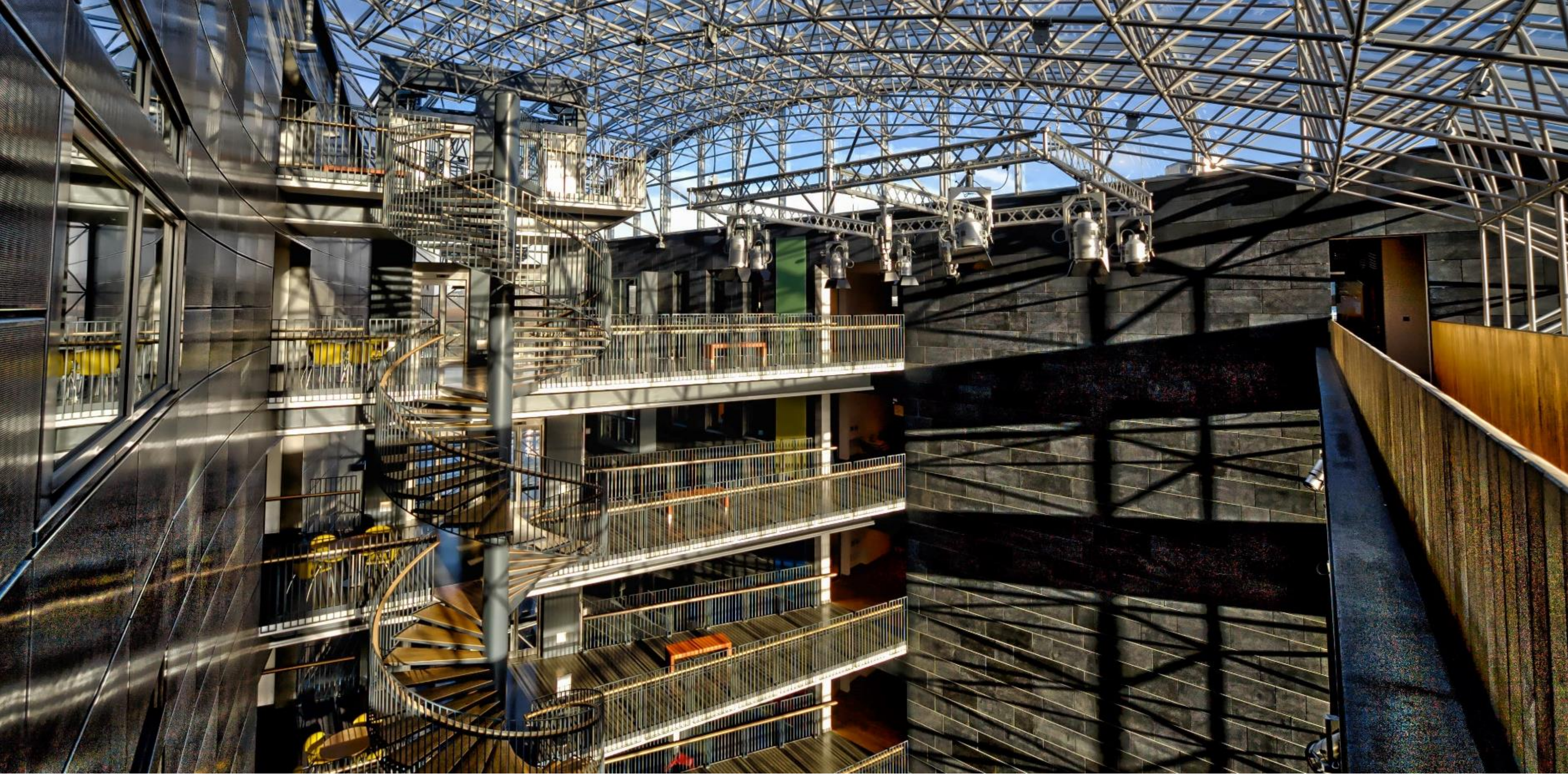


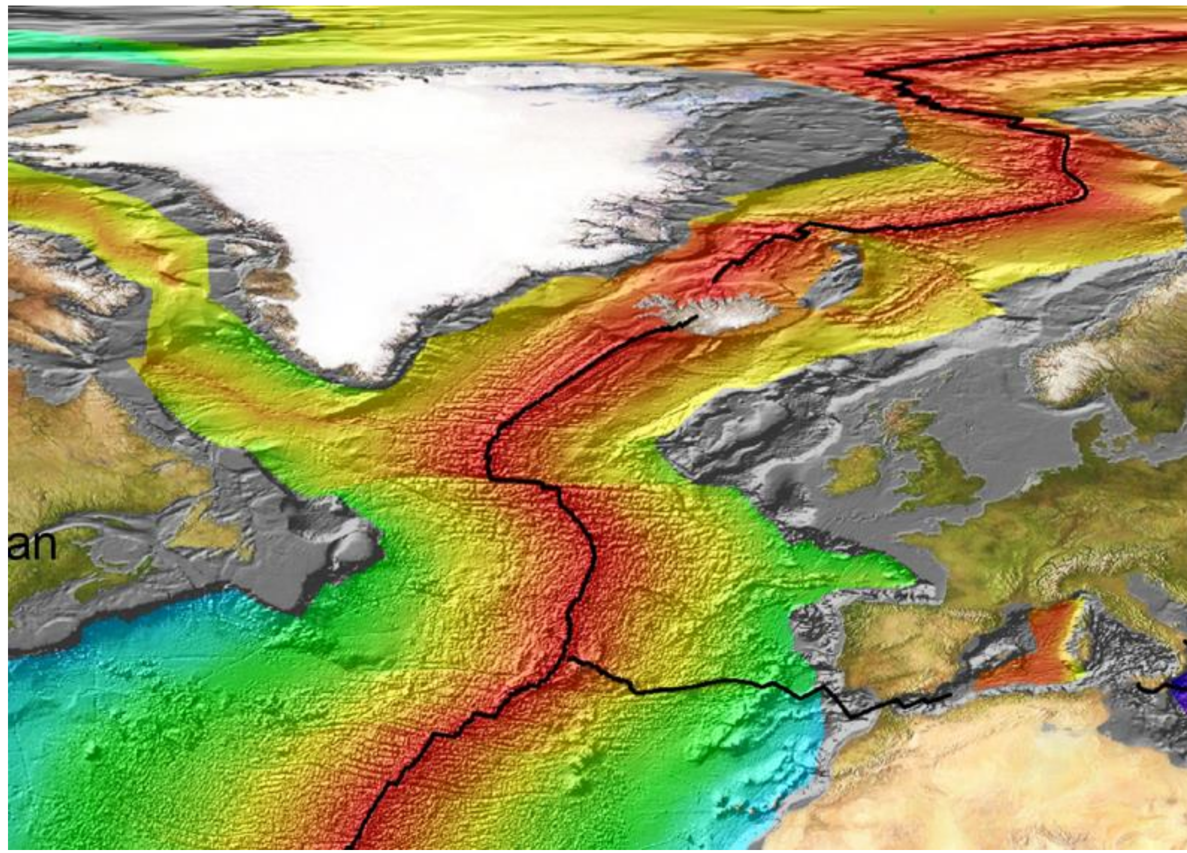
Space heating in Reykjavik

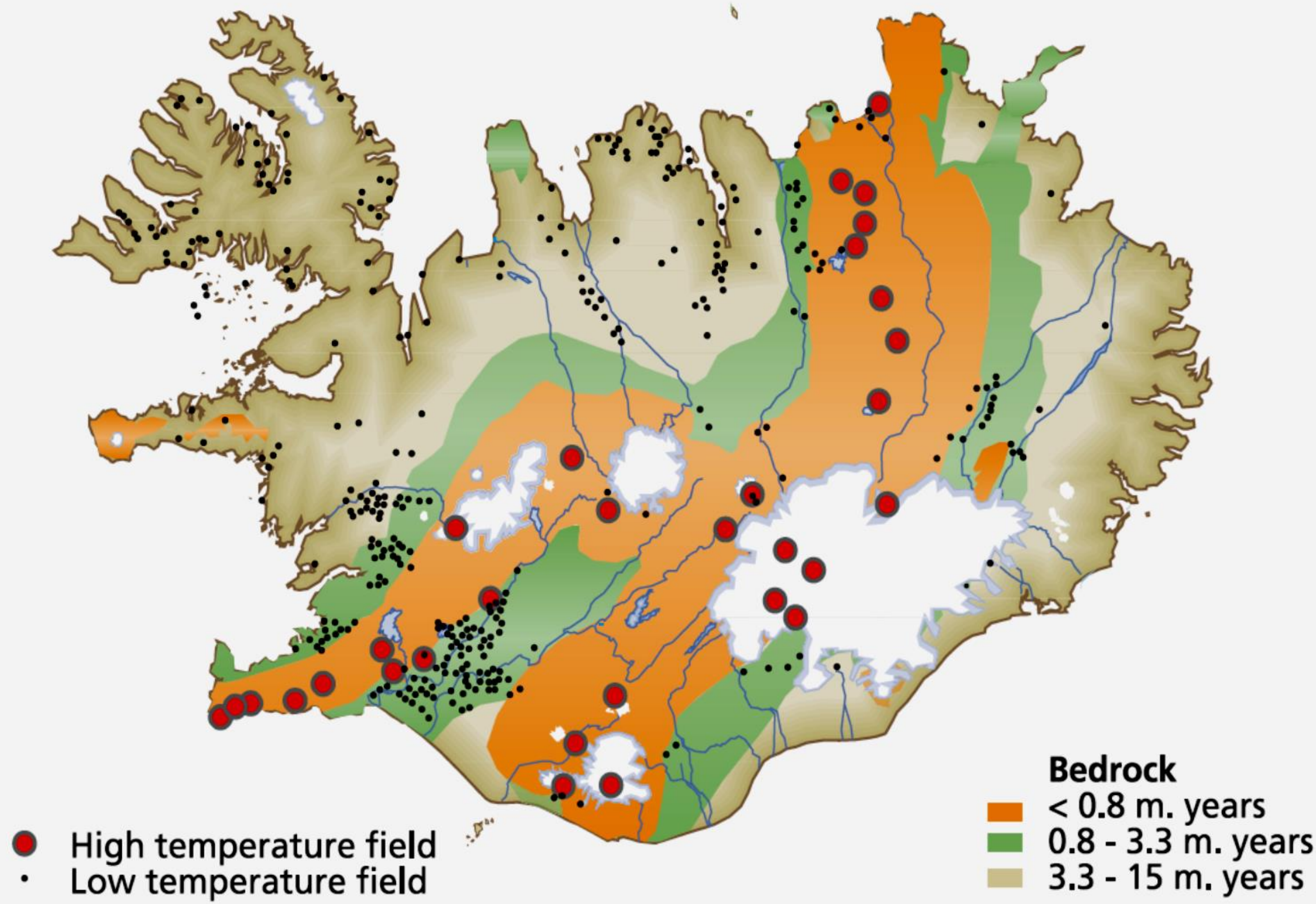
90 years of low temperature and
30 years of high temperature utilization.

Orkuveita Reykjavíkur

Dr. Gretar Ívarsson

Volcanism and plate tectonics




Bedrock
< 0.8 m. years
0.8 - 3.3 m. years
3.3 - 15 m. years
High temperature field
Low temperature field

Geothermal fields

- **Low temperature fields**
  - Temperature under 150 C at 1000 meters.
  - Surface manifestations warm springs and clear pools.
  - Low temperature fields are outside of the volcanic zones.
  - Low temperature fields are in most cases believed to be former high temperature fields that have drifted outside the volcanic zones.
  - Low temperature fields in Iceland are more than 200

Geothermal fields

- **High temperature fields**
  - Temperature over 200 C at 1000 meters.
  - Surface manifestations are boiling pools, geysers, mudpools and fumaroles.
  - Extensive alteration of bedrock and scaling
  - High temperature fields are all on the volcanic zones.
  - High temperature fields in Iceland are 25 - 30

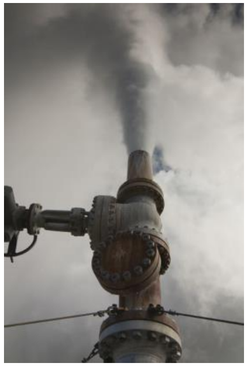
Energy source – Magma – Holuhraun 2014

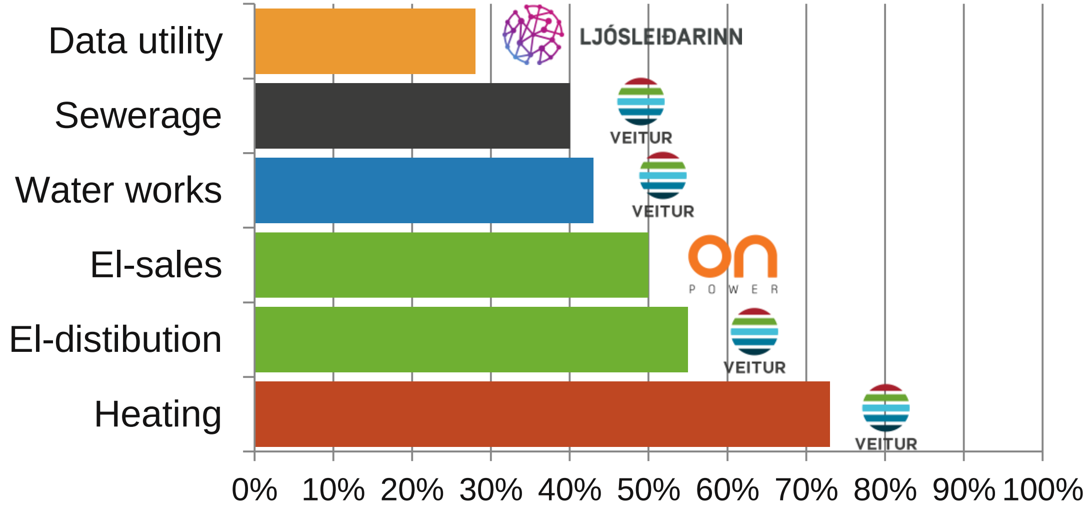
Energy source - Magma – Holuhraun 2014

Energy source - Magma – Holuhraun 2014

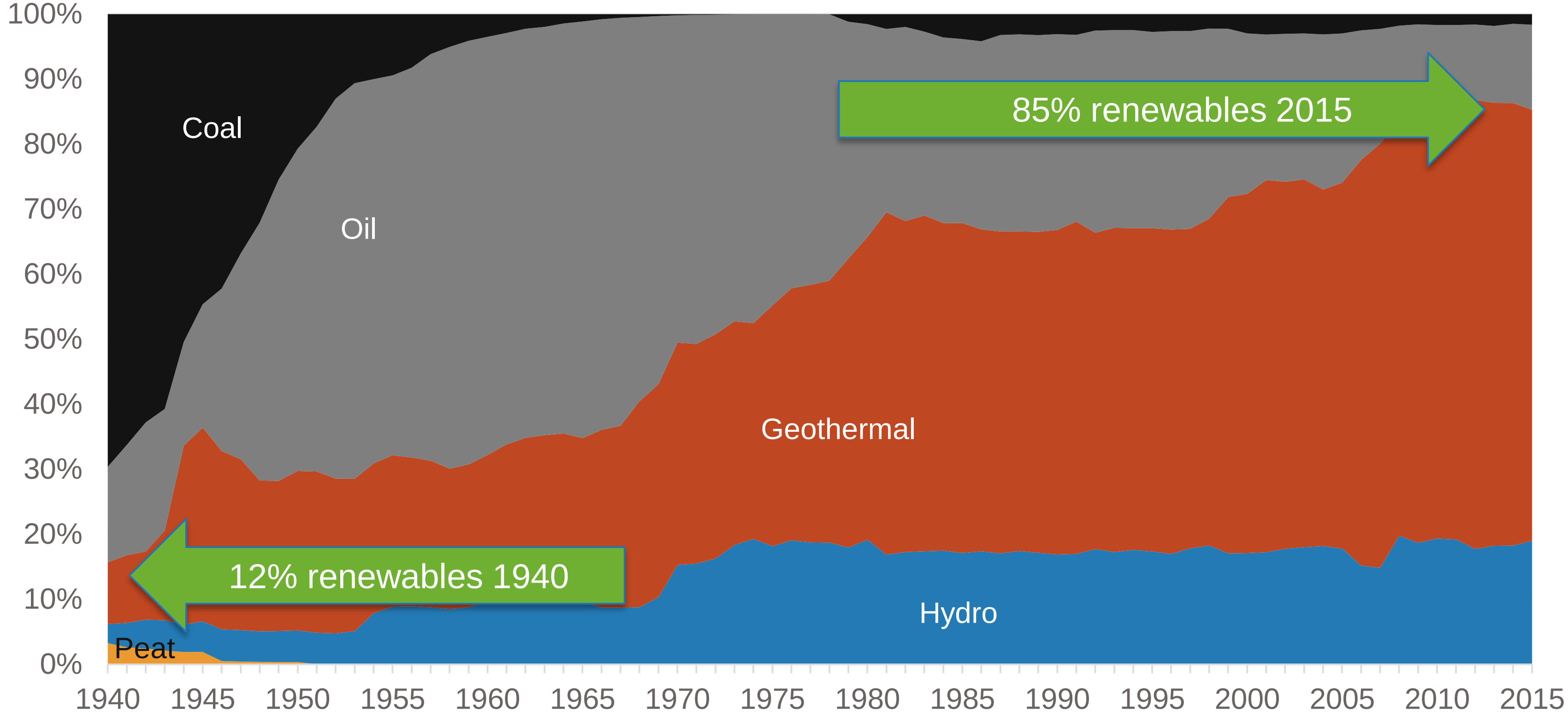
Reykjavik Energy

OR and subsidiaries serve 30 – 75% of Icelanders





Relative primary energy use in Iceland 1940-2015

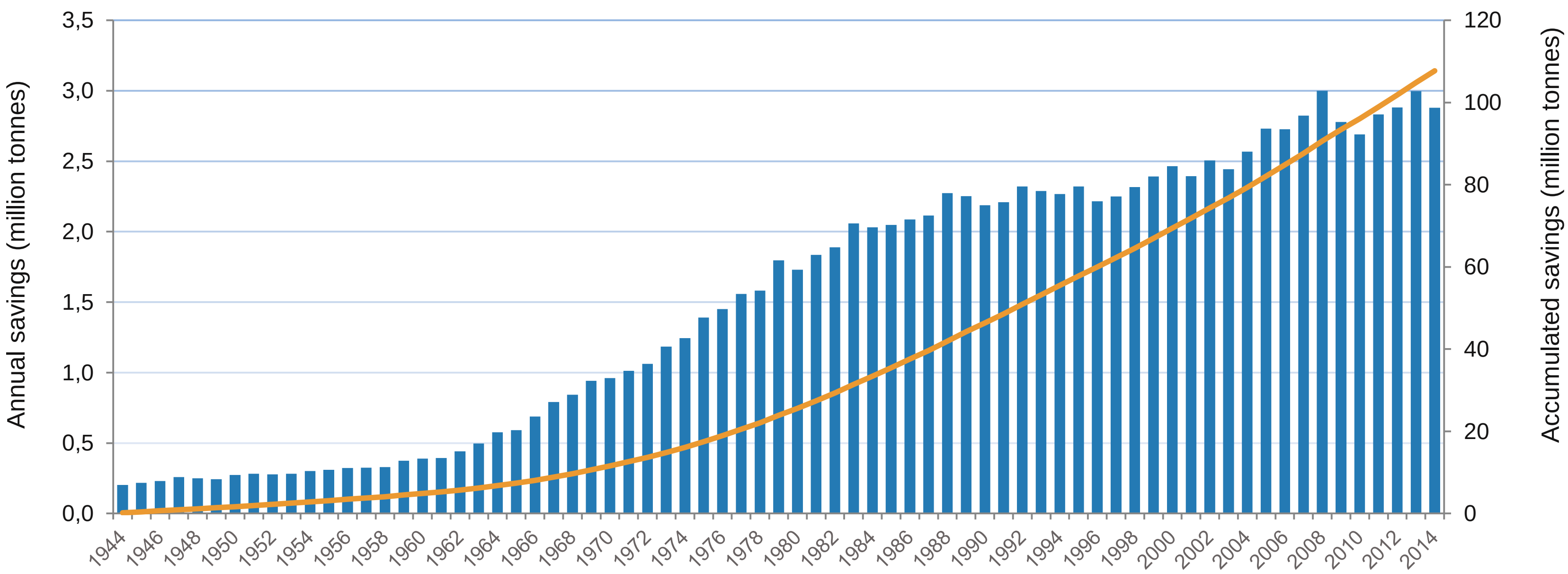


Data: IEA, 2016

The use of geothermal energy for space heating saves us $3.500 per capita per year compared to importing fossil fuel.

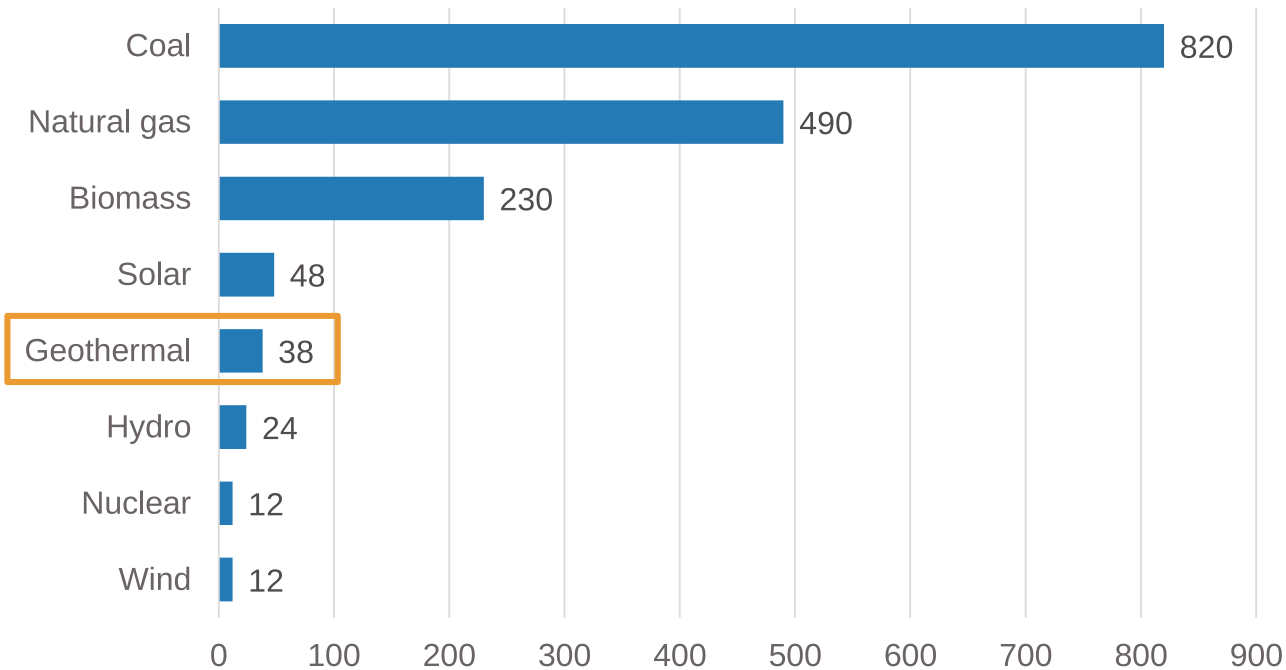
Environmental benefits

Avoided CO_2 emissions through Iceland's capital area's district heating 1944-2014

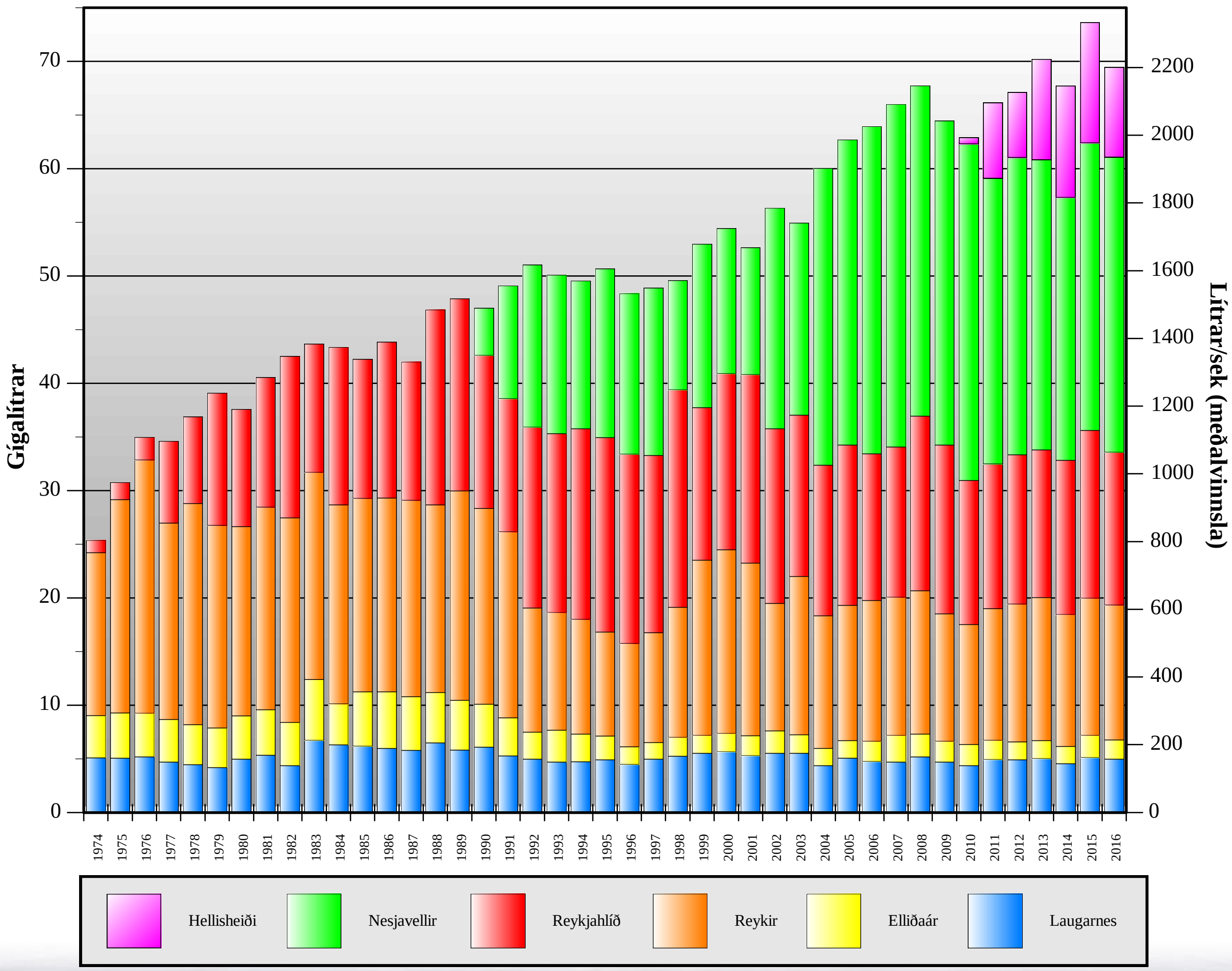


CO_2 footprint of electric generation

by source in grams of CO_2 equivalents per kWh



Hot water production 1974 – 2016 for Reykjavik



Laugarnes

- Area: 0,28 km2
- Temp: 120 – 135C
- Max production: 330 l/s
- Equals 120 MWt
- **Good for 30.000 people**
- Average production 120 l/s
- 10 drillholes

Elliðaár

- Area: 0,08 km2
- Temp: 65 – 91C
- Maximun production: 260 l/s
- Equals 45 MWt
- **Good for 11.000 people**
- Average production 55 l/s
- 7 drillholes

Reykir

- Area: 3,2 km2
- Temp: 61 – 100C
- Maximun production: 880 l/s
- Equals 140 MWt
- **Good for 35.000 people**
- Average production 400 l/s
- 22 drillholes

Reykjahlíð

– Area: 2,3 km2

– Temp: 84 – 98C

– Maximun production: 850 l/s

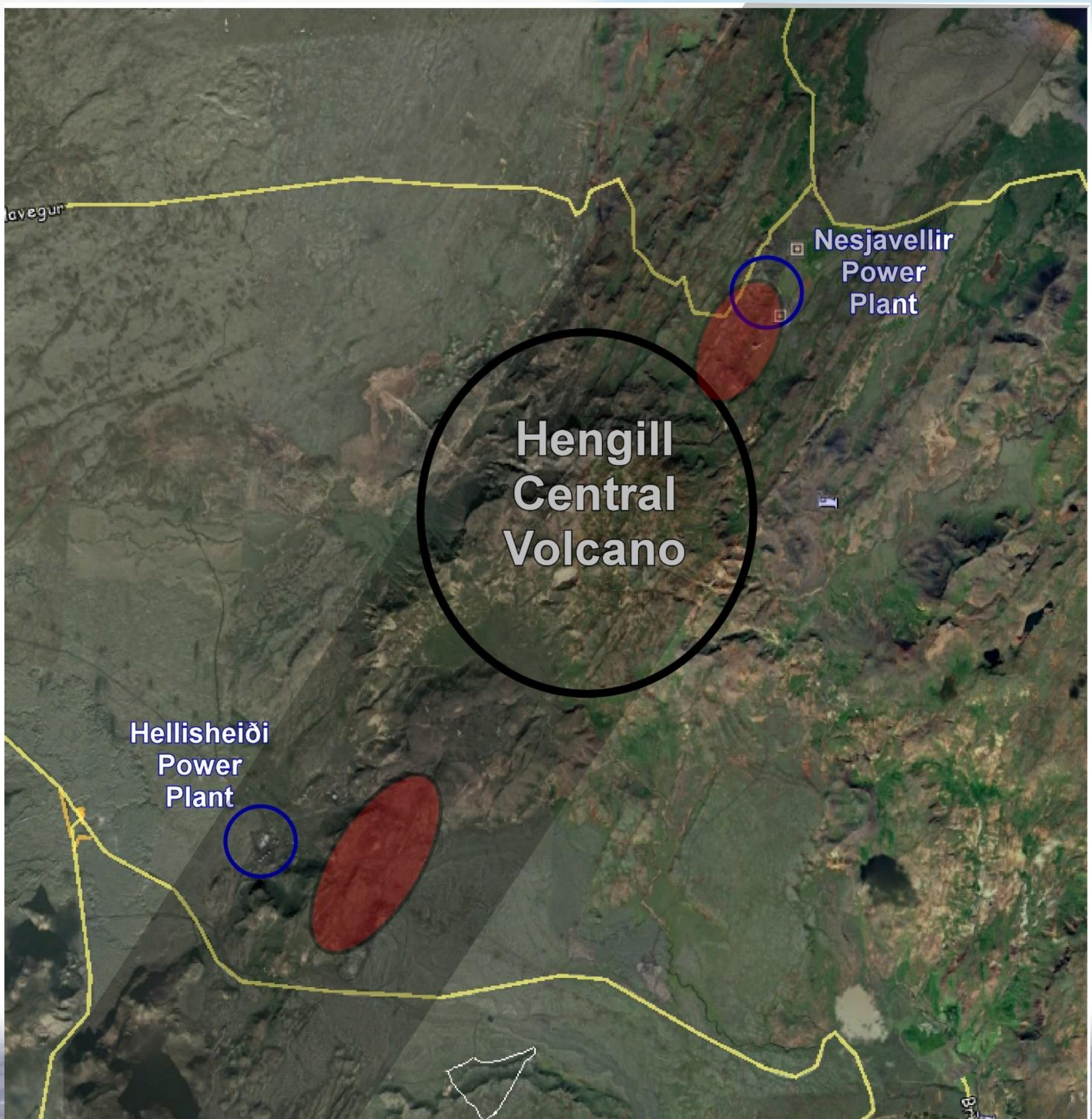
– Equals 180 MWt

– **Good for 45.000 people**

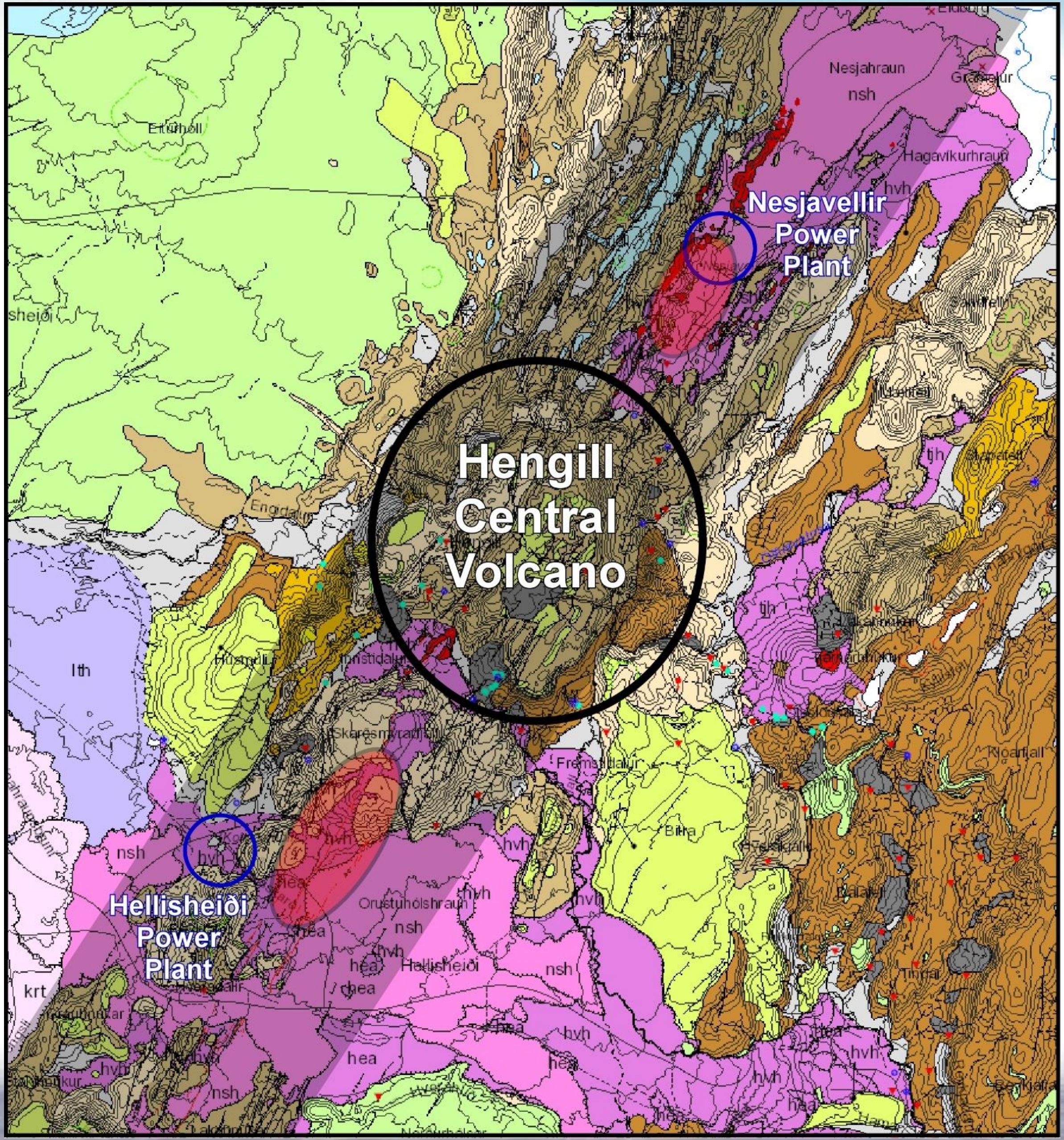
– Average production 450 l/s

– 12 drillholes

Hengill Central Volcano



Hengill Central Volcano



High Temperature Geothermal Fields and Co-Generation Power Plants

More expensive, more complex, higher cost, higher risk.

You can build them correctly or you can do it incorrectly.

We at OR (RE) have done both, one at Nesjavellir (1990) and one at Hellisheiði (2006).

More or less the same personel and same scientist,
but different CEO and a „hands on“ political environment.

Designing an incremental geothermal power station

– Surface research (geological, geophysical, geochemical)	5-10 years
– Experimental drilling and well testing	1-3 years
– Design and build a pilot power station	1-2 years
– Drill production wells and do well testing	2-4 years
– Design and build a power station	2-4 years
– Run power station, monitor wells and reservoir	3 years
– Drill more wells and increase size of power station	2-4 years
– Run power station, monitor wells and reservoir	3 years
– etc, etc, finally stopping	? years

Nesjavellir (1990)

- Temp: 200 – 300C
- Max production: 1640 l/s
- Equals 274 MWt
- **Good for 68.000 people**
- Average production 850 l/s
- 17 drillholes
- 120 MWe
- **Good for 120.000 people**

How not to design a geothermal power station (the reverse way)

- Make a long term (10-30 years) agreement to a high energy user (200-300 MWe)
- Buy turbines
- Design and build a large power station
- Drill for geothermal steam
- Start production
- In less than five years you realize that the field cannot sustain this production
- Power production drops by 5% per year

Hellisheiði (2006)

– Temp: 200 – 300C

– Max production: 650 l/s

– Equals 109 MWt

– **Good for 27.000 people**

– Average production 350 l/s

– 35 drillholes

– 300 MWe

– **Good for 300.000 people**

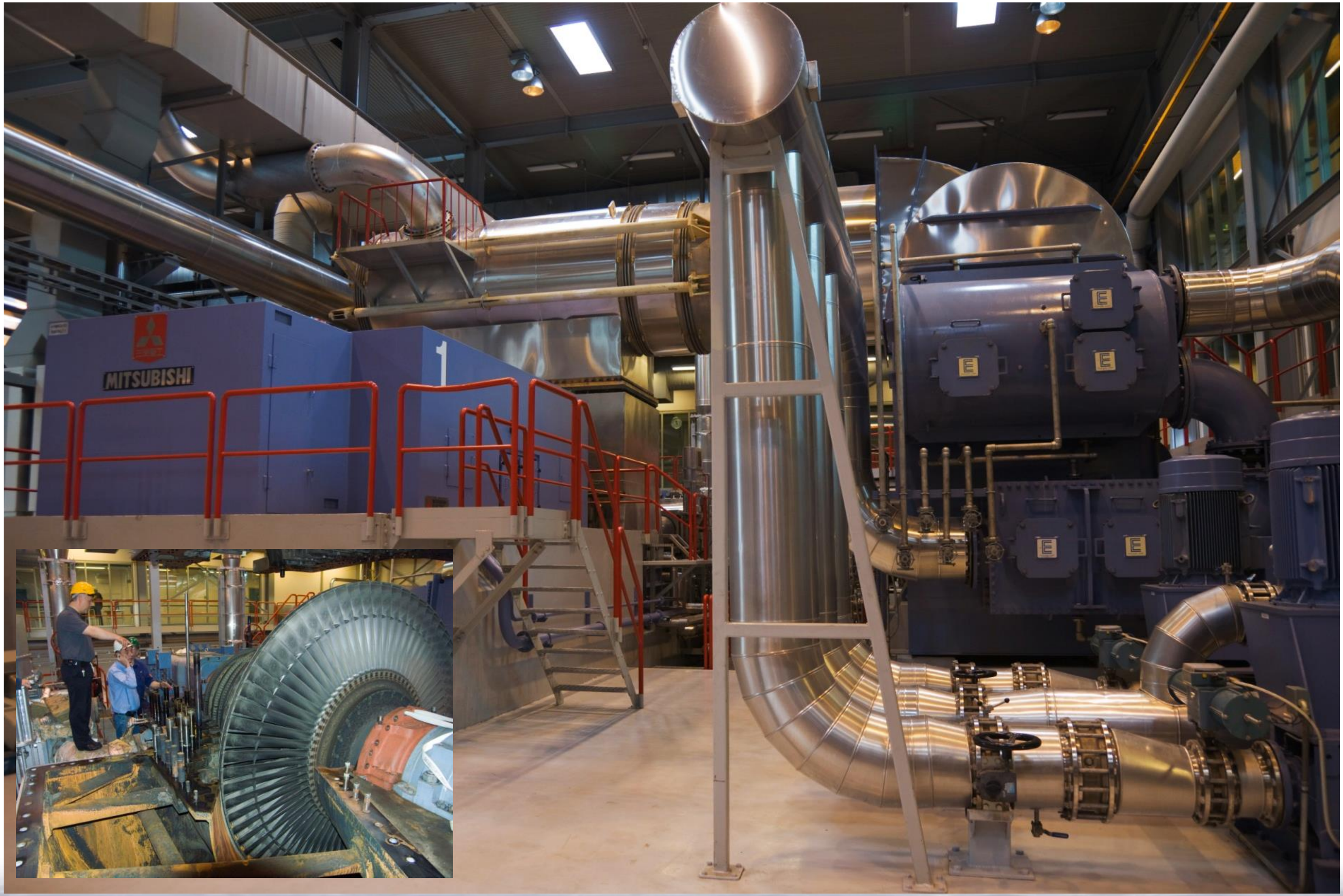
Drilling of a 2 km deep directional well

4 million euros

Well testing

Separation station

Generator, turbine and condenser (30 MWe).

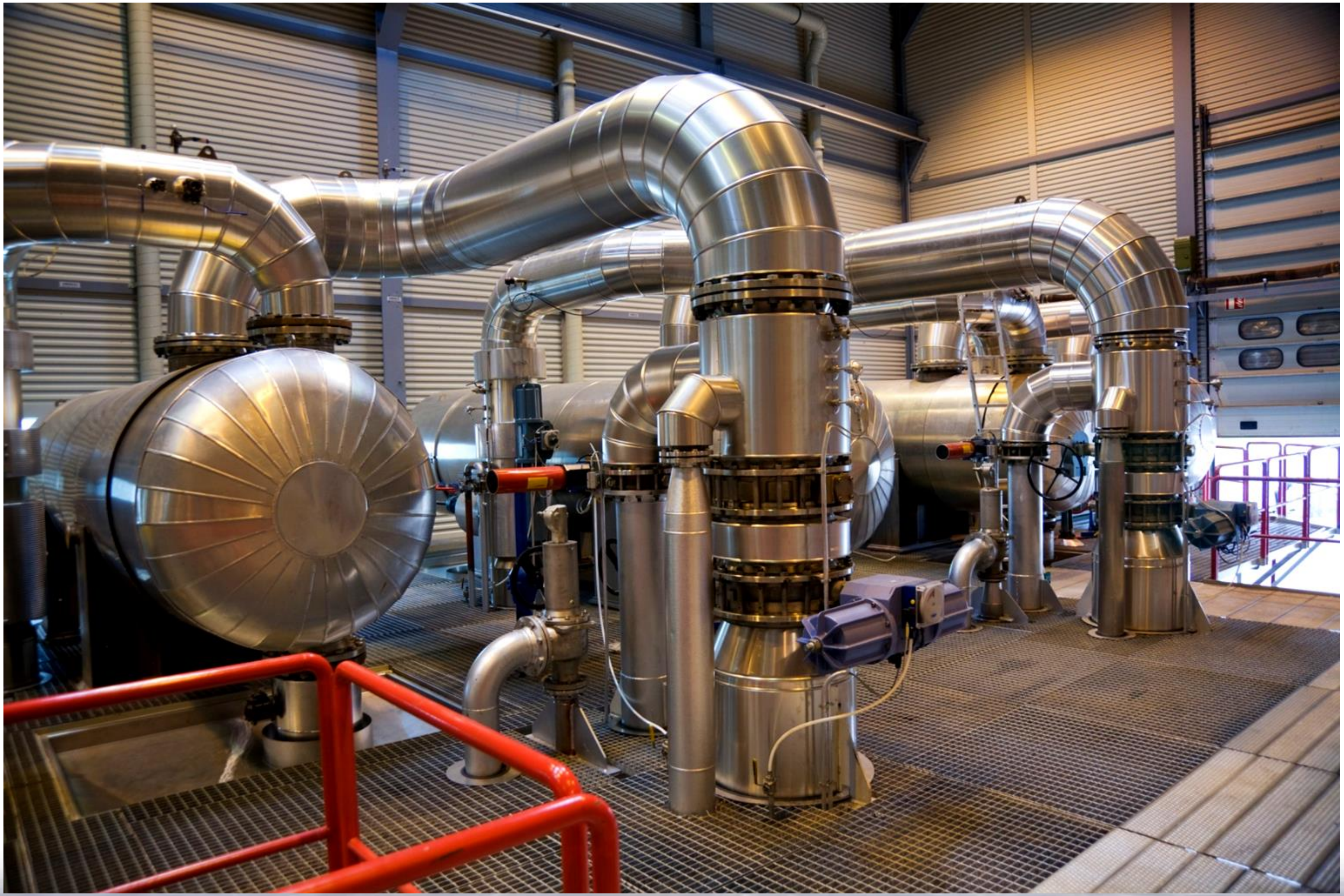


Condenser

The steam is condensed in the condenser using cold groundwater from shallow wells close to the lake. During the process the cold water heats up from 5 C to 55 (first stage).

Heat Exchangers

Separted water (192 C) from the wells is used for the second stage of heating. The water is heated from 55 C to 85 C.



Deareators

The heated water is boiled undur vaccum conditions to release oxygen to prevent corrosion. During the process the temperature of the water drops to 82 C. A minor amount of H2S is injected to react with the remaining oxygen and to control the pH.

Nesjavellir pipeline

27 km long and it takes the water approximately 16 hours to reach Reykjavik (0,4 m/s). Less than 1 C is lost in transit.

Not without challenges

Geothermal energy and geothermal gas emissions
850 kg/s to generate 420 MWe

Emissions besides H_2O (99,50% - 845,8 kg/s)

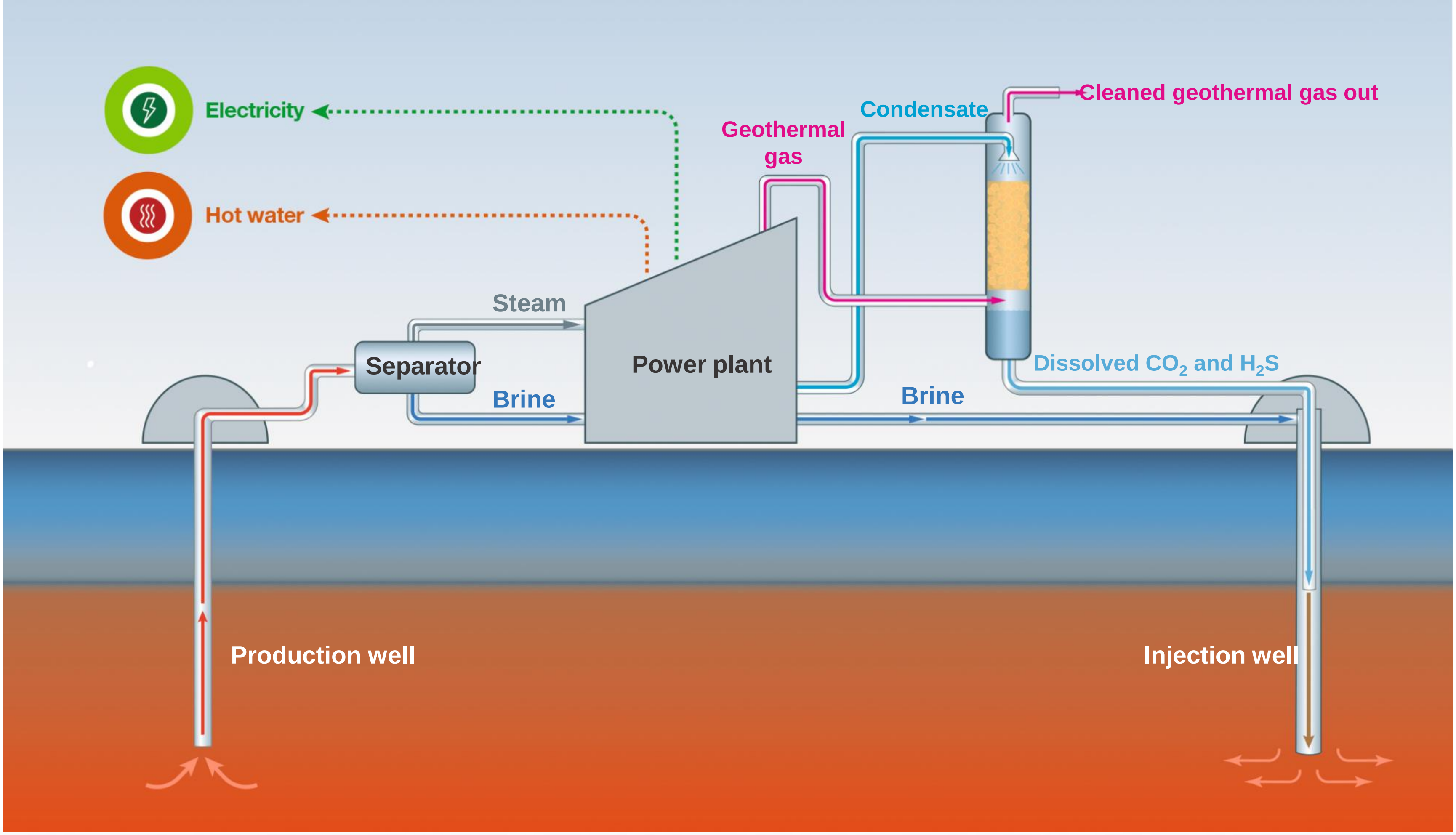
CO_2 (0,40% - 3,4 kg/s)
H_2S (0,15% - 1,3 kg/s)
H_2, N_2, CH_4, Ar (sum 0,05% - 0,4 kg/s)

Environmentally significant
GHG, corrosive, toxic, flammable, smelly

Origin

Magmatic
Meteoric/precipitation
Water rock reactions

Gas into rock – the open source method

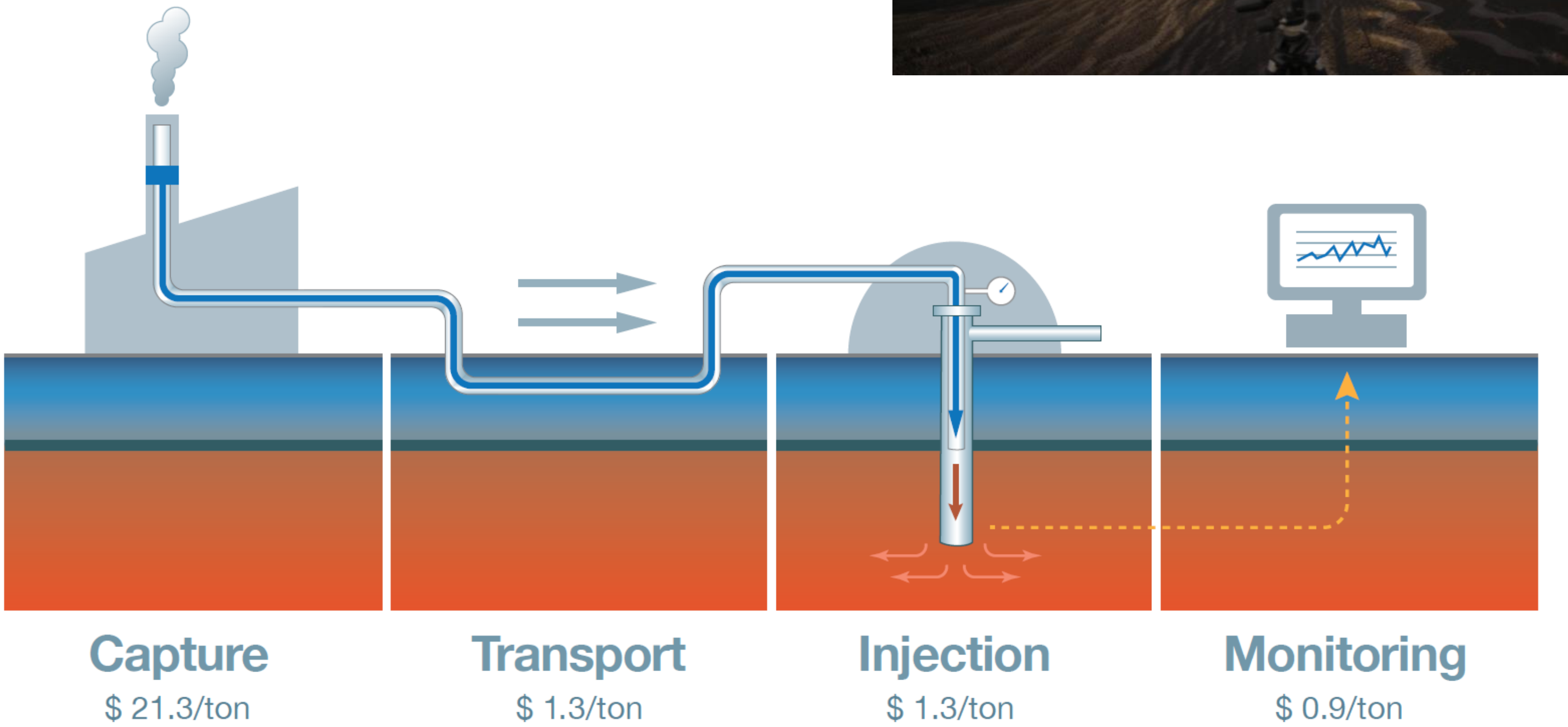


In reality


Condensate in
Cleaned gas out
Geothermal gas in
Water and dissolved gases out

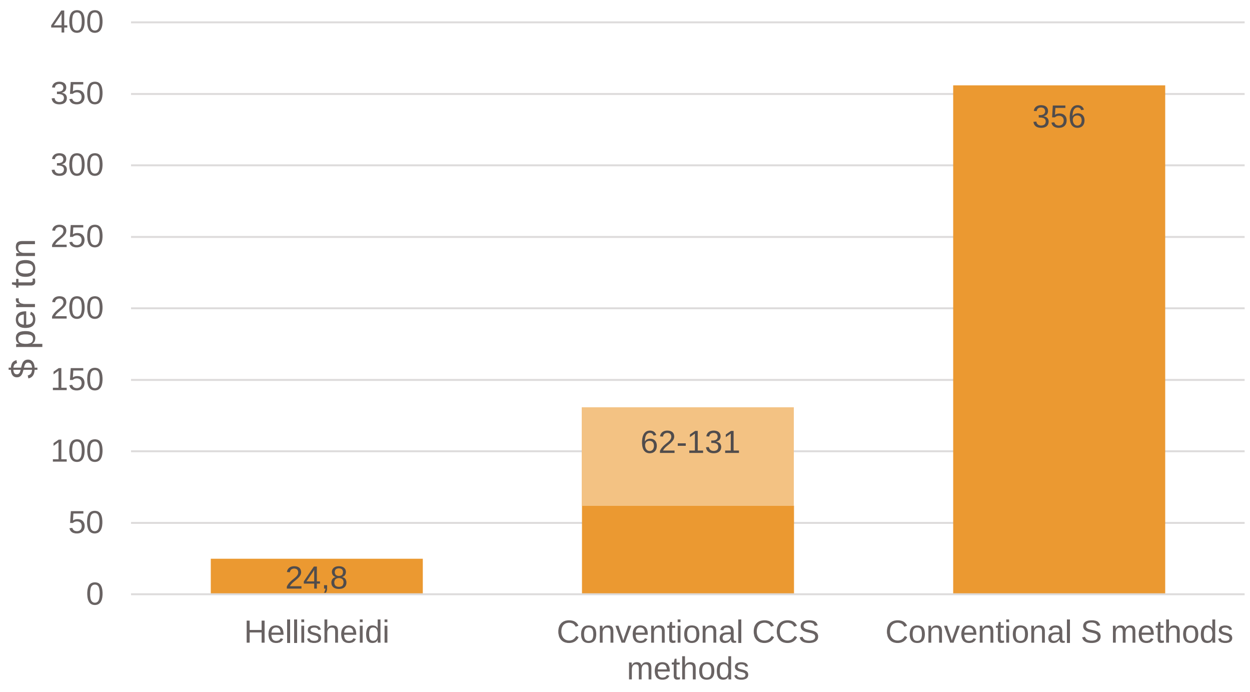
Cost per ton injected

$ 24.8 at Hellisheidi



Comparison of cost

Conventional carbon and sulfur removal methods



Orkuveita
Reykjavíkur

HAGSÝNI FRAMSÝNI HEIÐARLEIKI