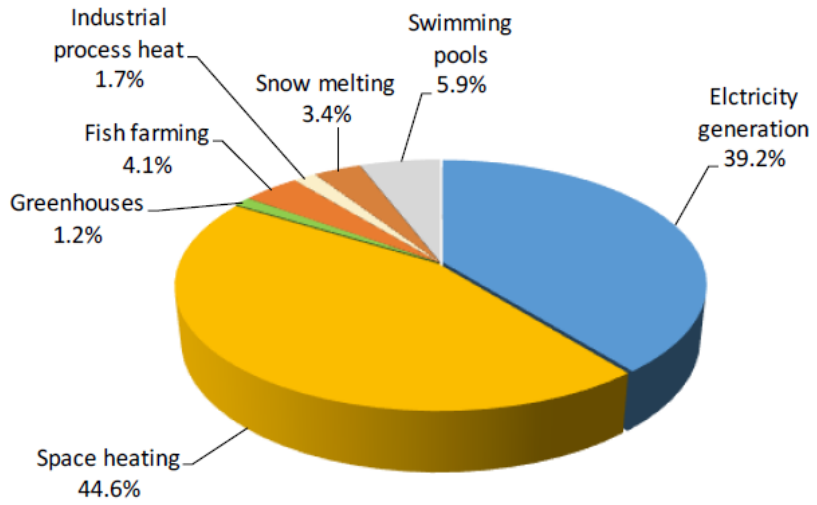



81% of the primary energy supply comes from indigenous renewable sources
(Ragnarsson et al.

Source: Energy Statistics 2018, National Energy Authority Iceland

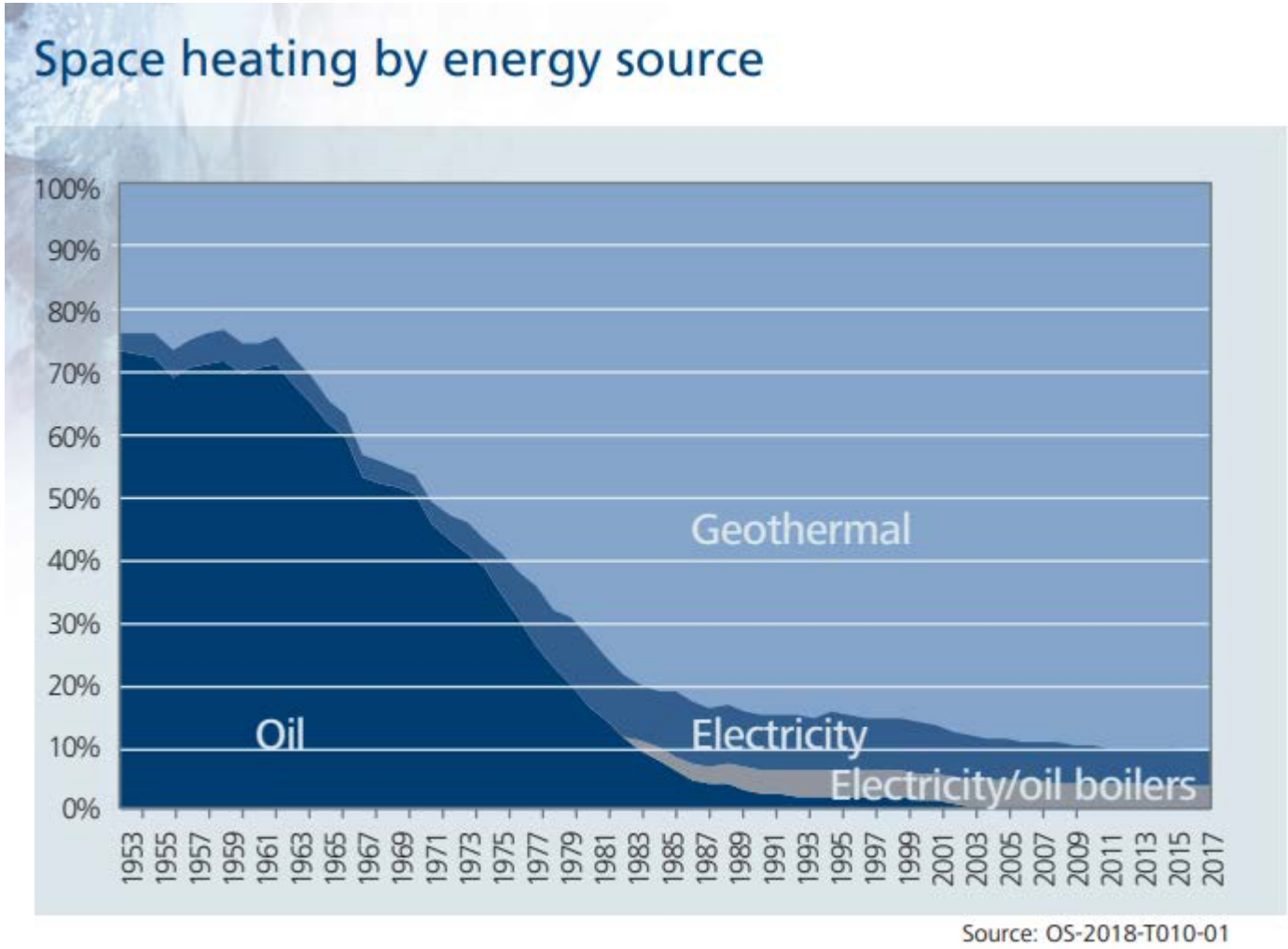
# Geothermal energy in Iceland

Source: Ragnarsson et al. Geothermal Development in Iceland 2015-2019




| | Installed power | Energy consumption | |
|---|---|---|---|
| | MW | TJ/year | GWh/year |
| Space heating | 1,650 | 24,603 | 6,834 |
| Greenhouses | 57 | 668 | 186 |
| Fish farming | 110 | 2,264 | 629 |
| Industrial process heat | 80 | 922 | 256 |
| Snow melting | 260 | 1,889 | 525 |
| Swimming pools | 210 | 3,232 | 898 |
| Direct uses total | 2,367 | 33,579 | 9,328 |
| Elctricity generation | 755 | 21,636 | 6,010 |
| Geothermal utilization total | 3,122 | 55,215 | 15,338 |

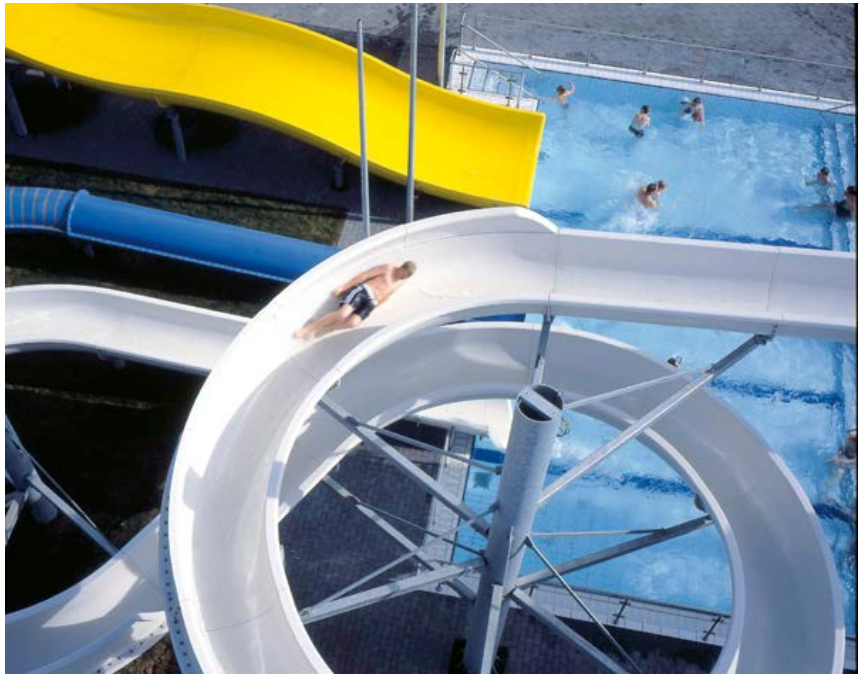
# Geothermal energy use in Iceland – Direct use - Space heating



# Geothermal energy use in Iceland – Direct use - snow melting

Figures: Árni Ragnarsson, ÍSOR

# Geothermal energy use in Iceland – Direct use - Swimming pools



Photos from www.sundlaugar.is

# Geothermal energy use in Iceland – Direct use - Industry

Fish farms (tilapia, salmon, ... )

Drying processes (fish, wood, salt ...)

Greenhouses

Dried fish (source: flickr/ Luke Behal, creative commons)

Greenhouse on a winter day in Iceland (flickr.com Rupert Maspero creative commons )

Tomatoes in Friðheimar (https://flickr.com/photos/-erin/14468641882/in/photostream/ creative commons )

# Geothermal energy worldwide – power generation

**Ten nations with the most installed geothermal generation MWe in 2020**

| | | | | | |
|---|---|---|---|---|---|
| 1. | USA | 3,700 | 6. | New Zealand | 1,064 |
| 2. | Indonesia | 2,289 | 7. | Mexico | 1,005 |
| 3. | Philippines | 1,918 | 8. | Italy | 916 |
| 4. | Turkey | 1,549 | 9. | Iceland | 755 |
| 5. | Kenya | 1,193 | 10. | Japan | 550 |

Source: Gerald Huttrer. Geothermal Power Generation in the World 2015-2020 Update Report

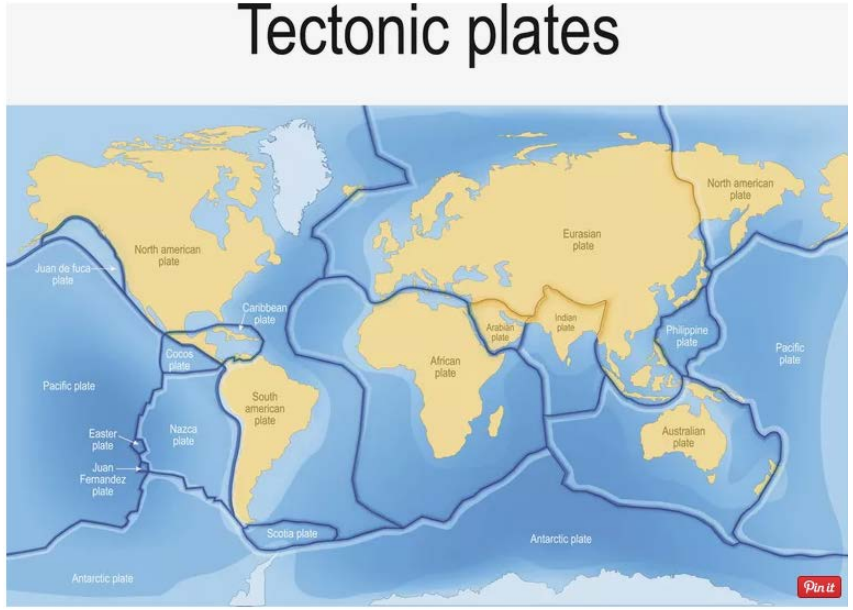

Figure 4: Geothermal Power Plants (source ThinkGeoEnergy)

Installed capacity in 2020:

**15.95 GW**

# Geothermal energy worldwide – power generation


ThinkGeoEnergy




https://www.thoughtco.com/map-of-tectonic-plates-and-their-boundaries-1441098

# Geothermal utilization – Electricity production

## Traditional power plants:

Simple ideal Rankine power cycle

Heat source into boiler from coal and nuclear

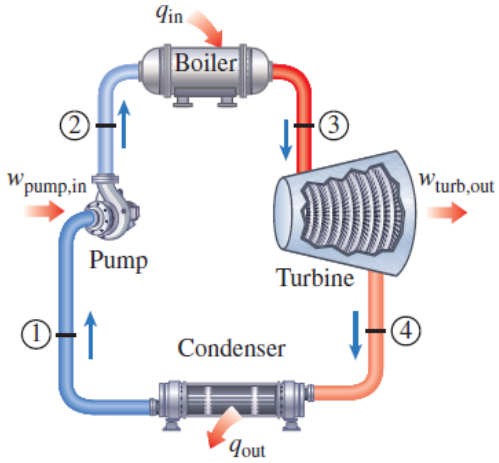
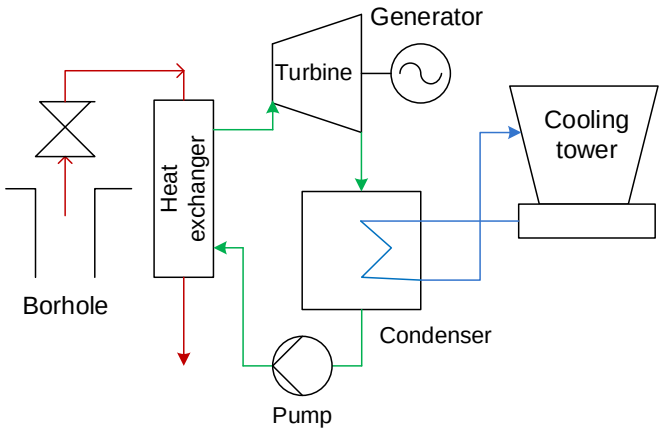



figure: Cengel & Boles

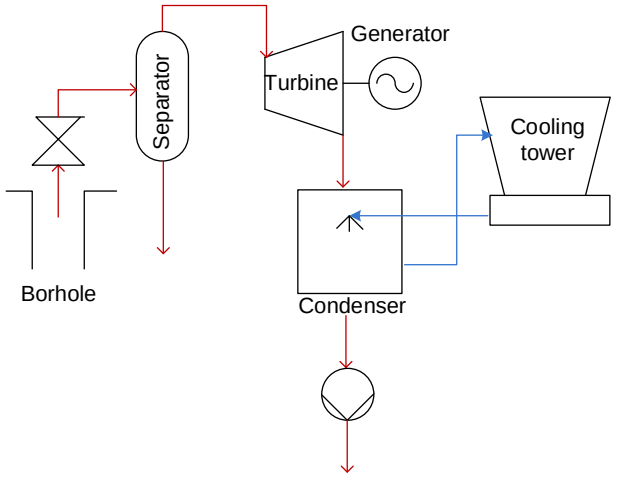
## Geothermal power plants:

Binary power plants:




## Geothermal power plants:

Single flash system



# Electricity Production

## Installed capacity, electricity production and consumption 2015- 2018

| Installed capacity in power plants | 2018 | | 2017 | | 2016 | |
|---|---|---|---|---|---|---|
| | MW | % | MW | % | MW | % |
| Hydro | 2.098 | 71,7 | 1.984 | 71,7 | 1.985 | 72,7 |
| Geothermal | 754 | 25,8 | 708 | 25,6 | 663 | 24,3 |
| Fuel | 72 | 2,5 | 72 | 2,6 | 81 | 3,0 |
| Wind | 3 | 0,1 | 3 | 0,1 | 3 | 0,1 |
| **Total** | **2.927** | **100** | **2.767** | **100** | **2.732** | **100** |

| Electricity production | 2018 | | 2017 | | 2016 | |
|---|---|---|---|---|---|---|
| | GWh | % | GWh | % | GWh | % |
| Hydro | 13.814 | 69,7 | 14.059 | 73,1 | 13.471 | 72,6 |
| Geothermal | 6.010 | 30,3 | 5.170 | 26,9 | 5.067 | 27,3 |
| Fuel | 2 | 0,01 | 2 | 0,01 | 2 | 0,01 |
| Wind | 4 | 0,02 | 8 | 0,04 | 9 | 0,05 |
| **Total** | **19.830** | **100** | **19.239** | **100** | **18.549** | **100** |

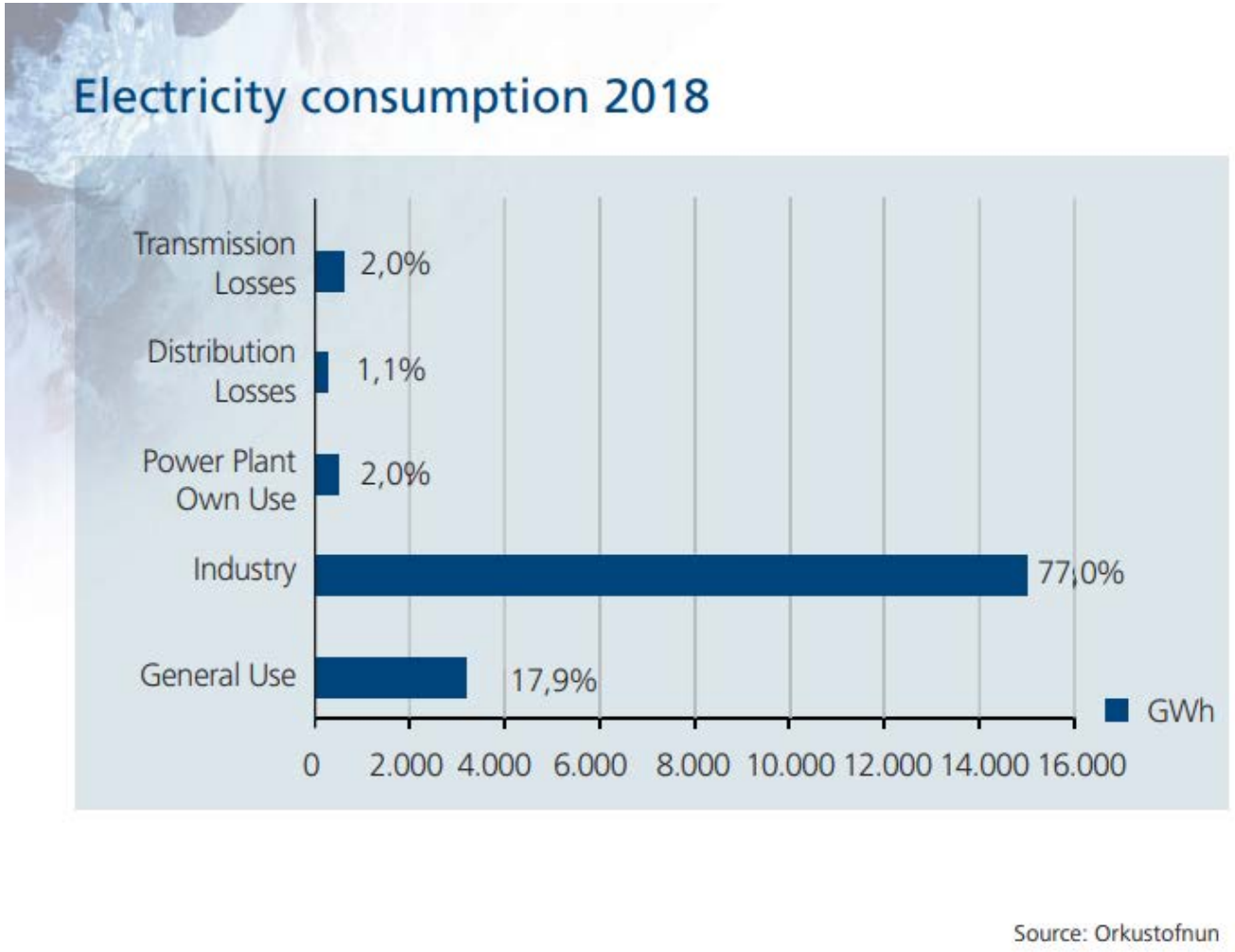
| Electricity consumption | 2018 | | 2017 | | 2016 | |
|---|---|---|---|---|---|---|
| | GWh | % | GWh | % | GWh | % |
| General use* | 3.558 | 17,9 | 3.386 | 17,6 | 3.291 | 17,7 |
| Heavy industry* | 15.260 | 77,0 | 14.870 | 77,3 | 14.334 | 77,3 |
| Losses&use-power plants* | 396 | 2,0 | 392 | 2,0 | 378 | 2,0 |
| Distribution losses* | 218 | 1,1 | 218 | 1,1 | 185 | 1,0 |
| Transmission losses.* | 398 | 2,0 | 373 | 1,9 | 361 | 1,9 |
| **Total** | **19.830** | **100** | **19.239** | **100** | **18.549** | **100** |
| *Estimate 2018 | | | | | | |

Source: Orkustofnun

Source: Energy Statistics in Iceland 2018, National Energy Authority Iceland

25% of installed capacity [MW]
30% of production [GWh]

# Electricity Production




Source: Energy Statistics in Iceland 2018, National Energy Authority Iceland

# Environmental Aspects – $CO_2$

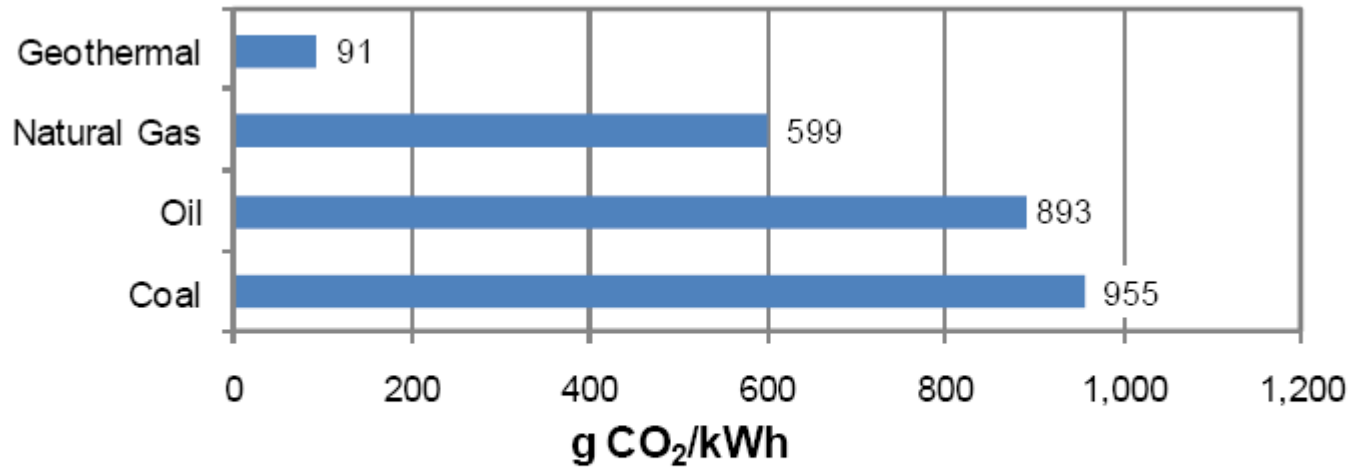



Figure 14. Comparison of $CO_2$ emission from electricity generation from different energy sources in the USA. Data from Bloomfield et al. (2003).

Fridleifsson et al (2008)

# Other Environmental Aspects

## Hydrogen sulfide emissions (H2S)

- Corrosive, toxic gas
- Abatement technologies exist, but somewhat expensive

## Induced seismicity and subsidence

## Production at economic versus sustainable levels

# Carbfix project

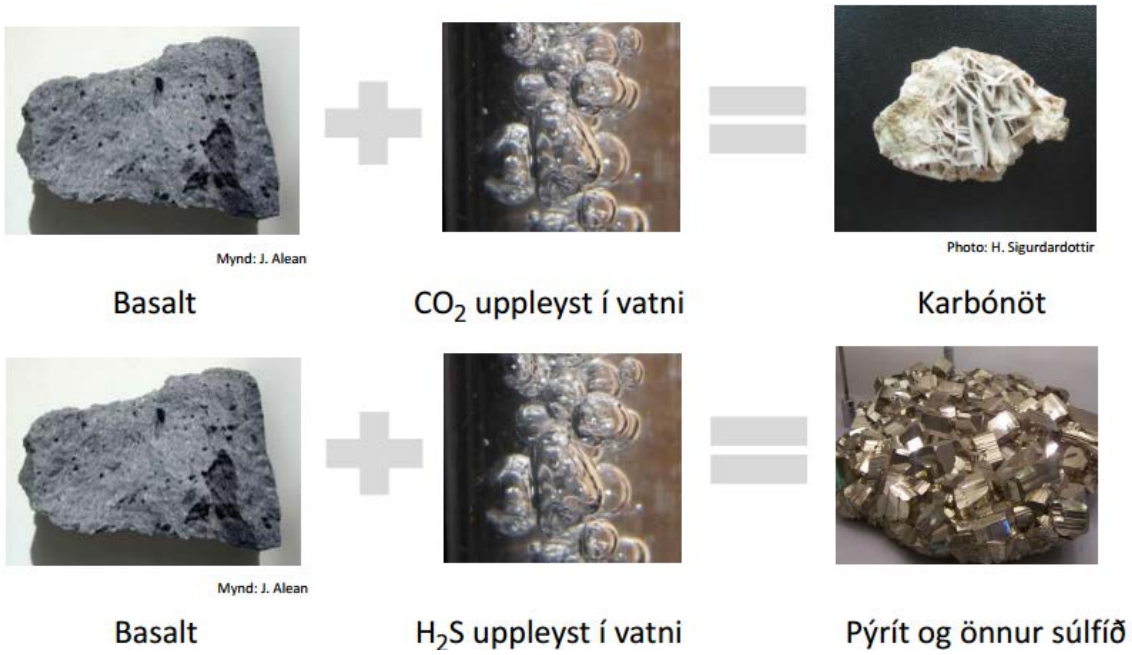
Carbfix project at Reykjavik Energy

Hellisheiði power plant

Emissions of gases reduced by 40%

New injection sites in project GECO

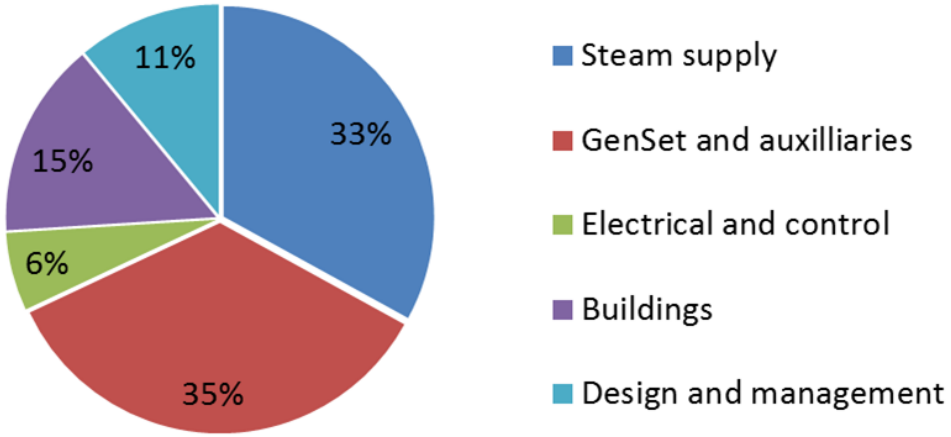

carbfix.com



# Economic considerations – Making of a geothermal power plant

Relative cost of geothermal power plants

"Typical" power plant 100-200 MW - Built in phases of 50 MW units




Source: Kristinn Ingason, Mannvit hf

**Cost Breakdown of Large Geothermal Power Projects**

- **Exploration** ..... **5%**
- **Confirmation** ..... **5%**
- **Permitting** ..... **1%**
- **Drilling** ..... **23%**
- **Steam gathering** ..... **7%**
- **Power plant** ..... **54%**
- **Transmission** ..... **4%**

Source: GEA

# CAPEX of a geothermal power plant

2,7 – 3,1 USD/W in Iceland (flash plant)

WGA Geothermal Task Force 2005 (USA):

- 3,0 – 4,0 USD/W, average 3,5 USD/W

International Energy Agency 2010:

- 2,0 – 4,5 USD/W (flash plant)
- 2,4 – 5,9 USD/W (binary plant)
- > 10 USD/W for small binary units

Cross og Freeman 2009:

- 3,65 USD/W

Source: Kristinn Ingason, Mannvit hf

# Use of geothermal energy – The Blue Lagoon

flickr.com / diamond geezer, creative commons

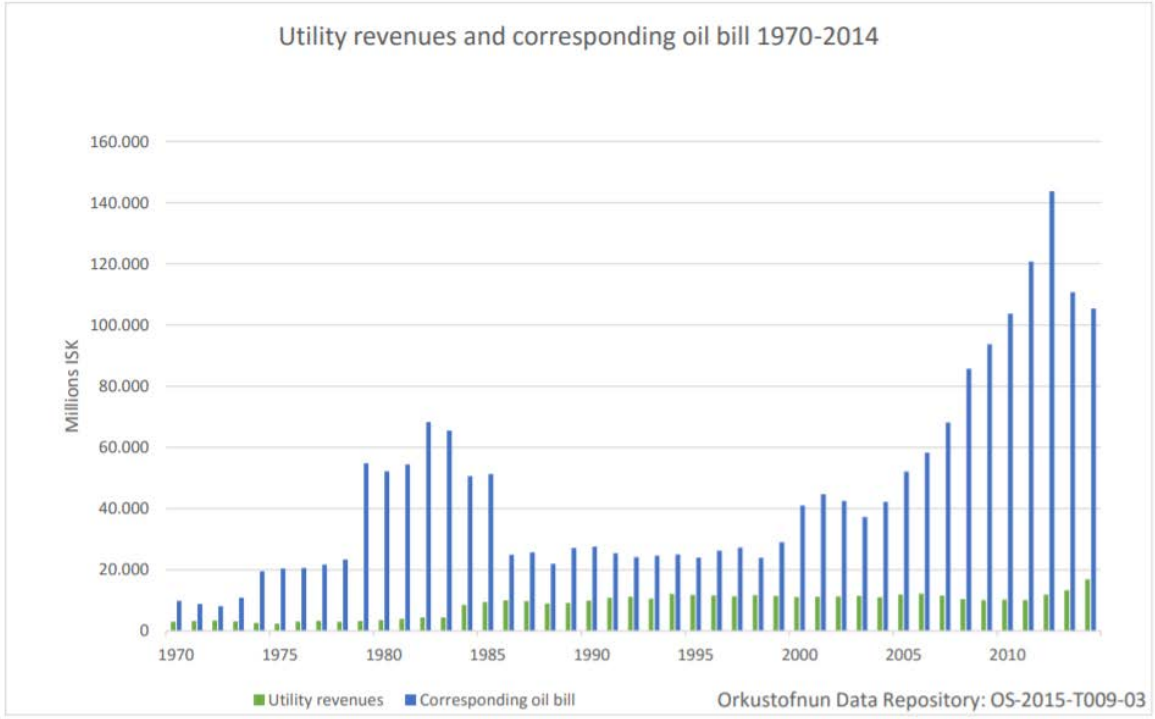
# Economic value of geothermal use in Iceland

Sale prices for geothermal energy for space heating vs. the cost of oil if it would have been used instead of geothermal

Cost in million ISK

Green bars:  Cost of heating with geothermal

Blue bars: Equivalent costs if heated with oil




Source: https://orkustofnun.is/gogn/Talnaefni/OS-2015-T009-03.pdf

# Social value of geothermal use in Iceland

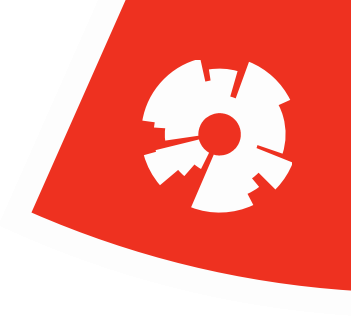
Municipality election 1938
Vote for the geothermal district heating!


Reykjavik around 1940. Photo: Reykjavik Energy

Reykjavik today
Photo: http://www.fosshotel.is/is/frettir/thvilikt-utsyni---fosshotel-reykjavik/82/

# Geothermal and sustainability

Sustainable development is "a development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland, 1987)



Thank you for your attention !