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Geothermal Energy
Jordens varme

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GEOTHERMAL ENERGY
JORDENS VARME

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DTU Civil Engineering

Plan of the presentation

Theoretical overview

- Planet Earth
- The origin of geothermal energy
- How hot is the Earth

Brief History of the use of geothermal energy

The basic principles behind the geothermal utilization

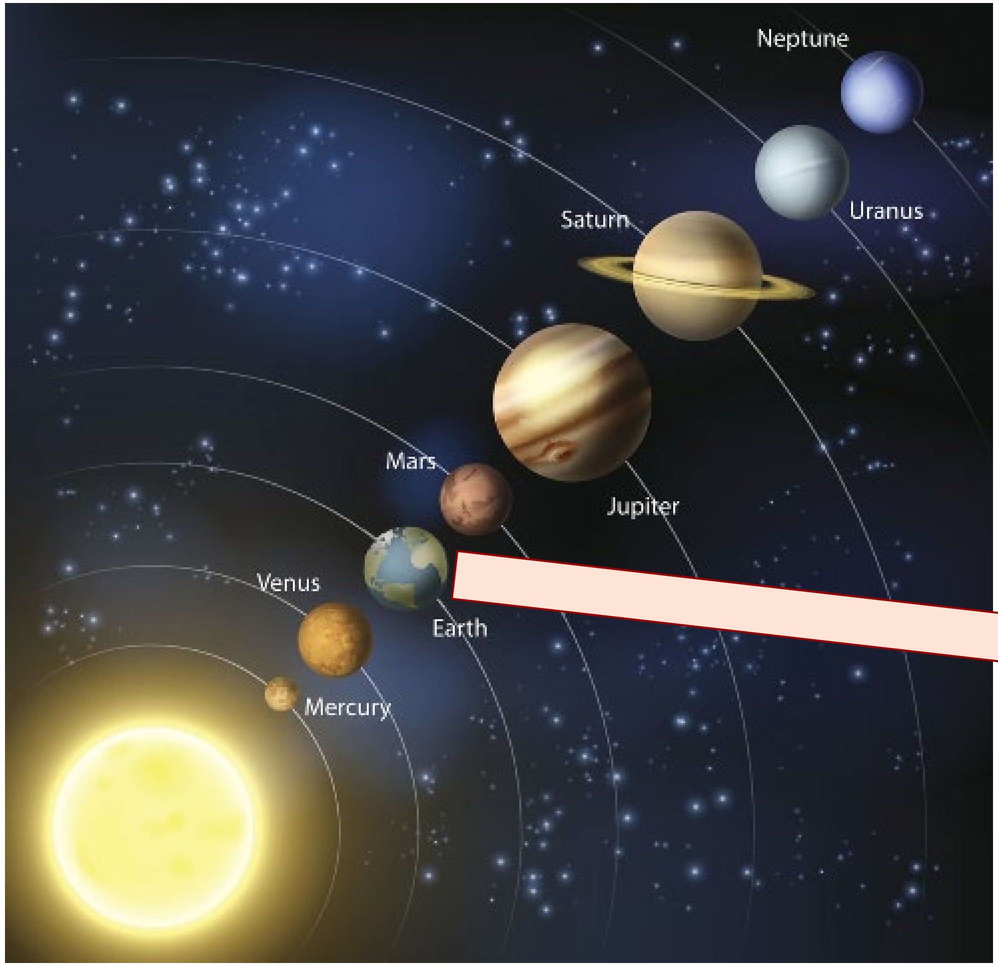
- Direct and indirect use
- Geothermal energy systems:
    - Heat storage systems
    - Producing electricity systems

Geothermal usage in the world, Europe, Iceland, Denmark

The Planet Earth

The 3rd rock from the Sun -☺   Created appr. 4.5 milliard years ago

https://pixfeeds.com/images/astronomy/solar-system/1280-1200-520442503-solar-system-planets.jpg

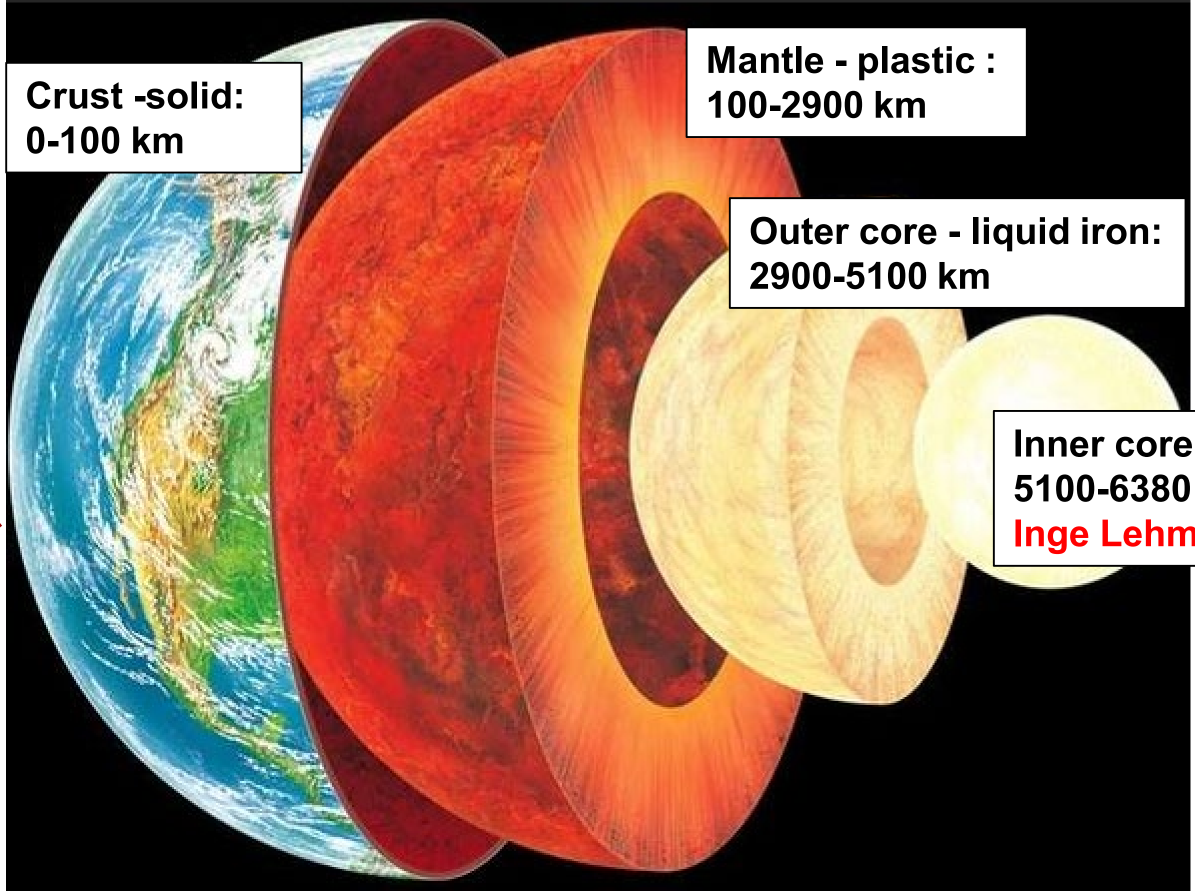


Layered structure

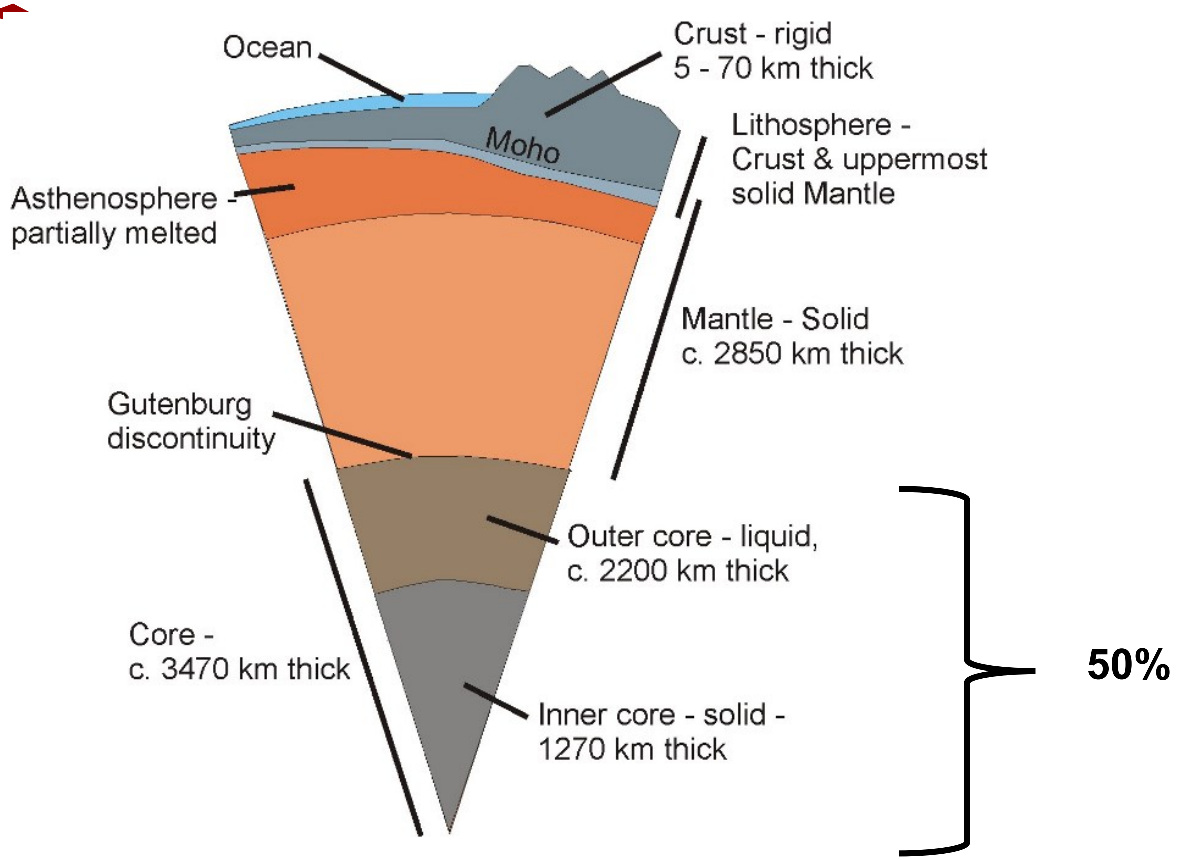
Crust and mantle: silicates

Core: mostly iron (with a bit of nickel)

https://phys.org/news/2016-09-temperature-earth-crust.html



The Planet Earth: layered structure

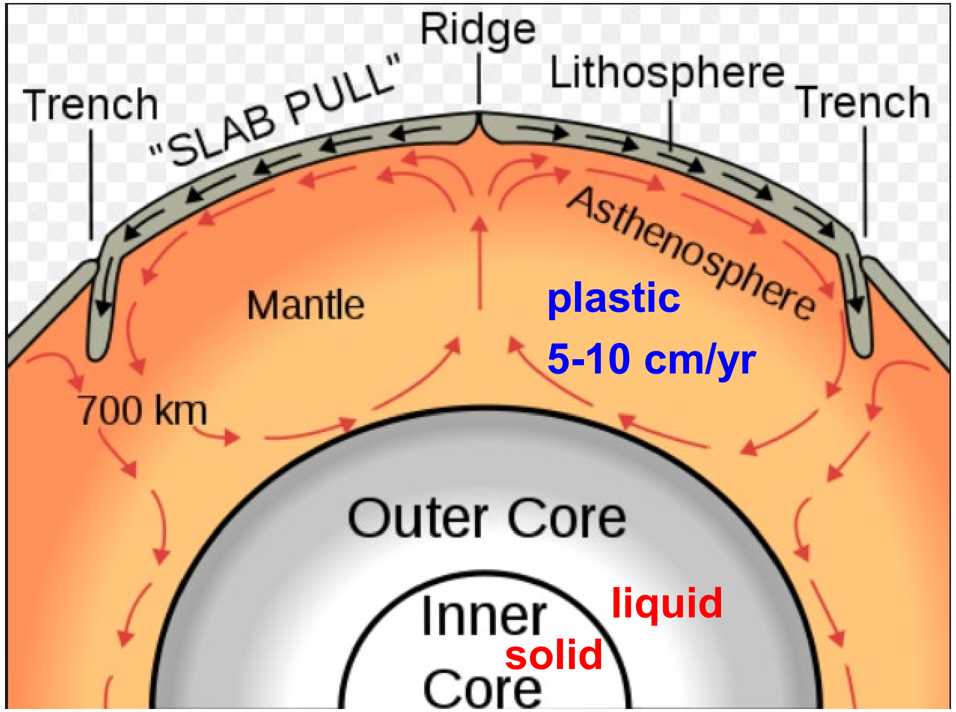


Radius: appr. 6380 km		
	Size /thickness (km)	% of total
Crust/Litho	100	1.6%
Mantle	2800	43.9%
Outer core	2200	34.5%
Inner core	1280	20.0%

Ever changing and evolving

All the parts are in constant motion:

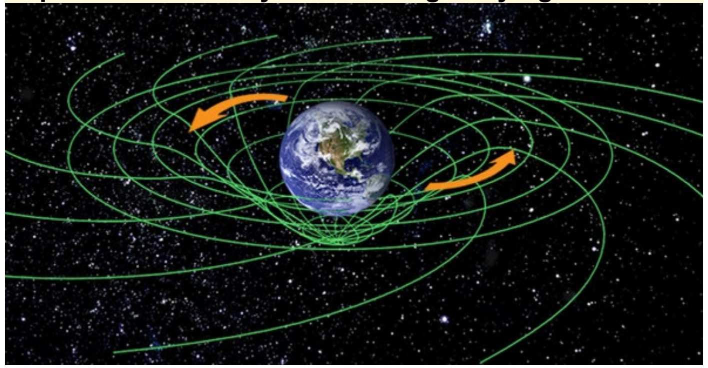
- Rotation around the Sun
- Convection (Mantle, Core)
- Tidal waves
- Plate tectonics (Crust, Mantle)



Sources / Origin of Geothermal Energy

Internal: Physical and Chemical Processes

https://universetoday.com/26775/gravity-og-the-earth



Formation of the planet

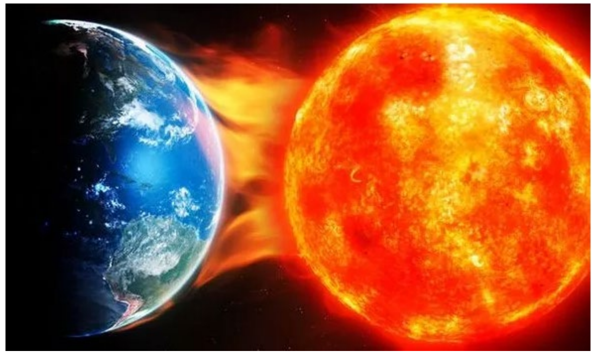
Gravitation and Rotation → friction

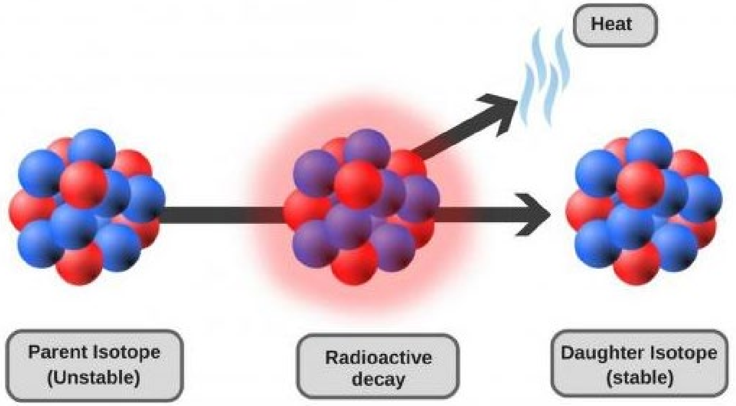
Radioactive – decay of isotopes

Chemical& physical reactions due to high pressure and high temperature: mineral transitions → release heat

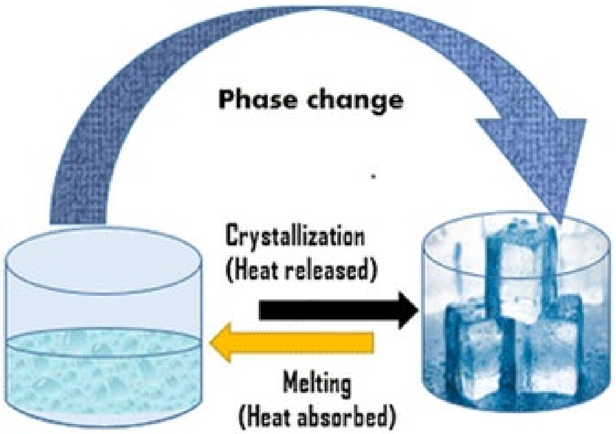
Latent crystallization: outer/inner core -> transition liquid to solid – releases heat

External: the Sun



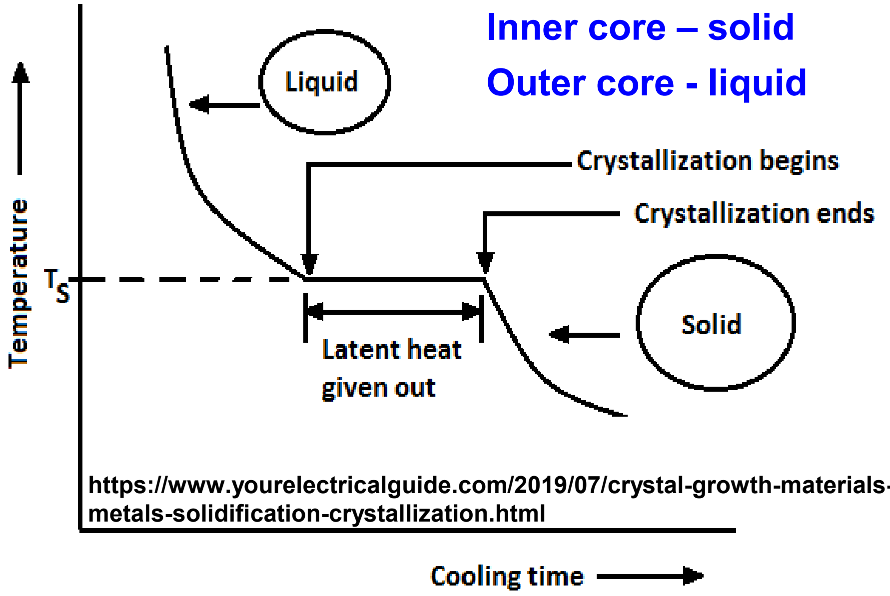


https://www.proprofs.com/quiz-school



Inner core – solid

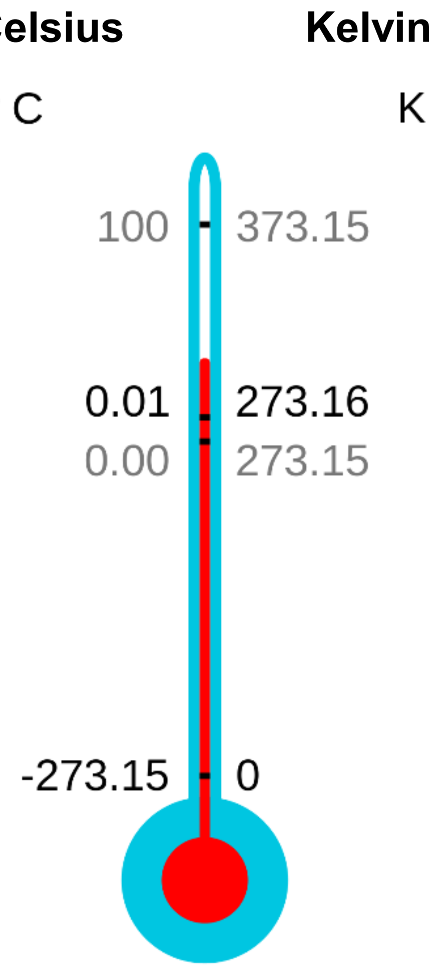
Outer core - liquid



https://www.yourelectricalguide.com/2019/07/crystal-growth-materials-metals-solidification-crystallization.html

GEOTERMI = JORDENS VARME

BASIC TERMS - BEGREBER



Temperature:

- Daily life: Celsius (SI): 0 ^{o}C – freezing water, 100 ^{o}C – boiling water
  Fahrenheit: 0 ^{o}F (original) – freezing of brine (equal parts water, salt, ice)
- Science (Physics, Chemistry, Engineering, etc.): Kelvin – the absolute temperature (absolute 0)
  0 ^{o}K = -273.15 ^{o}C =- 459.67 ^{o}F – the lowest possible temperature in our universe

Outer space/ interplanetary temperature – appr. 2.7 ^{o}K

Enthalpy, Entropy: refer to the energy contained/stored in a system

The absolute zero (0 ^{o}K) – temperature at which the enthalpy / entropy of an ideal gas are at minimum

Geothermal potential – the possible energy (in Watt or Joule) that can be extracted from geothermal sources

Sometimes, geothermal potential is expressed in **enthalpy**

Thermal conductivity – the ability to conduct heat (similar to electrical conductivity)

Geothermal gradient – change of temperature in depth

How hot is the Earth?

Temperatures in the Earth's interior are not measured directly

- Lab experiments on melting of basalt, iron under extreme pressures (100-200 GPa), 1 Gpa =10000 atm.

Temperature in the mantle – more or less "fixed"

~2-400 °C to ~4000 °C

The temperature in, especially the inner core – still debated

Large uncertainty in the experimental set ups to detect material conditions at the centre of the Earth

Experiments in early 1990's (1993, Nature)

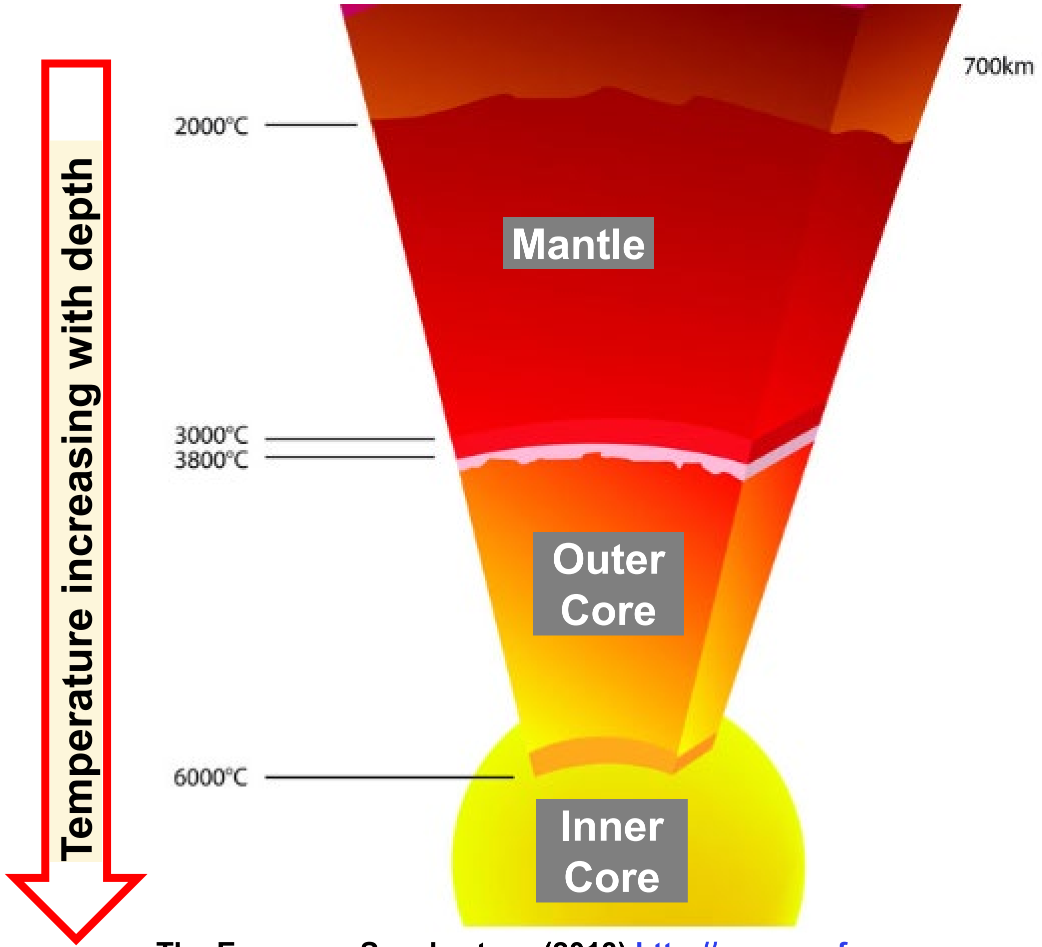
- 1993: ~ 5000 °C @ Pressure ~ 200 GPa

Experiments at the European Synchrotron (ESRF), published in Science:

- 2013: > 6000 °C @ Pressure ~ 200 GPa
- 2015: ~ 3090 °K @ Pressure = 103 GPa

Temperature scala:

- Celsius (°C), Fahrenheit (°F) – daily life
- Kelvin (°K) – planetary sciences
- 0 °C = + 273.15 °K; 0 °K = - 273.15 °C



The European Synchrotron (2013) http://www.esrf.eu
https://www.esrf.eu/news/general/Earth-Center-Hotter

How hot is the Earth?

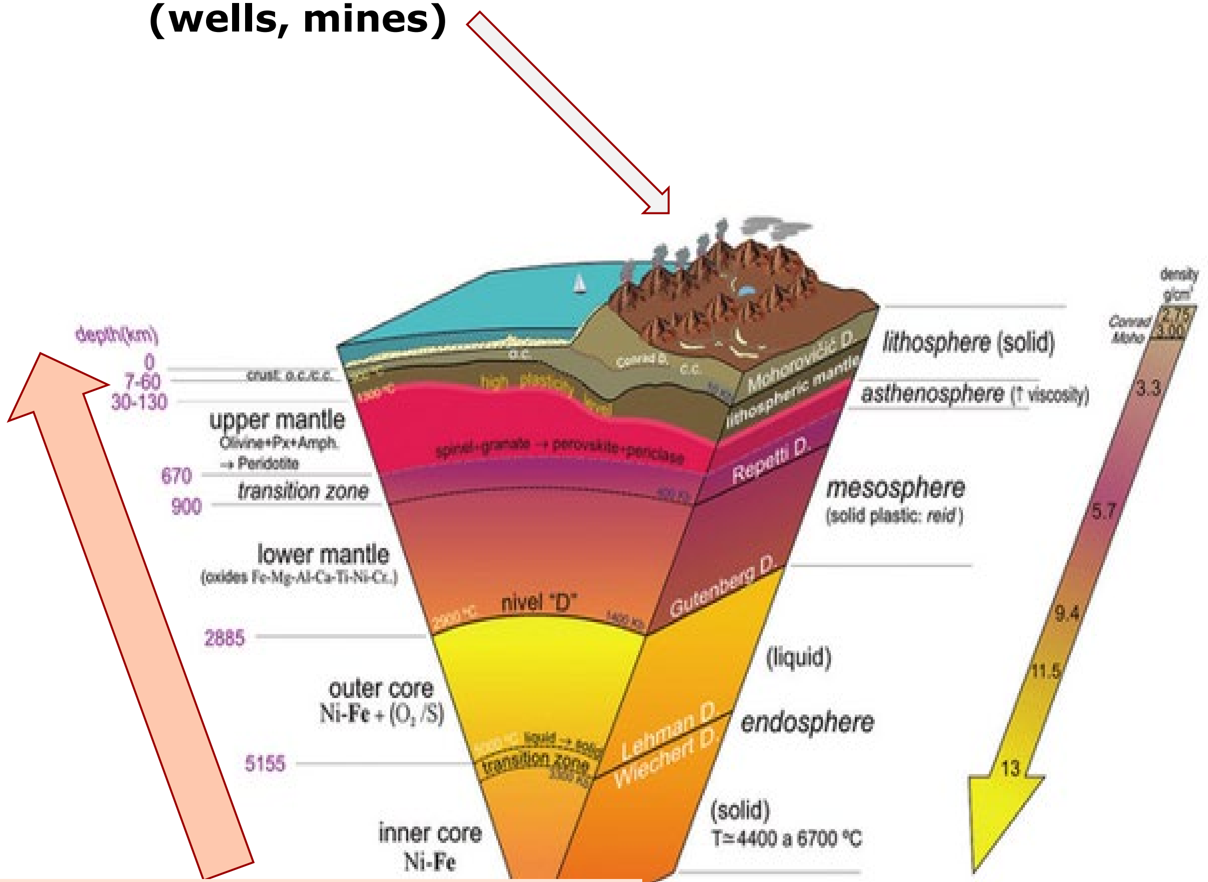
Average surface ground temperature (global): ~ 15 °C
(2017 data, www.space.com)

Direct Temperature measurements in the crust

- **North Sea (wells): ~ 150-160 °C at 5 km**
- **Amager (wells): ~ 73 °C at 2.5 km**
- **S. Africa (gold mine): ~ 55 °C at 3.9 km**
- **Volcanos (lava): ~ 700-1200 °C**

Temperature at the Crust/Mantle boundary:
From 2-400 to ~8-900 °C

Direct measurements:
only in the upper 5-10 km
(wells, mines)

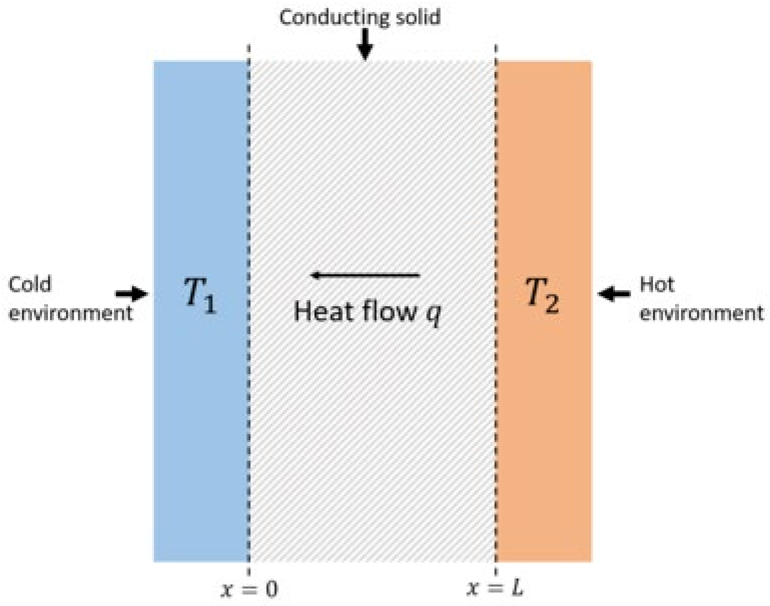


Heat is "transmitted" from the interior of the planet outwards →"Thermal conductivity"

GEOTHERMAL ENERGY USAGE: 2 basic parametrs

Thermal conductivity: **The ability to conduct/transfer heat (e.g. from the Earth's core to surface)**

Geothermal gradient: **By how much the temperature changes per unit of depth, fx 1 m , or 1 km**

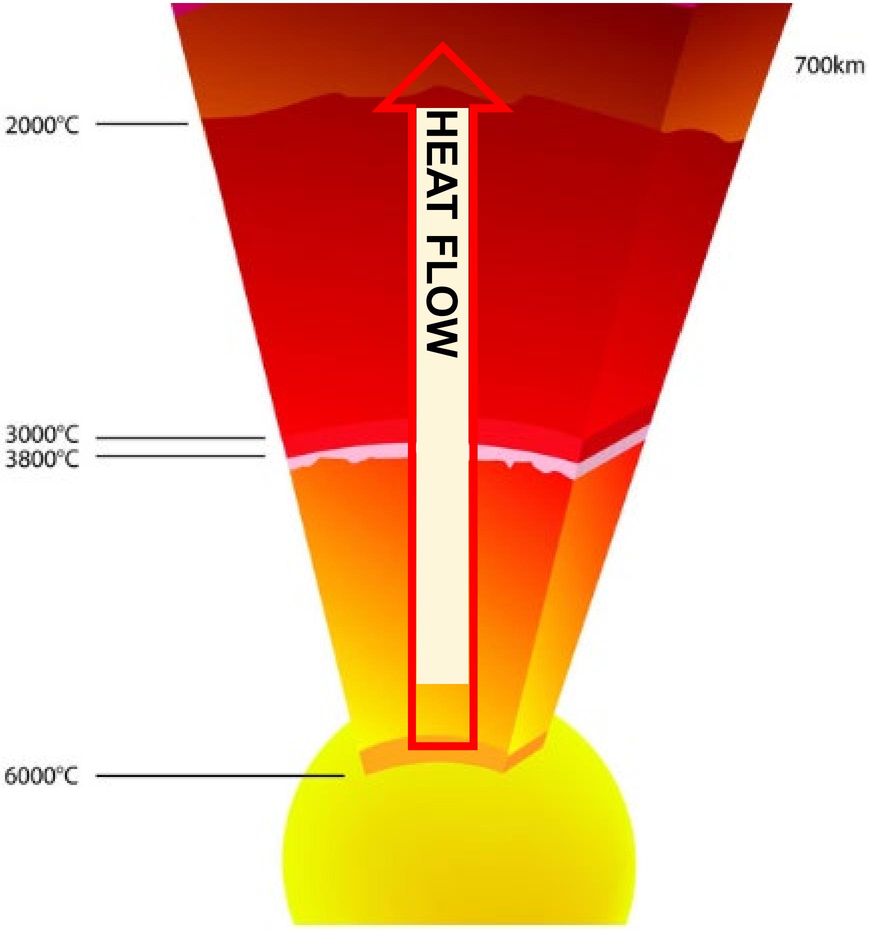


Heat Flow: ***Q = -k(T2-T1)/L ,***

k – thermal conductivity;

Heat transfer coefficient, ***C = k/L***

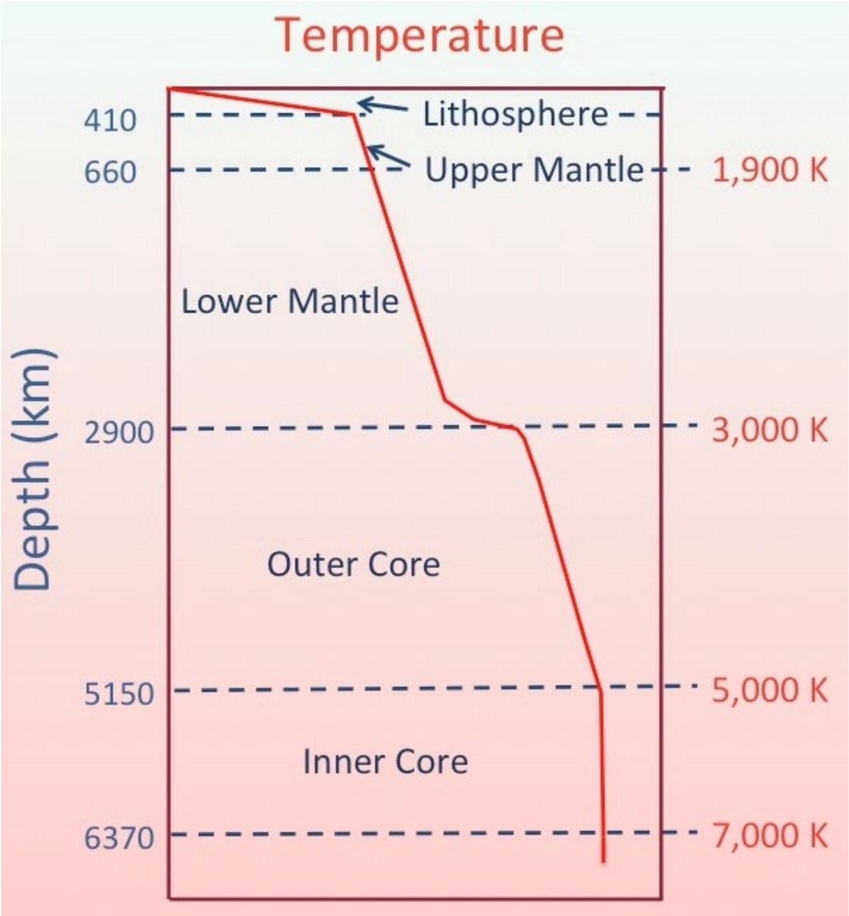
$$\textbf{Geothermal Gradient} = \frac{\boldsymbol{Temp\ at\ Depth2 - Temp\ at\ Depth1}}{\boldsymbol{Depth2 - Depth1}}$$

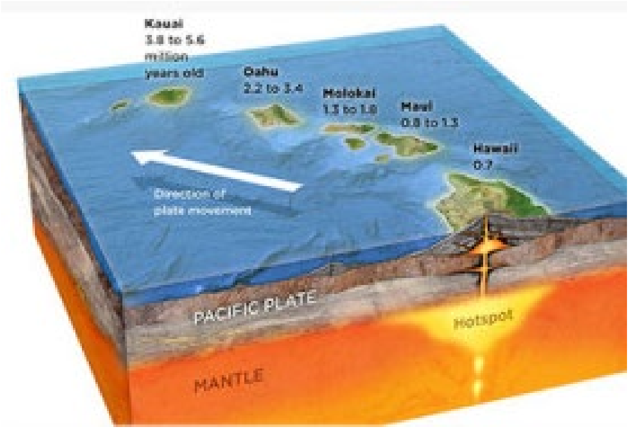


GEOTHERMAL ENERGY USAGE: 2 basic parametrs

The geothermal gradient is different in the different parts of the planet:

- largest in the crust (the part we use)



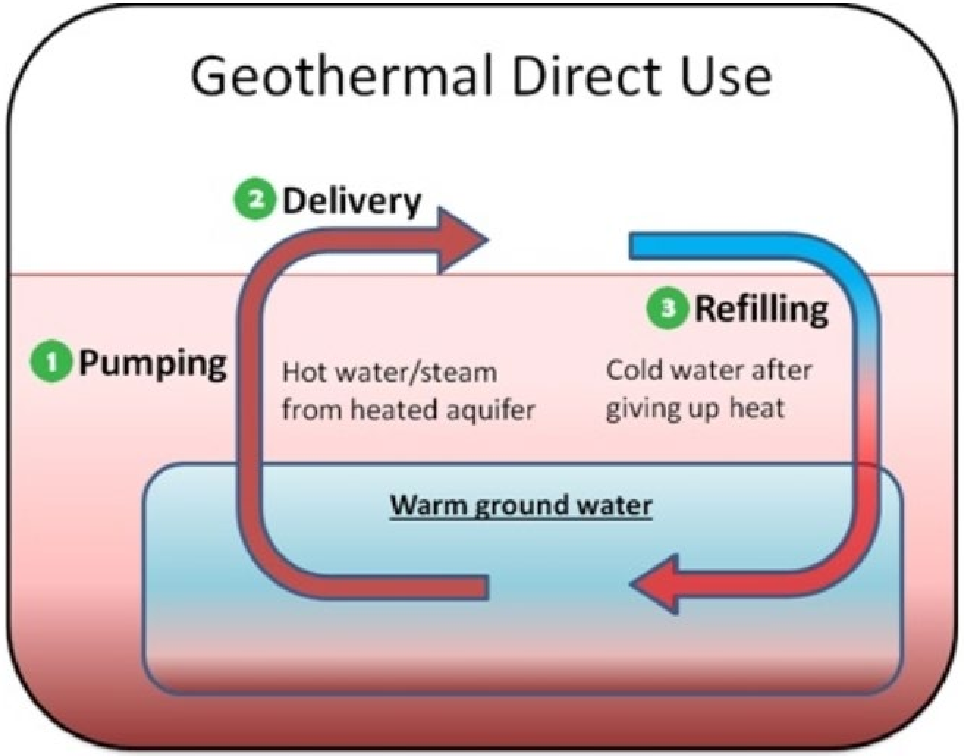


In the crust, the geothermal gradient (^{o}C/km) depends by how far way is the heat source and by the thermal conductivity of the rocks/soils

	Region	Geothermal Gradient (^{o}C/km)
"Normal"	North Europe / DK	25.0-30.0
Hot Spot, Volcano	Iceland, Hawaii	≥ 100.0
Active tectonics	California	> 50.0
Old crust	Fennoscandia	≤ 20.0
Young crust	Mediterranean	≥ 40.0
Average	World	33.0

HOW TO USE GEOTHERMAL ENERGY

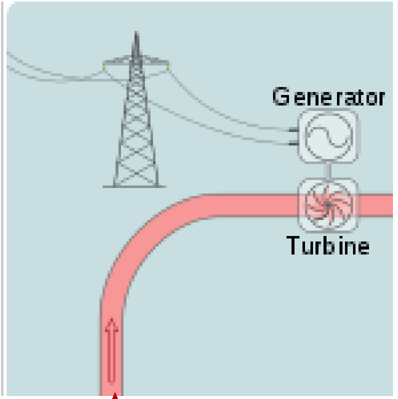
DIRECT USE: HEATING



https://www.energy.gov/eere/articles/heat-beneath-ground-working-advance-deep-direct-use-geothermal

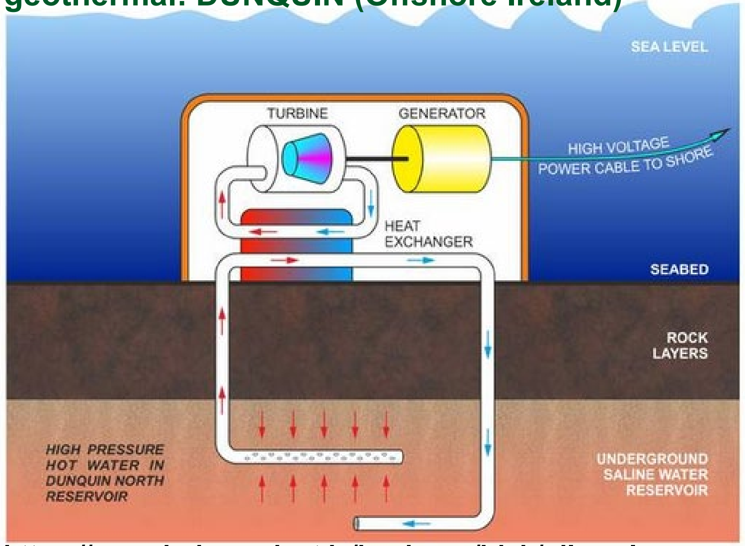
INDIRECT: TURN IT INTO POWER

Very simple principle: heat is used to turn a turbine of a generator
to produce electricity
or movement
or other kinds of mechanical energy



HEAT

Even offshore oil fields can be transformed to geothermal: DUNQUIN (Offshore Ireland)



https://www.independent.ie/business/irish/oil-explorer-could-strike-it-rich-after-finding-hot-water-in-sea-37628149.html

DIRECT USE OF GEOTHERMAL ENERGY

DIRECT USE: HEATING/COOLING – ATES (Aquifer Thermal Energy System)

In addition to the "classic" hot water/steam usage:

ATES: Aquifer Thermal Energy Storage
– uses the low thermal conductivity of the rocks to store heat
- uses temperature differences
– works with low temperatures (20-50 ^{o}C)

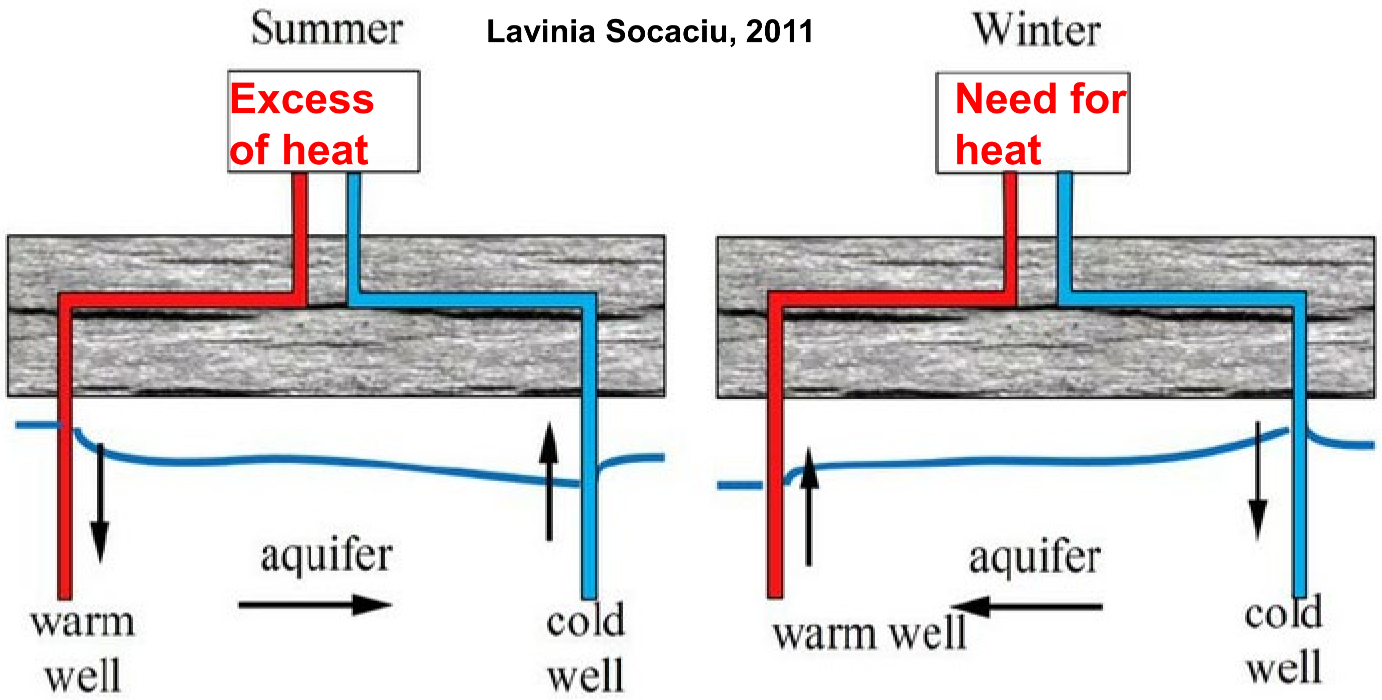
During summer – excess of heat/warm water
(solar, wind, but also IT datacentres, servers etc.)
→ pump it and store it underground

During winter – need for heat/warm water
→ pump the water from the underground

Needs a reservoir – porous rock (aquifer) where to put the water with low thermal conductivity to keep the warmth

Example - Stenlille

Lavinia Socaciu, 2011



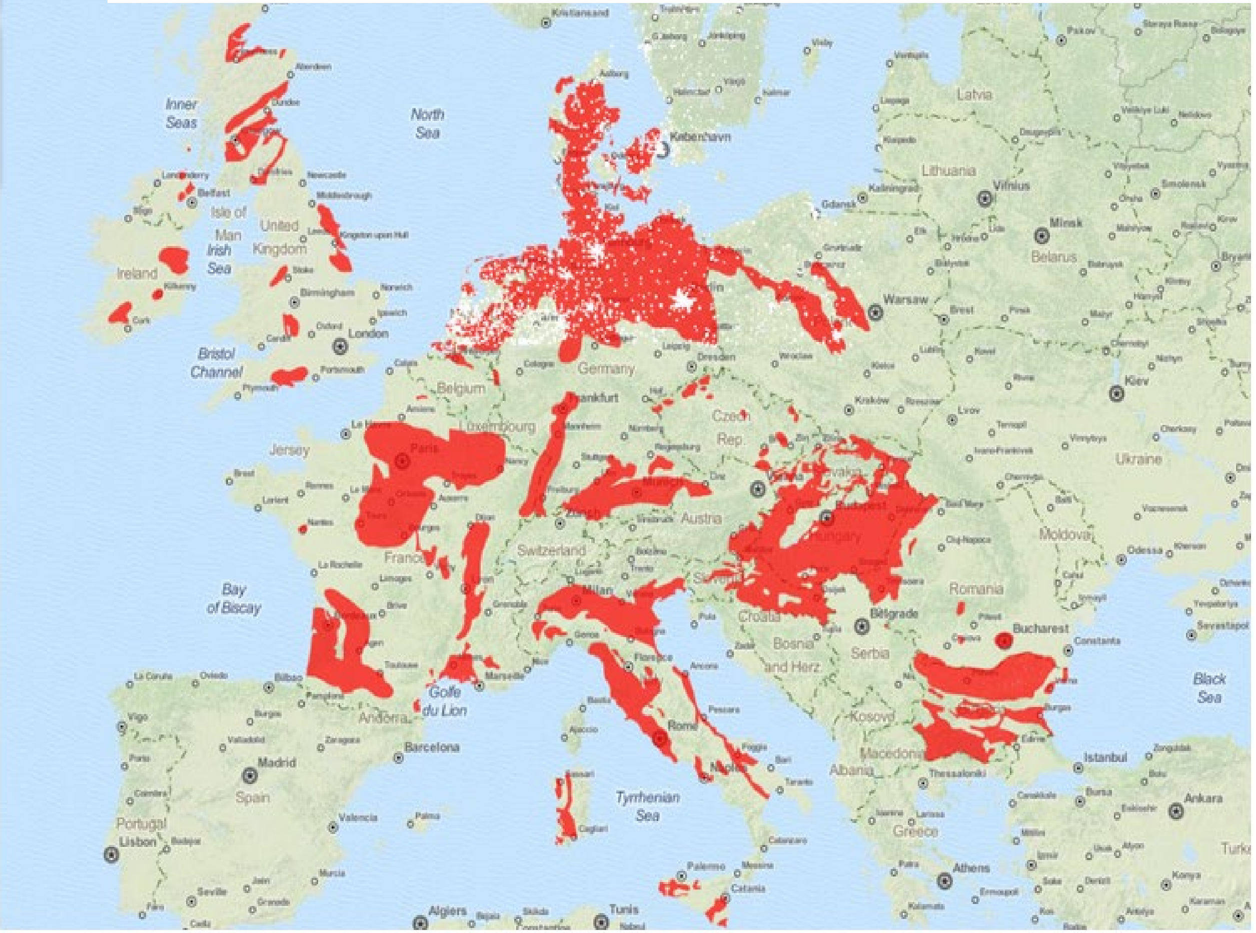
NB. Similar mechanism can be used for underground CO_2 storage

GEOTHERMAL HEATING POTENTIAL IN EUROPE

This maps shows where in Europe the geological conditions (aquifer / porous rocks with suitable thickness and thermal conductivity) are favourable for producing geothermal heat.

Stratego

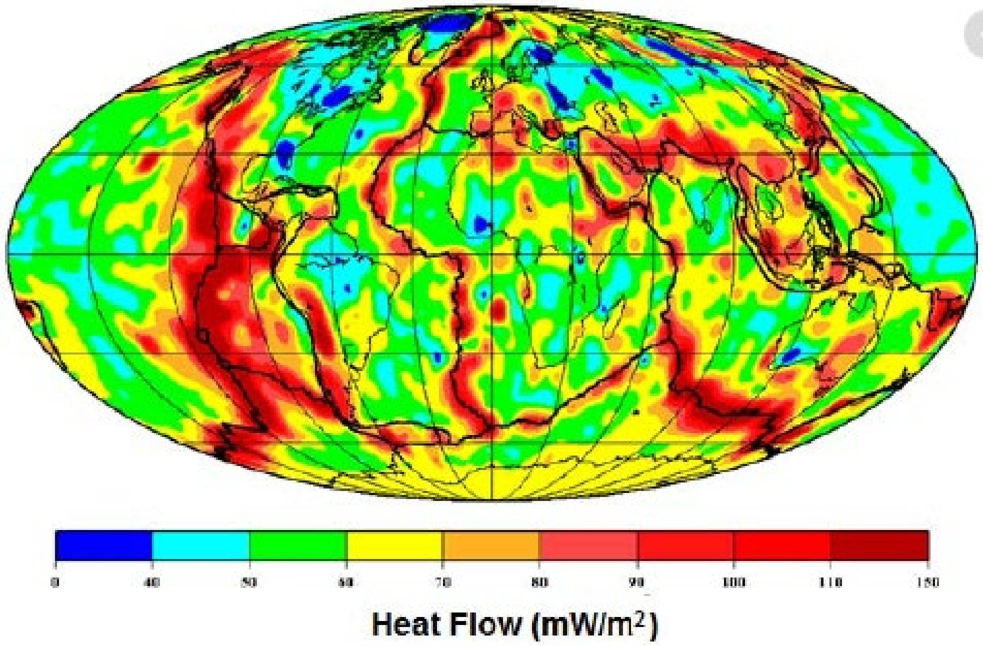
NB. The map does not show the temperature of the rocks or the geothermal gradient.

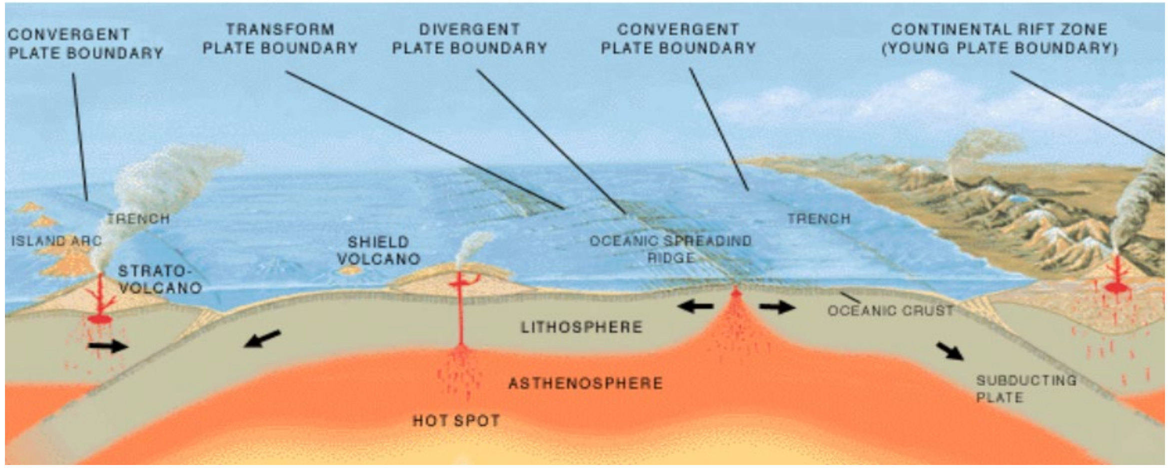


Pan-European Thermal Atlas/ Heat Roadmap Europe 20150 (source: heatroadmap.eu)

HEAT FLOW IN THE WORLD

The hottest areas are the plate boundary regions





GEOTHERMAL ENERGY SOURCES

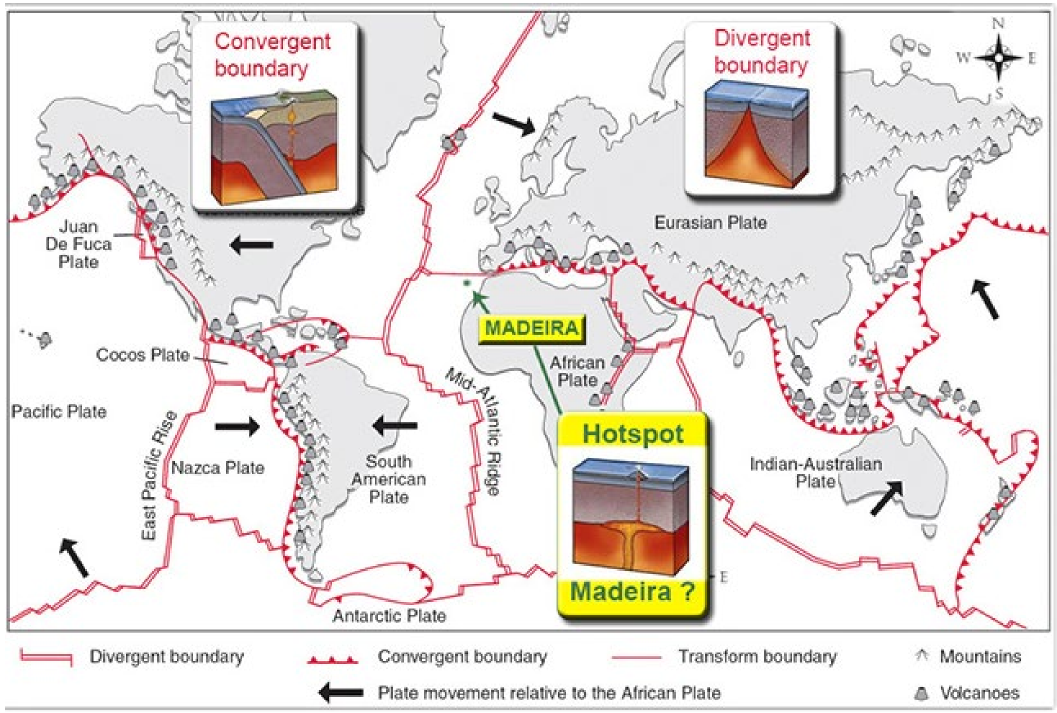
- Underground steam (temperature ≥ 100 ᵒC) → the first industrial usage (Italy)
  Where: Italy, Japan, USA, Iceland, S. Europe, etc.

- High-temperature (≥ 60 ᵒC) hydrothermal shallow sources (≤ 1 km depth)
  Where: volcanic regions: Iceland, Italy, USA, Turkey, Japan, etc.

- Low-temperature (20 - 60 ᵒC) aquifer (porous rock layers)–,
- Where: Many places, Denmark, Germany, Poland, S. Europe, etc.

- Hot rocks layers – **everywhere in the world**
  ≥ 100 ᵒC at appr. 3 km depth (deep) – North Sea (150ᵒC at 5 km)
  ≥ 200 ᵒC at appr. 5-6 km depth (ultra deep) – Finland (6km well, 2018)

- Magma – volcano and/or hot spot regions, plate boundaries
  Where: Iceland, Italy, Hawaii, Japan, USA, etc.



GEOTHERMAL ENERGY/ GEOTERMI = JORDENS VARME

USAGE / HVORDAN MAN BRUGE GEOTERMISK ENEGRI

- Well being: Thermal baths & spa ("**S**alute **P**er **A**cqua" – "Helbred fra Vand") : used since the Paleolithic, oldest China, 3rd century B.C.
- Heating –public buildings (antiquity), district heating / fjernvarme
- Pavement /Road – de-icing (Iceland);
- Agriculture – greenhouses;
- Chemical (boric acid, Italy); aluminium (Iceland) or other substances production;
- Electricity/power production – Italy , Iceland, USA, Turkey, etc.;
- Cooling, etc.

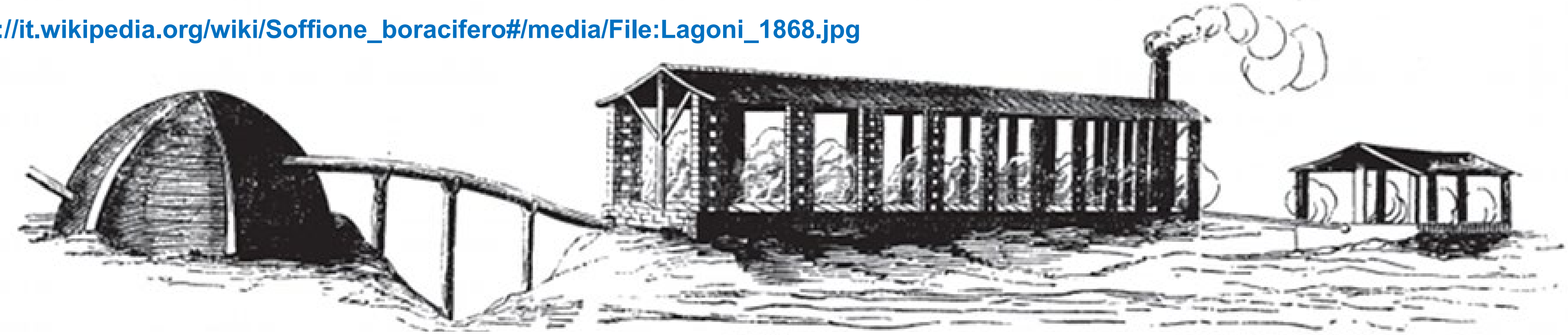
INDUSTRIAL USAGE OF GEOTHERMAL ENERGY

TOSCANA, ITALY – First in the world and the only one until 1958

- **1827** – Francesco de Larderel (France, Italy): invented the "Lagone coperto" – capturing the geothermal vapour from natural vents.
  - First Geothermal plant at Larderello (close to Pisa) to produce boric acid

Steam temperature: 202 °C
NB. Not a volcano!

https://it.wikipedia.org/wiki/Soffione_boracifero#/media/File:Lagoni_1868.jpg



- **1904** – Electricity production (5 light bulbs), Prince Piero Ginori Conti (Firenze, Italy; married to the granddaughter of de Larderel): building upon the invention of de Lardarel
- **1911** – First geothermal power plant
- **1916** - produced 2750 kW
- Today: Italy is still among the top 10 producers of geothermal electricity in the world

GEOTHERMAL ELECTRICITY PRODUCTION

- 1911 – First geothermal power plant – uses steam to rotate a turbine → generates electricity
- 1958 – New Zealand – the Waikarei station → the first flash steam technology (details follow). Problems with subsidence
- 1960 – USA – The Geysers in California
- 1967 – USSR: developed the binary cycle power plant - more details later
- 1970's (Oil crisis) – geothermal power production accelerates
- 1977 – USA – R&D 1st demo project on Deep Geothermal Systems (details later)
- 1981 – USA introduces the binary cycle power technology
- 2006 – Alaska – producing electricity form only 56 °C hot water
- 2007 – Australia – a large research funding to Enhanced/Engineered Geothermal Systems **EGS** – **a game changer**

EGS projects worldwide

- Landau-Pfalz (Germany)
- Soultz-sous-Forets (France) – produces 1.5MW
- Basel, Switzerland – terminated (suspected possible induced earthquake)
- Australia, USA, UK, Finland, Sweden, etc.

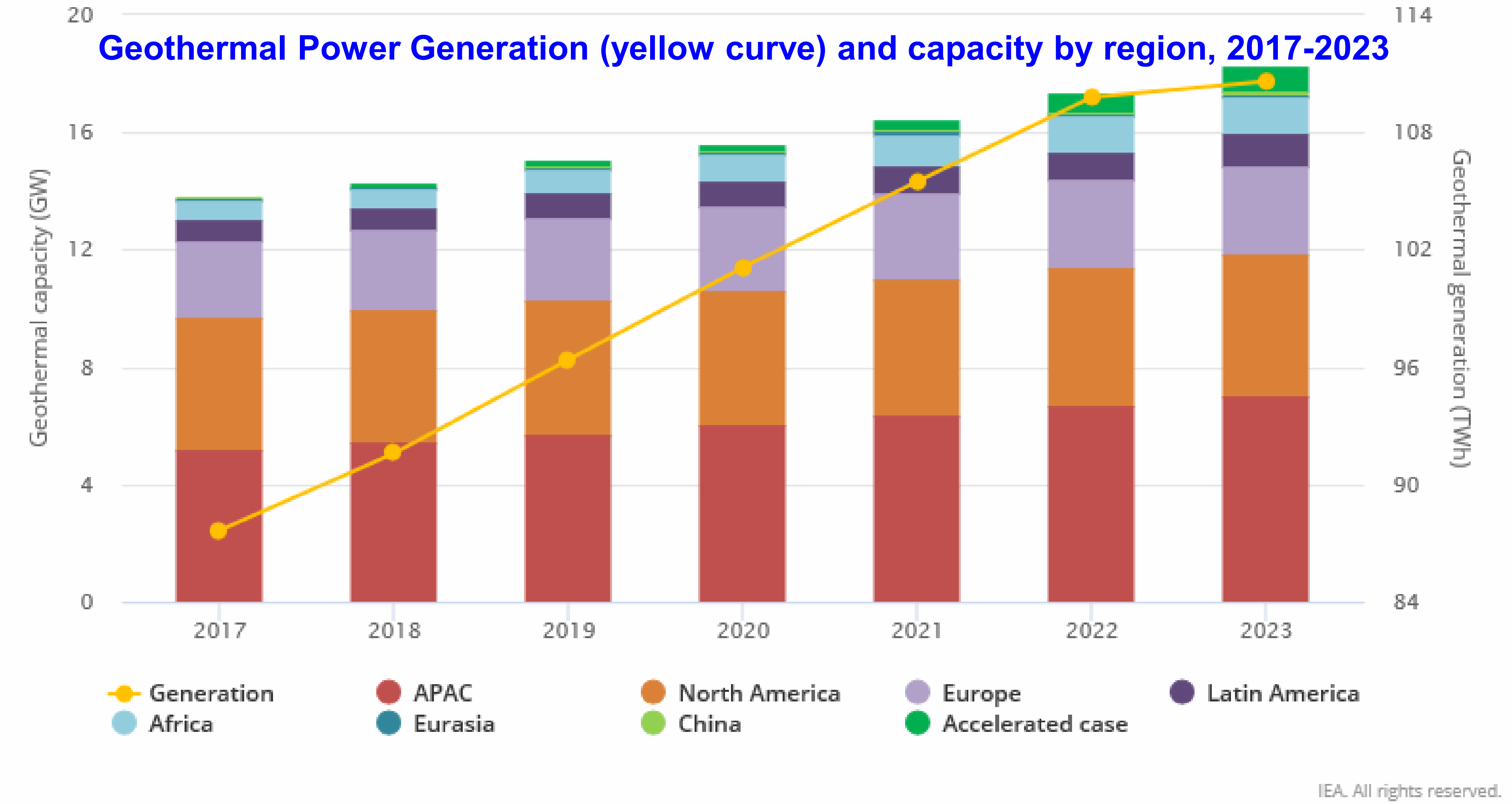
Still to improve: **Efficiency** - low 10-13% (compare to wind, solar) → constantly improving

Best in class: **Capacity factor** (For a given time period: Produced electricity/Maximum possible electricity production)

very large 74.5% (2008), demonstrated that can be up to 96%

GLOBAL GEOTHERMAL ELECTRICITY PRODUCTION

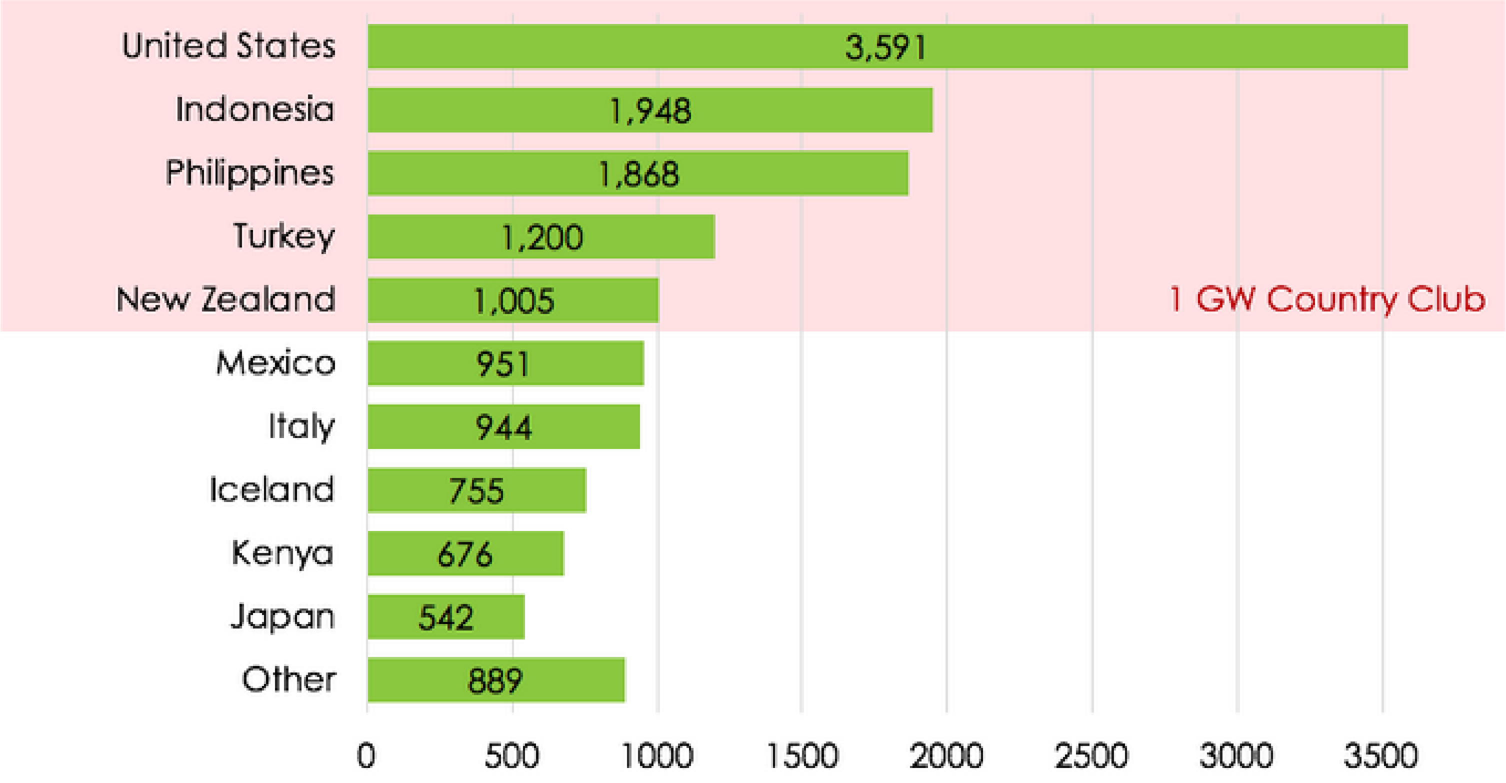
International Energy Agency (IEA)
https://www.iea.org/topics/renewables/geothermal/



INSTALLED GEOTHERMAL ELECTRICAL CAPACITY

TOP 10 GEOTERMAL COUNTRIES IN THE WORLD - 2018, Global Capacity (2018): 14,369 MW

http://www.thinkgeoenergy.com/global-geothermal-capacity-reaches-14369-mw-top-10-geothermal-countries-oct-2018/



Source: TGE Research (2018), GEA (2016), IGA (2015), JESDER (2018)

GEOTHERMAL POWER STATIONS FOR ELECTRICITY

Dry steam power station

Dry steam power stations:

- The oldest (Italy), simplest and most efficient
- Uses directly geothermal energy

Produces only steam

Needed:

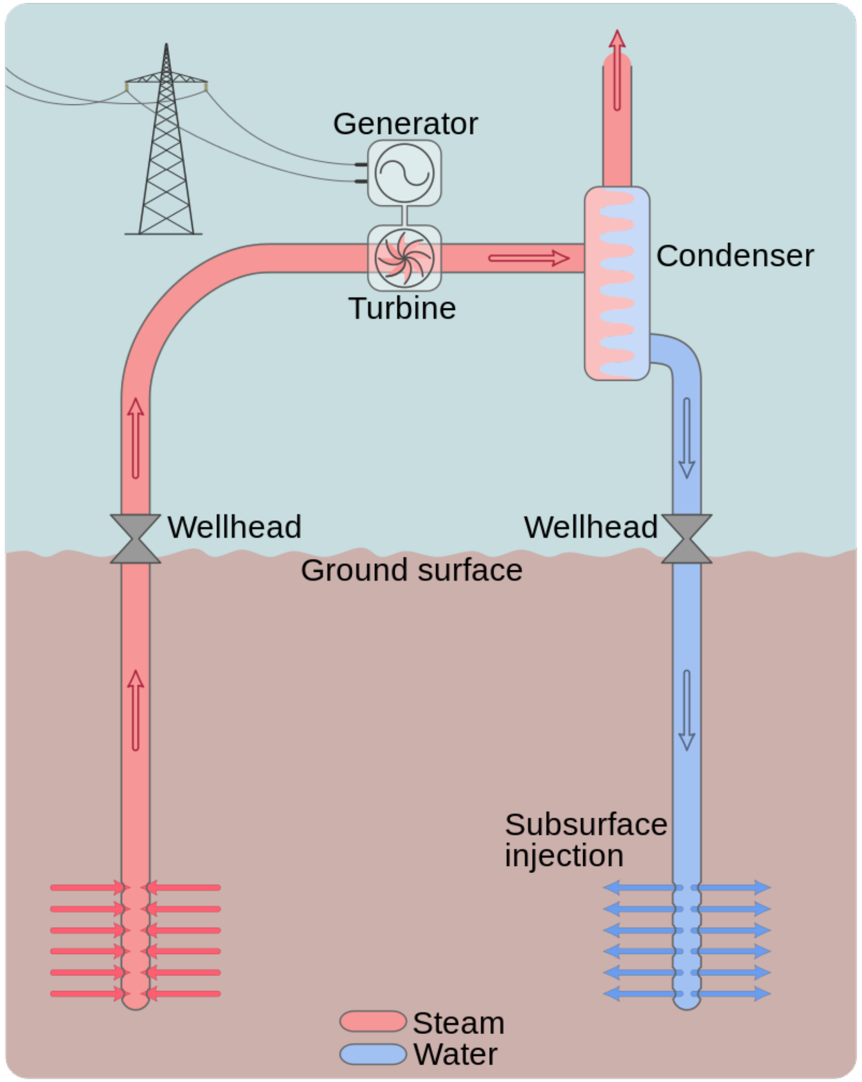
- Steam ≥ 150 °C, which requires a source of very hot water underground (> 200 °C)

Used in very limited places:

- Italy, Iceland, Japan, USA

Reservoir depletion (The Geysers, CA)

Not suitable for the most of the world



How it works:

- Well or pipes bring the steam to the turbine
- The steam turns the turbine and generates electricity
- The steam is conducted to the condenser where it cools and go back to water
- From the condenser the water can be released into a water stream/lake/pool (the Blue Laguna in Iceland) or re-injected into the subsurface by another well

GEOTHERMAL POWER STATIONS FOR ELECTRICITY

Flash steam power station

Flash steam power stations:

- The most common today

Produces hot water and turns it to steam

Needed:

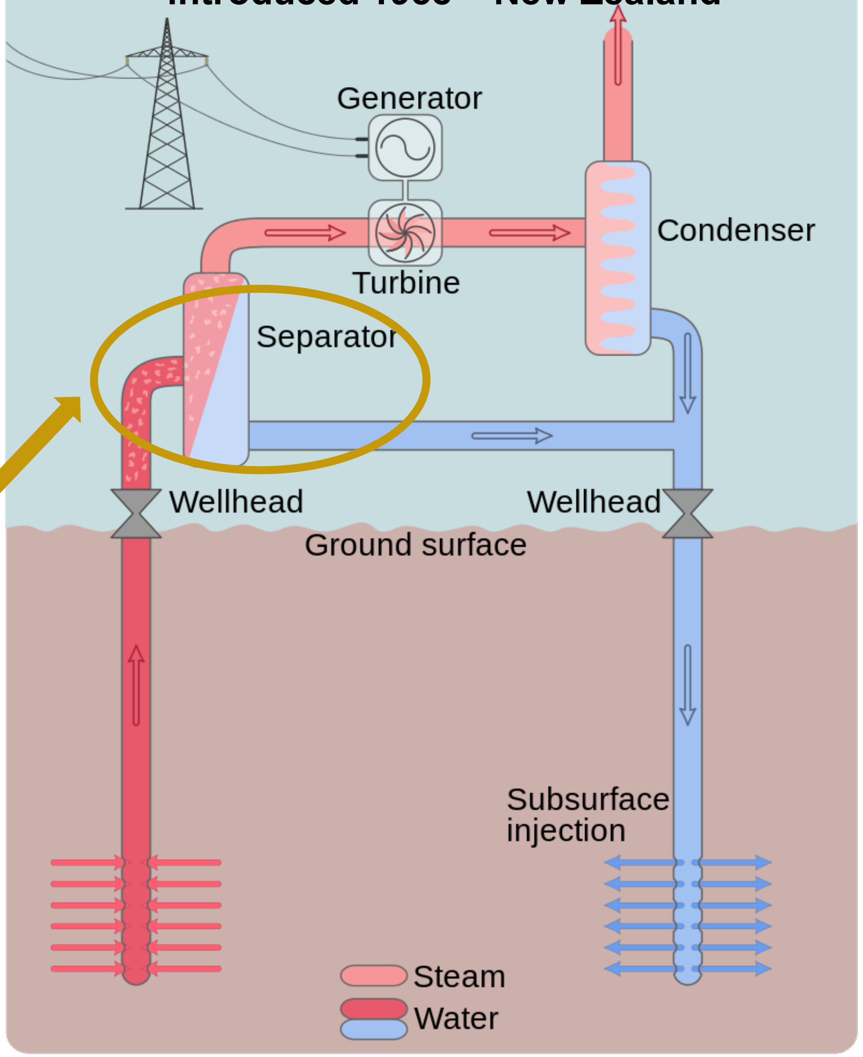
- Deep hot water reservoirs with ≥ 180 °C, high pressures

Difference with the dry steam station

Most used today

Sustainable: re-charge the reservoir

introduced 1958 – New Zealand



How it works:

- Well accessing the hot water reservoir and brings the hot water at surface
- The pressure decreases and part of the water is turned into steam
- The steam is separated by the water
- The steam turns the turbine and generates electricity
- The steam is conducted to the condenser where it cools and go back to water
- **Sustainability:** The leftover water and condensed steam may be injected back into reservoir

GEOTHERMAL POWER STATIONS FOR ELECTRICITY

Binary cycle power station

developed 1967 – USSR

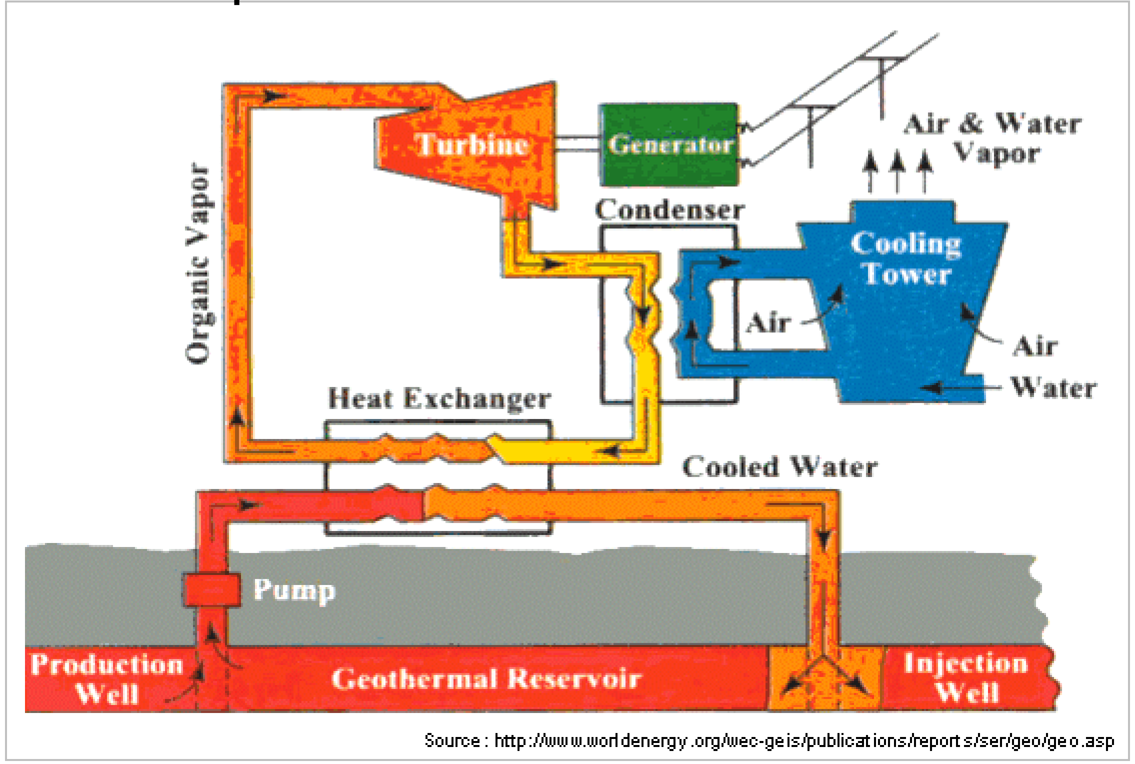
Binary cycle power stations:

- The most recent development
- Power cycle – combination of high and low temperatures

Produces hot water and transfer the heat to a secondary fluid with much lower boiling point

Needed:

- Moderately hot water with ≥ 55 ^{o}C



How it works:

- Moderately hot water is pumped to surface
- In the heat exchanger the water is in contact with a fluid with low boiling point
- The fluid vaporize and turns the turbine and generates electricity
- The vapour is conducted to the condenser where it cools and goes back to the exchanger
- The water may be injected back into reservoir or led to streams/lakes/pools

Most common station to **build** today, Can be used many places

Low efficiency: 10-13%

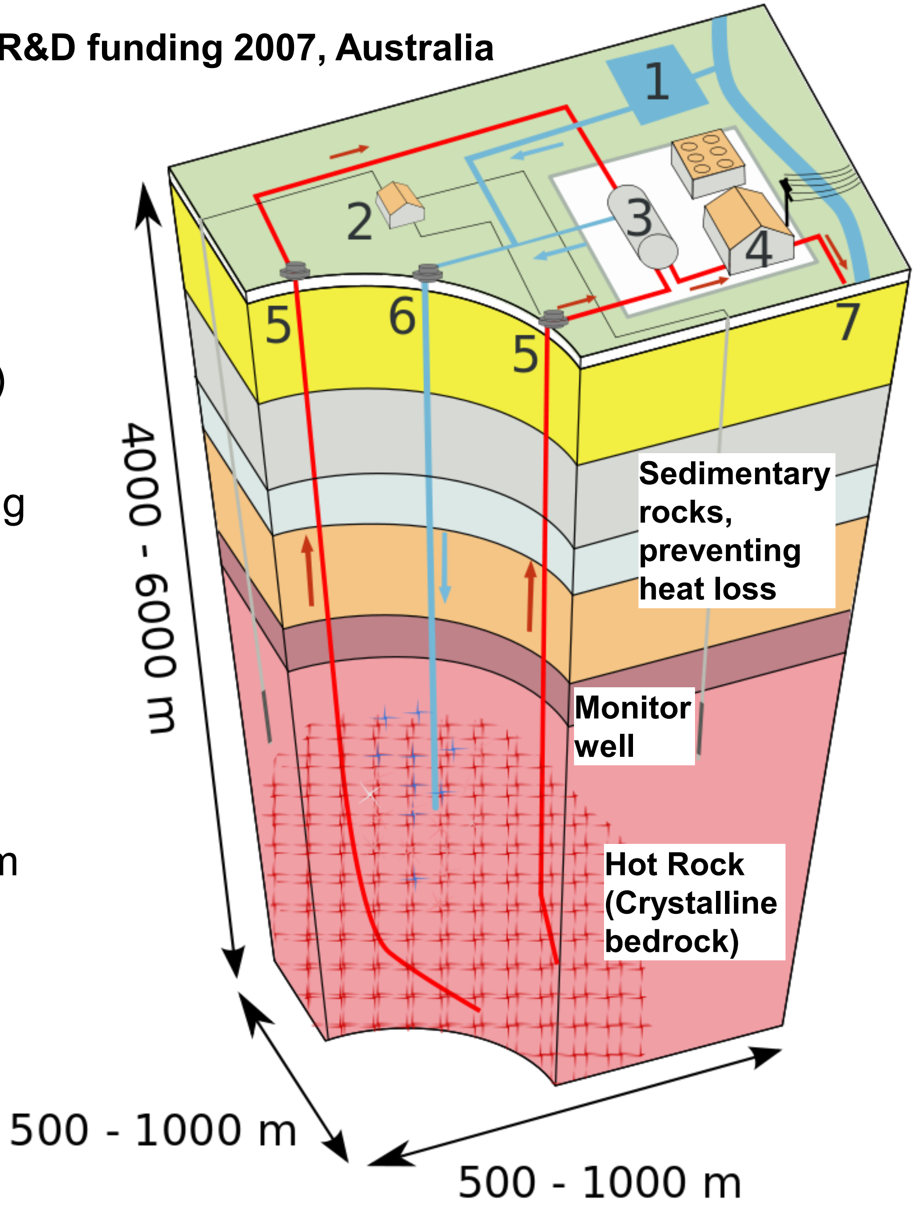
ENHANCED (or ENGINEERED) GEOTHERMAL SYSTEM (EGS)

1. Cold water reservoir
2. Pumps
3. Heat Exchanger
4. Turbine
5. Production well (producer)
6. Injecting well (injector)
7. Hot water to district heating

Where/ When it is useful:

- No shallow source of high temperature water or steam
- Low water pressure
- Dry, impermeable rocks

R&D funding 2007, Australia



Advantages:

- Can be used everywhere in the world
- Does not need hydrothermal or steam resoures
- Provides inexhaustible source of hot water
- Very low CO_2 emissions

Disadvantages

- Cost of drilling
- Cost of maintenance – pumps, tubing
- Water chemistry – corrosion, scaling, erosion
- Induced seismicity

ELECTRICITY PRODUCTION BY DEEP GEOTHERMAL

Further technology development:

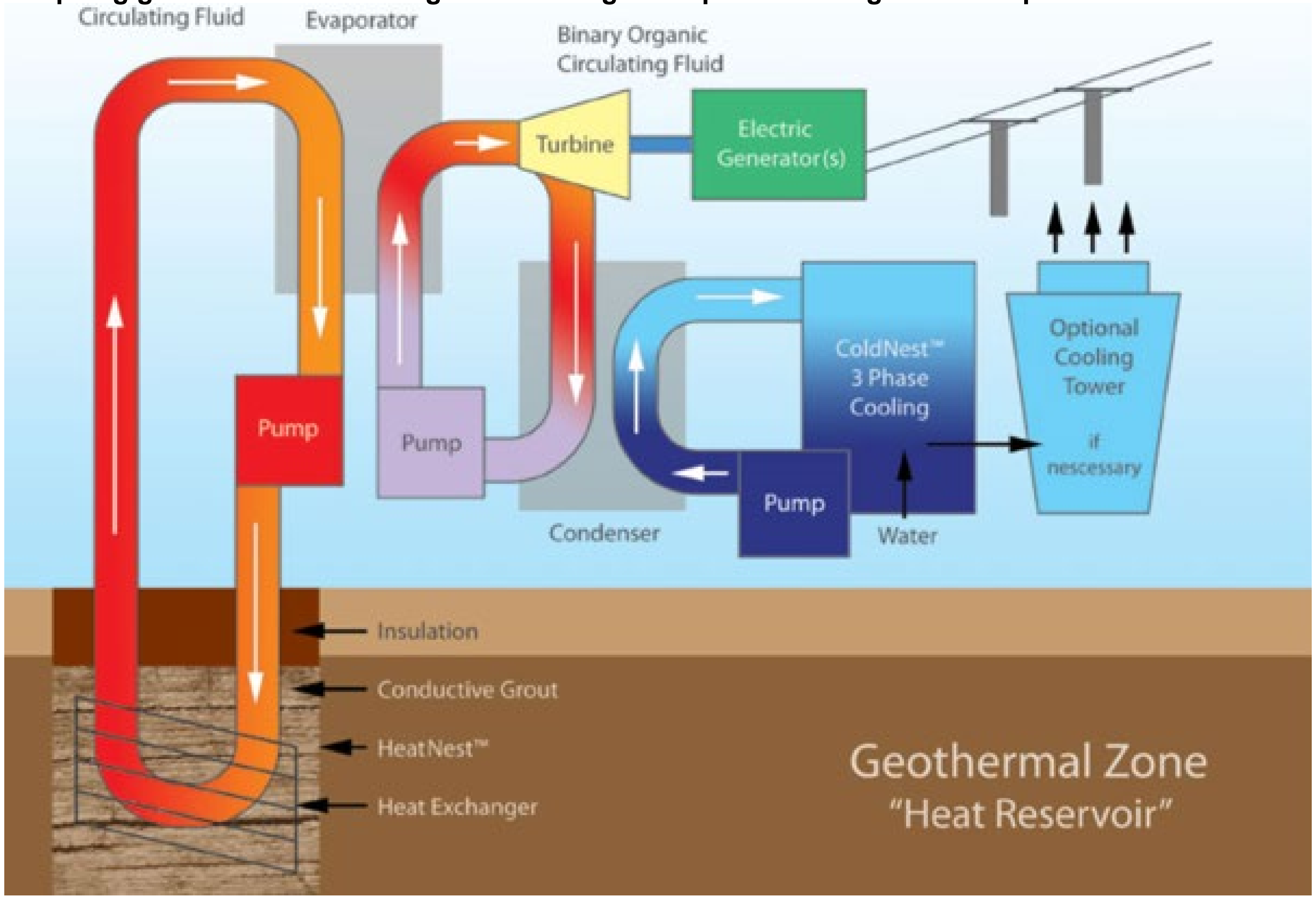
MOVING HEAT INSTEAD OF WATER

A nest of horizontal wells underground

The heat exchanger is underground

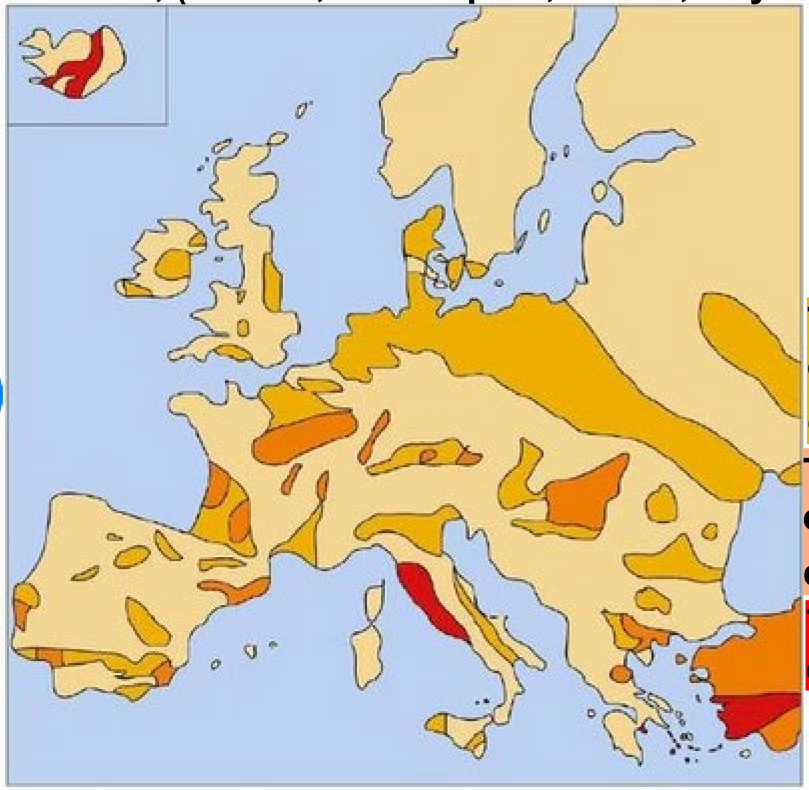
Combing EGS with Binary cycle (Duratherm fluid) – no fracking

https://gigaom.com/2011/05/26/gtherm-cutting-cost-quakes-from-geothermal-power/



POTENTIAL FOR GEOTHERMAL USE IN EUROPE

Modified, (Grosse, Christopher, Stefan, Geyer & Robbi, 2017)



T > 20 °C
Shallow
ATES
EGS

T: 20-50 °C – electricity, district heating

T: 50-120 °C electricity, district heating

T > 120 °C - electricity

T [°C]	Depth [m]	Usage	Denmark
20-50	Shallow 300 – 1500	Store and produce heat ATES, HT-ATES* HTC: Heat and Cold Storage	Yes, ~1000 ATES (hospitals, hotels) Bispebjerg Hospital - 2019
50-120	Deep 1500-4000	House heating, greenhouses	Yes, 3 installations Thisted Amager Søndeborg
> 120	Ultra-deep 4000-8000, EGS**	Industry (steam), Electricity,	No (for the moment)

HT-ATES = High Temperature Aquifer Thermal Energy Storage

EGS = Enhanced or Engineered Geothermal Systems

ECONOMICS AND ENVIRONMENTAL IMPACT

Major economics issue – the need to drill wells (dublets, triplets)

Depending on how deep the well is – the cost can be up to 10 Million USD

- District heating in Bavaria: estimated drilling cost 1 Million Euro per MW

Always risks – do not find a suitable reservoir

The cost of pumps, pipes, maintenance

Depending on water chemistry – erosion, scaling, corrosion

When all these costs are paid – **the cheapest heating (Thisted)**

Geothermal power plants

- **Use much less energy and fresh water than coal, oil & gas, nuclear**
- **Emit MUCH less CO_2**
- **Do not need batteries to store excessive energy**

Some environmental issues

- Drilling
- Underground gasses and fluids at surface
  - H_2S, sulphur, methane, ammonia, CO_2
  - traces of mercury, arsenic, boron, antimony
- When pumps are used – need for energy from polluting sources
- Reservoir depletion – alternation of natural resources
- Subsidence – New Zealand etc.
- In case of EGS – possible induced seismicity (Basel, Switzerland)

When we know the risks – solutions/alternatives are (or can be) found:

- Better/cheaper drilling methods;
- Filters/utilization of the underground gasses and fluids - > **The Italians are dealing with this since 1830**
- More efficient pumps
- Re-injection
- Etc., etc., etc.

EXAMPLE: GEOTHERMAL IN ICELAND

- 200 volcanos,
- 600 hot springs
- Started to use geothermal in 1907,
- Very intensively since the 1970's (the oil crisis)
- Combined potential ~ 10-13 TWh/y (2003)

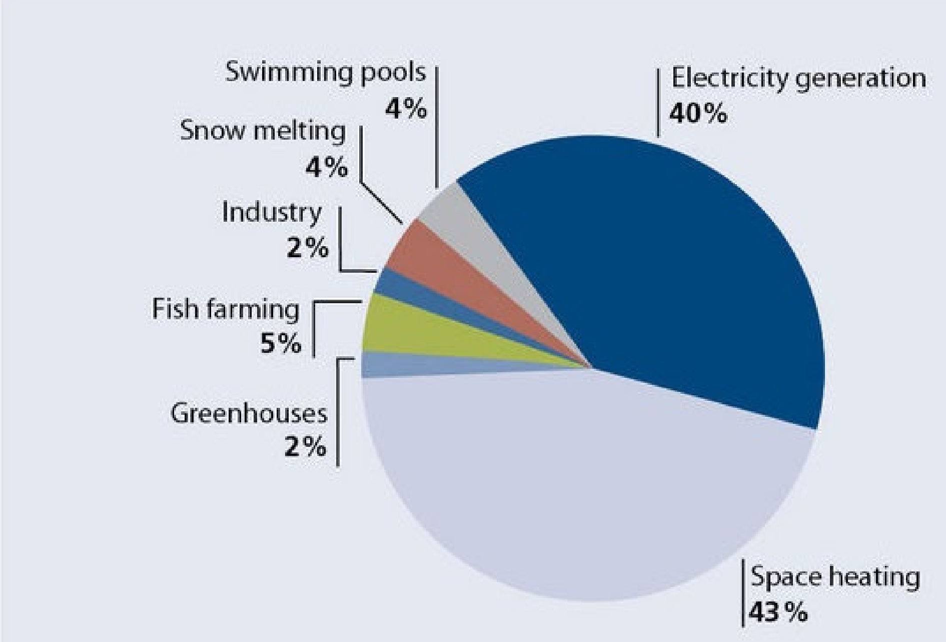
In total (incl. hydropower) 99.96% renewable energy supply

7 major geothermal plants

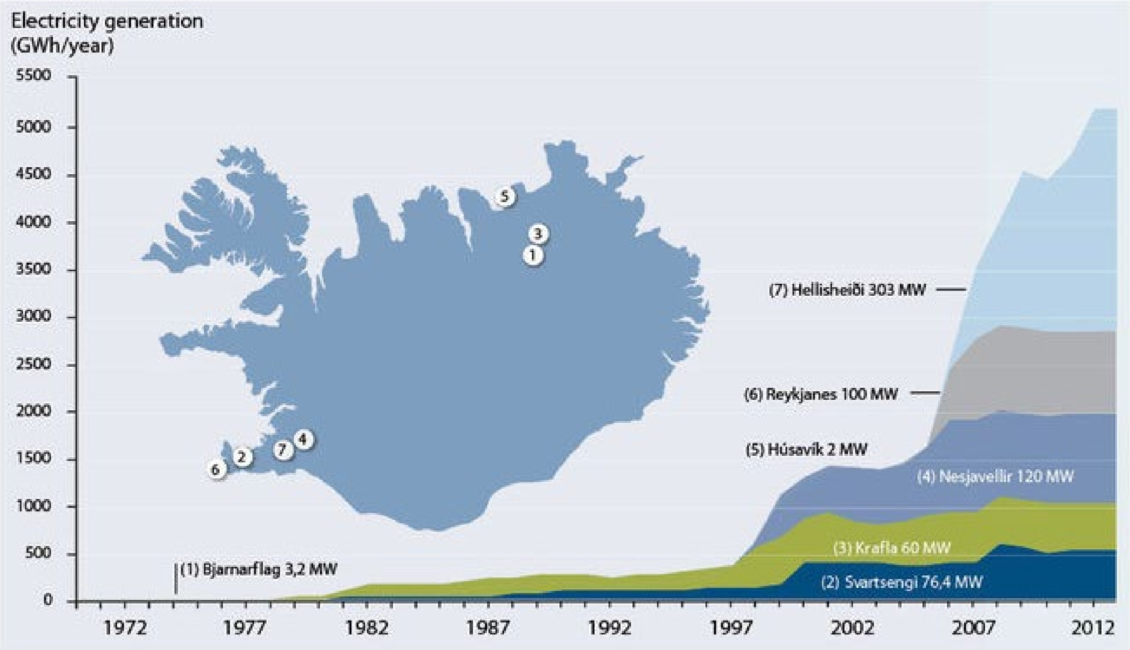
- Total production 5245 GWh (2013)
- 25-29% of the electricity supply
- 66% of the housing heating

Utilisation of geothermal energy 2013

https://nea.is/geothermal/electricity-generation/

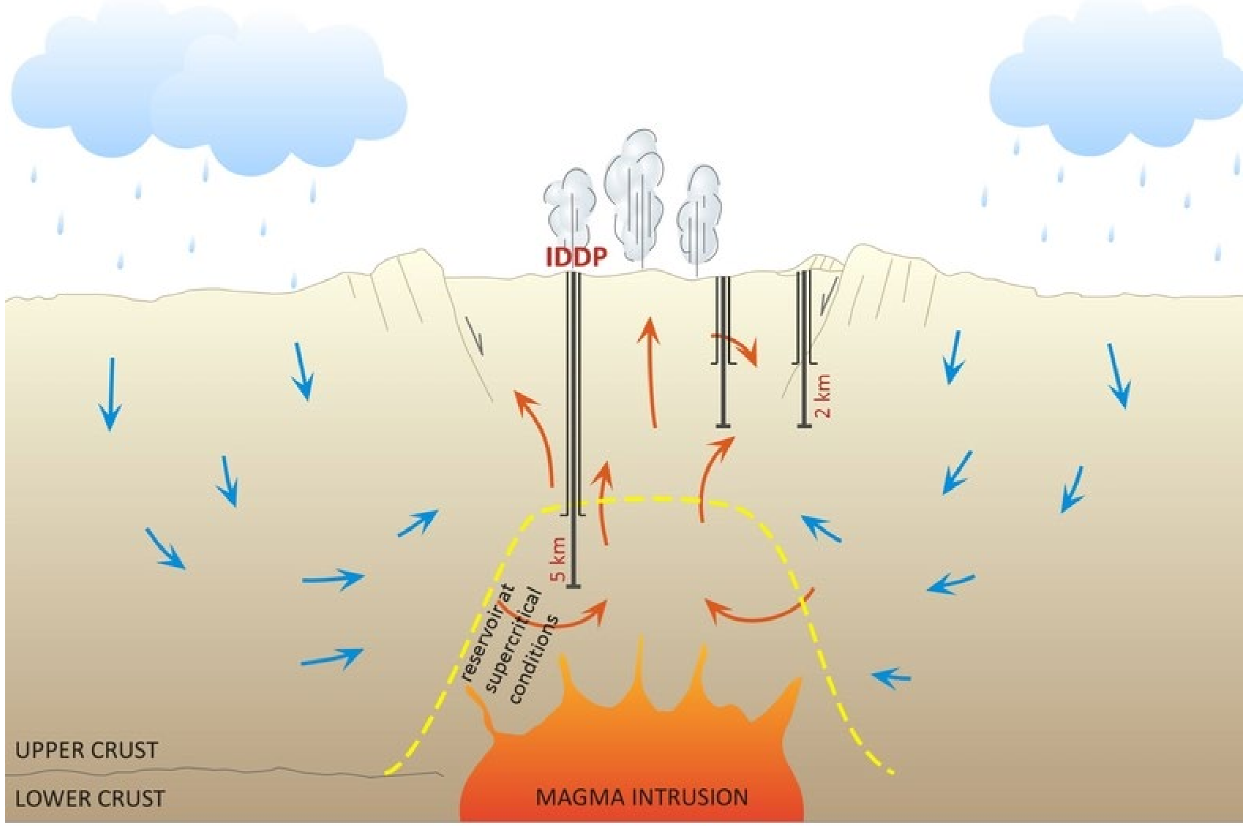


Generation of electricity – geothermal energy



The Iceland Deep Drilling Project (IDDP)

https://nea.is/geothermal/the-iceland-deep-drilling-project



IDDP well

Long-term study of high-temperature hydrothermal systems (HTHS) to test if deep geothermal fluids can improve economics of geothermal power production

Temperatures ~450-600 ^{o}C at 5 km depth

Geothermal well at 2.5 km ~ 5MWe (2003)

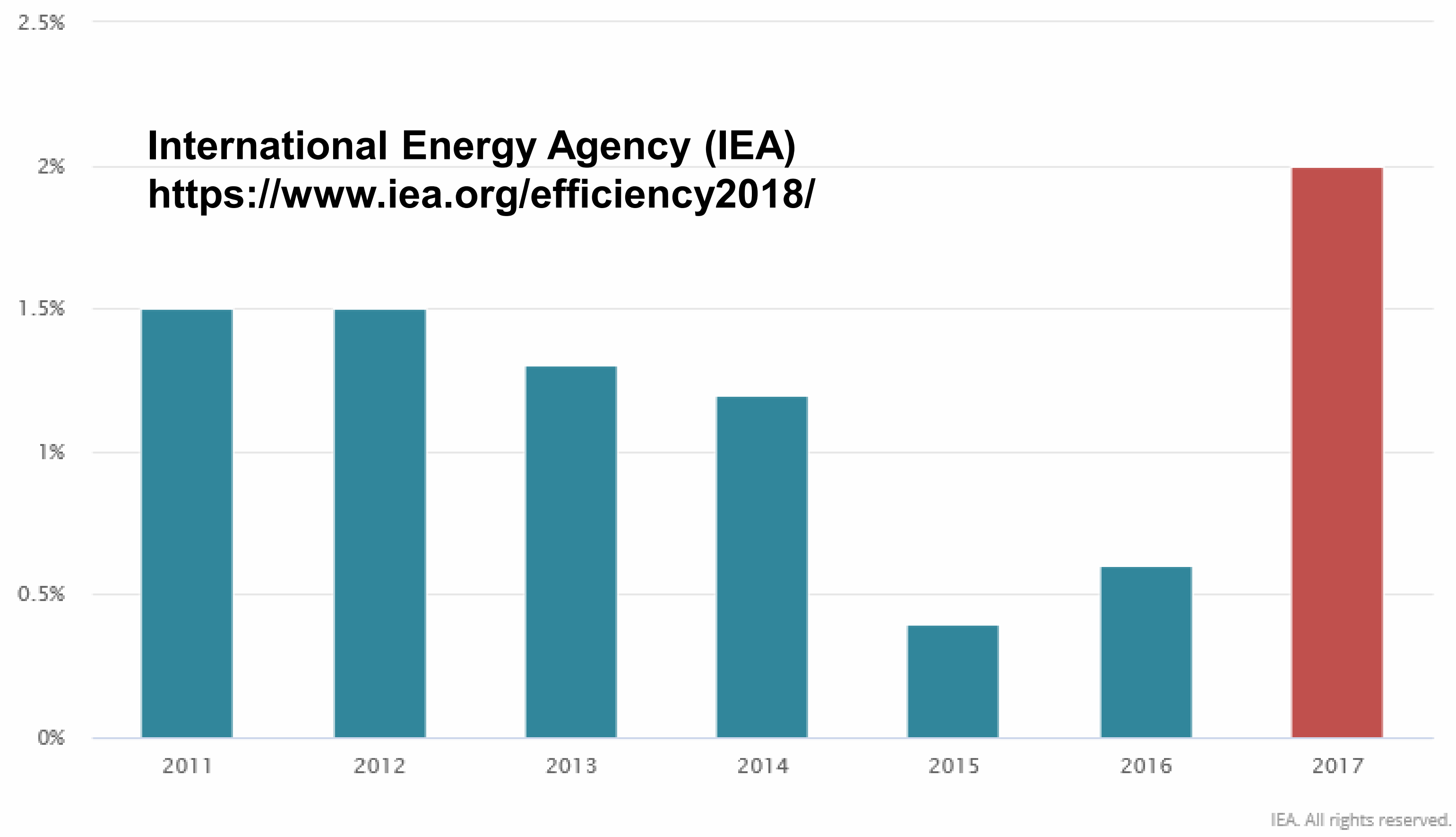
Why it is needed:

- Energy demand is increasing
- Cost efficiency
- Environmental impact of present day utilization of hydro-power & geothermal fields

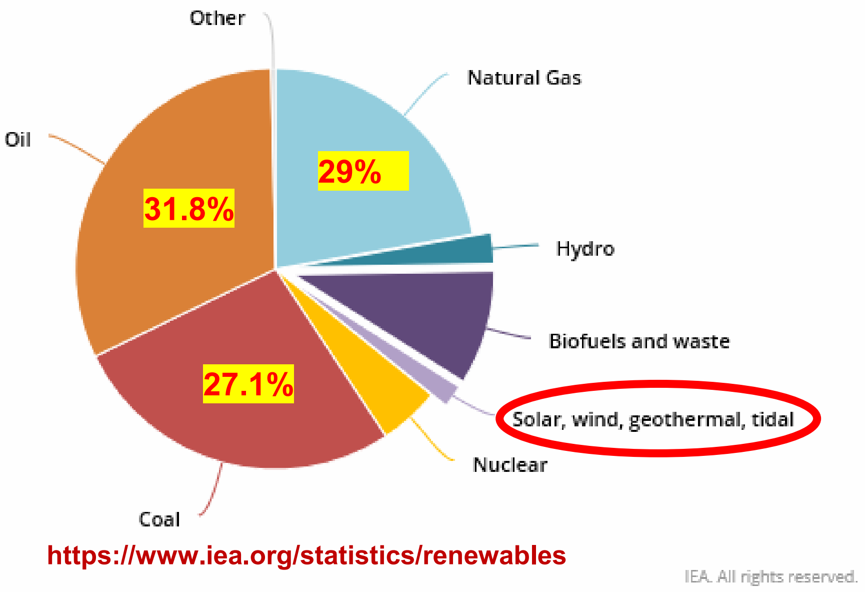
GLOBAL ENERGY DEMAND AND SUPPLY

Growth in primary energy demand 2011-2017

International Energy Agency (IEA)
https://www.iea.org/efficiency2018/



World's Total Primary Energy Supply (TPES) by source of energy in 2017



https://www.iea.org/statistics/renewables

2017: TPES = 13 972 Mtoe (Mega Ton Oil Equivalent)

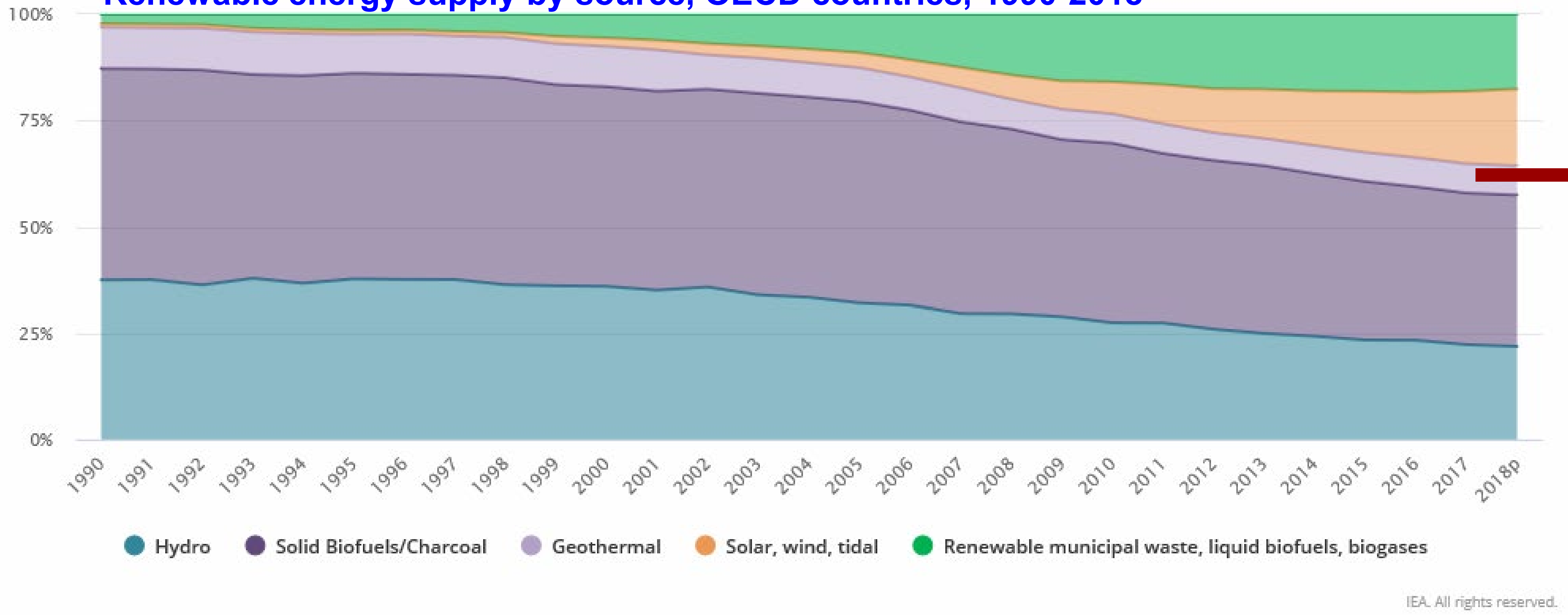
Renewables (hydro, biofuels & waste, solar, wind, geothermal and tidal) in total: 13.5%

Huge potential

RENEWABLE ENERGY

International Energy Agency (IEA)
https://www.iea.org/staistics/renewables

Renewable energy supply by source, OECD countries, 1990-2018



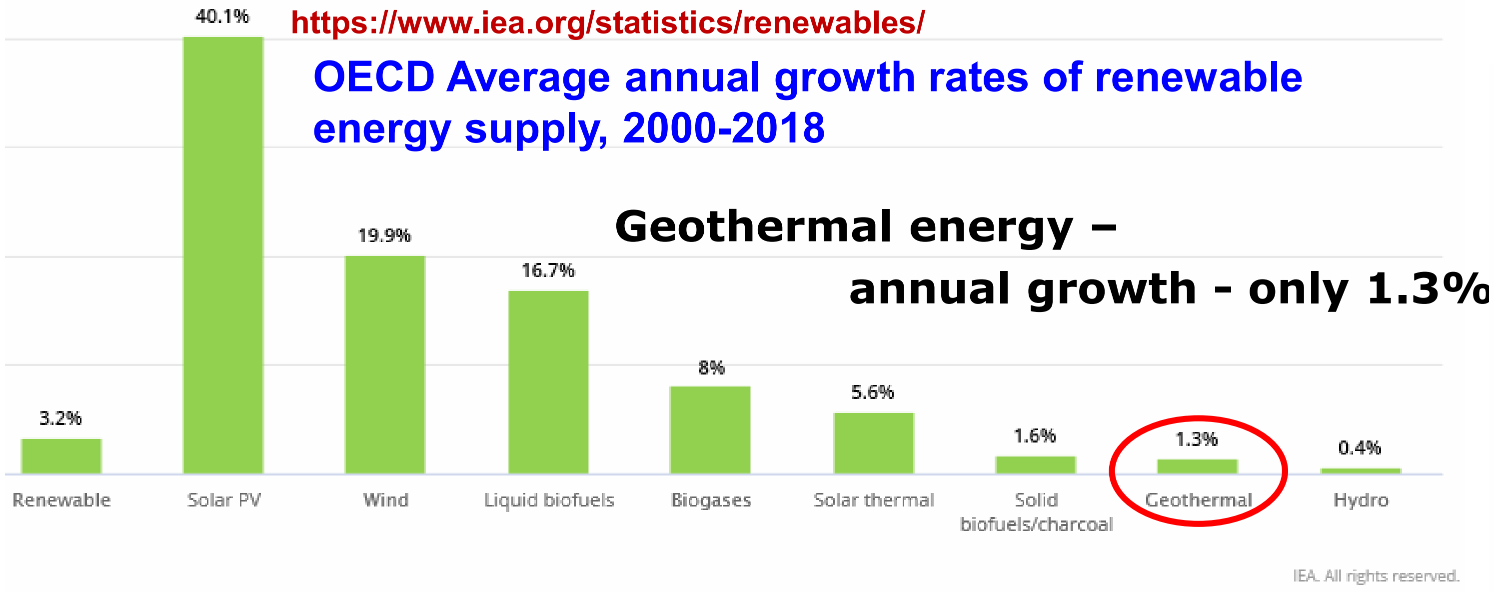
Geothermal –
very "modest" supply

GLOBAL RENEWABLE ENERGY

https://www.iea.org/statistics/renewables/

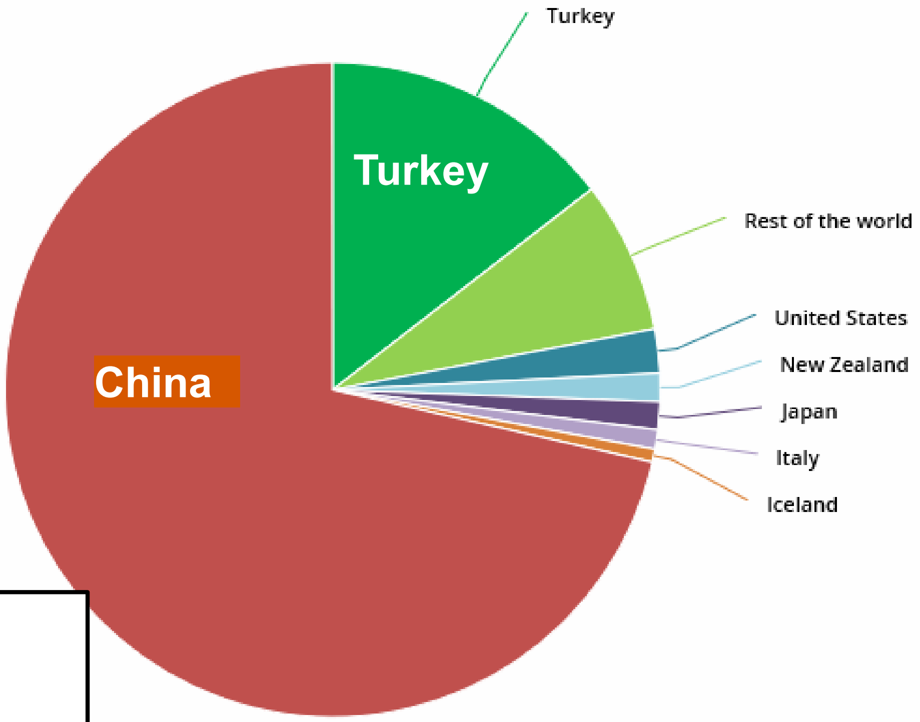
OECD Average annual growth rates of renewable energy supply, 2000-2018

Geothermal energy – annual growth - only 1.3%



Use of geothermal energy, 2016

https://www.iea.org/topics/renewables/geothermal/



Why so little geothermal?

Geology/Technical
- Availability Geothermal
- Risk
- Depth
- Energy efficiency
- Equipment
- Etc.

Economics/Cost
- Drilling & related risks
- Maintenance
- Consumer willingness/possibility to pay
- Competing technologies
- Etc.

Organizational/Legislation
- Who is doing what?
- Responsibility
- Legislation
- State support (taxes, incentives)
- **Public opinion: NIMBY – Not In My Back Yard)**

EU: in 2017, 9 new geothermal plants put in operation
France, Italy and the Netherlands
Mainly – district heating (fjernvarme)

Example: Turkey – the state is covering the drilling cost and risk – huge increase in geothermal projects (more than 5 times in 5 years)

GEOTHERMAL ENERGY IN DENMARK – District heating/fjernvarme

64% of all households in Denmark use district heating (fjernvarme) –huge potential for geothermal energy usage

GEUS

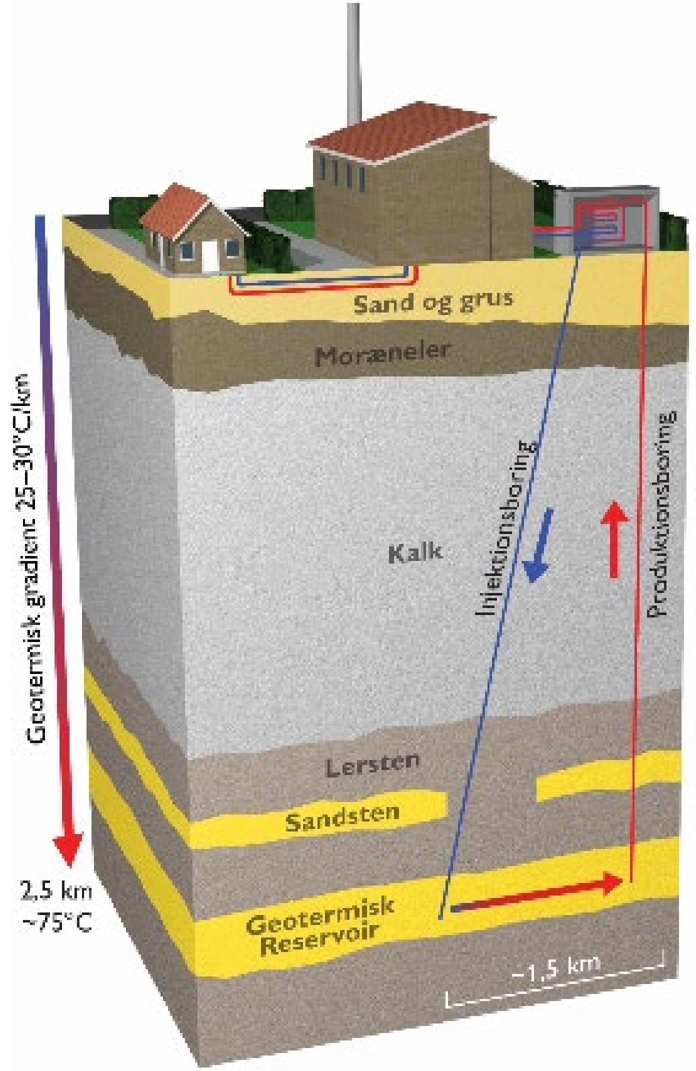
Geothemisk window: 800 – 3000 m

Geologiske "krav":

- Sandstone – permeable (Gassum)
- Thickness > 25 m
- Good lateral permeability and conductivity

Barrierer:

- Geologiske/tekniske
- Økonomiske
- Organizatoriske/lovgivning



ATES

jordvarme (ikke geotermi)

Hot geothermal water can be transported at approximately max 2 km from the facility – too much heat losses on the way

Deep geothermal wells

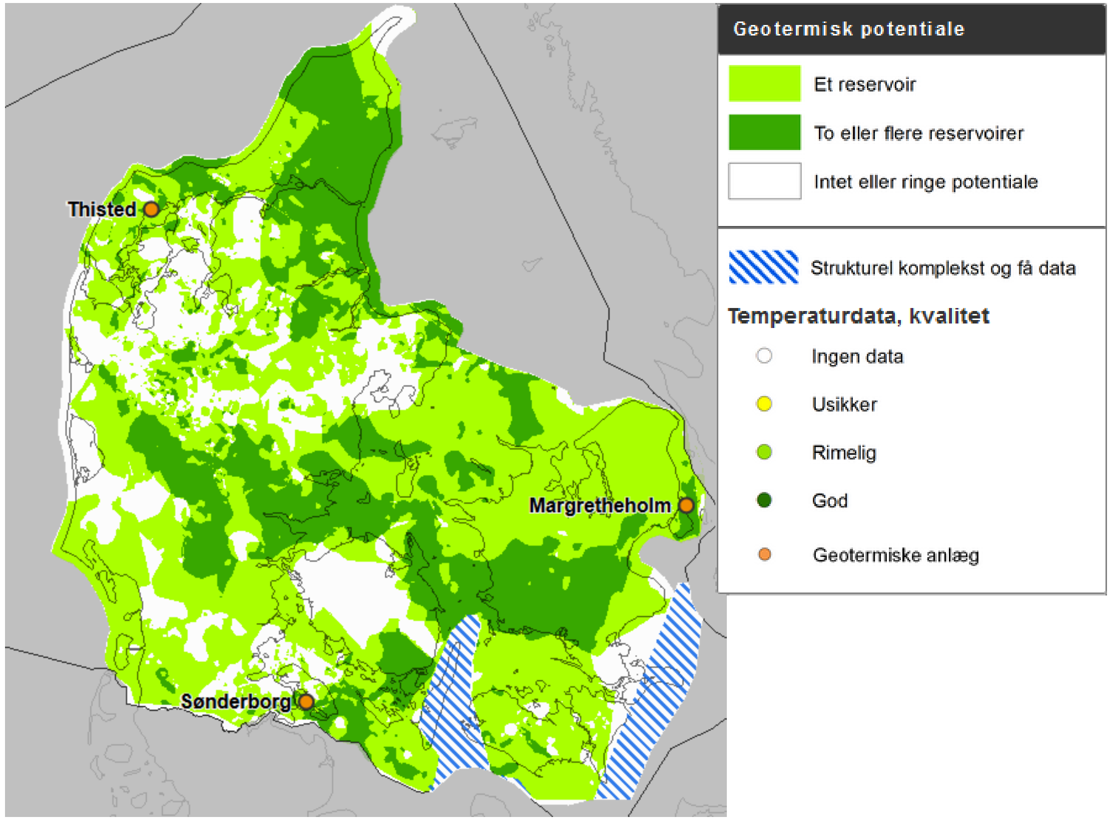
Only hot water

No electricity production

GEOTHERMAL ENERGY IN DENMARK

64% of all households in Denmark use district heating (fjernvarme) –huge potential for geothermal energy usage

http://data.geus.dk/geoterm/



Ca. 1000 ATES Anlæg I Danmark

- Størrest – Bispebejrg Hospital, Mart 2019

- Tre fjernvarme anlæg med geotermi
  - Thisted – 1984, 45 ^{o}C, 1200 m: 2000 husstandes årlig varmeforburg
  - Margretheholm (Amager) – 2005 (pt lukket), 73 ^{o}C, 2600 m, ca. 4600 husstandes årlig varmeforburg
  - Søndeborg – 2013, 48 ^{o}C, 1200 m, 2400 husstandes årlig varmeforburg

https://www.geus.dk/energi/geotermi-og-jordvarme/

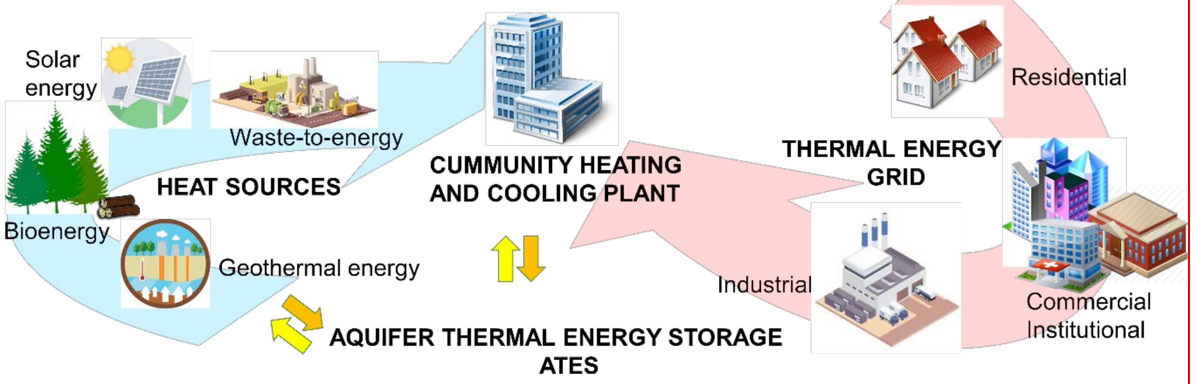
GEOTHERMAL ENERGY IN DENMARK

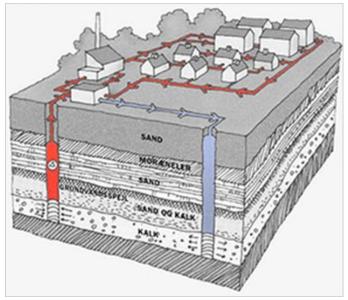
Goals:

- Reduce CO_2 by 70%,
- Reduce fossil fuels,
- Fossil free by 2050,
- etc. etc. etc.

The energy systems of the future: a mix of various types of energy: solar, wind, geothermal etc.

Laura Paci et al., 2017: Energy Mix





- Aquifer → medium for the temporary storage of heat or cold.
- An aquifer is a saturated and permeable underground layer (sand, gravel or limestone).
- Thermal energy is transferred by extracting and re-injecting groundwater from the aquifer using wells.
- Possible heating temperature range 40 - 150°C.

NEED FOR MORE RESEARCH!

- **Improve energy efficiency**
- **Risk Mitigation,**
- **New and/or cheaper drilling methods,**
- **New geological mapping (existing– aimed at the O&G industry),**
- **New emerging technologies to address corrosion, erosion, scaling**
- **etc.**

GEOTHERMAL ENERGY SUMMARY

THERE IS HUGE POTENTIAL IN THE USE OF GEOTHERMAL ENERGY

IT MUST BE PART OF THE ENERGY MIX OF THE FUTURE

It is most suitable for:

- **Heating/cooling of buildings and other infrastructure - DENMARK**
- **Agriculture – green houses**
- **Recreation/well being**
- **Electricity production**
- **Industry – chemicals/aluminium etc. production**

ADVANTAGES (among many):

- Stable and reliable – 24/7
- In principle – inexhaustible
- Small/discrete installations
- No storage need
- Low CO_2 emissions
- Relatively cheap (main cost – drilling)
- Sustainable
- No use of fuels

DISADVANTAGES	POSSIBLE SOLUTIONS
Not everywhere is easy to access it – North Europe / Denmark	ATES/EGS, new developments
Drilling – cost, risk, pollution	State Investment (examples: wind energy, Turkey,) Improving technology
Cannot be transported at long distance – district heating – max 1.5 km	Improving technology, new insulating materials
Deep underground chemicals and gasses at surface Corrosion, scaling, water chemistry	Already in place: Filters, capture and utilization (Italy) New materials
Reservoir depletion → Subsidence	Improved reservoir management – lessons from the O&G sector
Low efficiency	New research and technology solutions