university of groningen
faculty of science and engineering
energy and sustainability research institute groningen

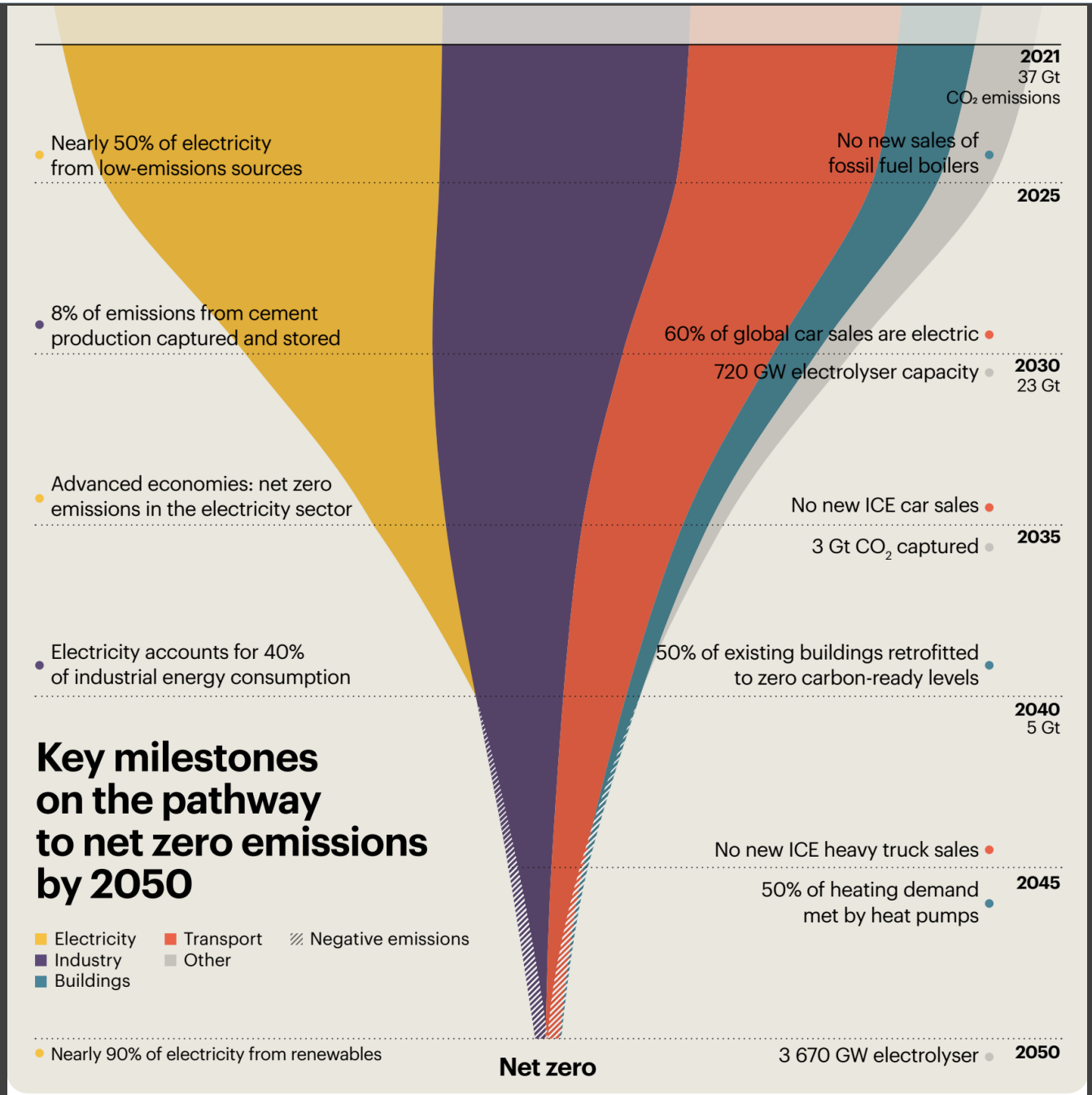
The role of the subsurface in the energy transition

Prof Dr Johannes M. Miocic

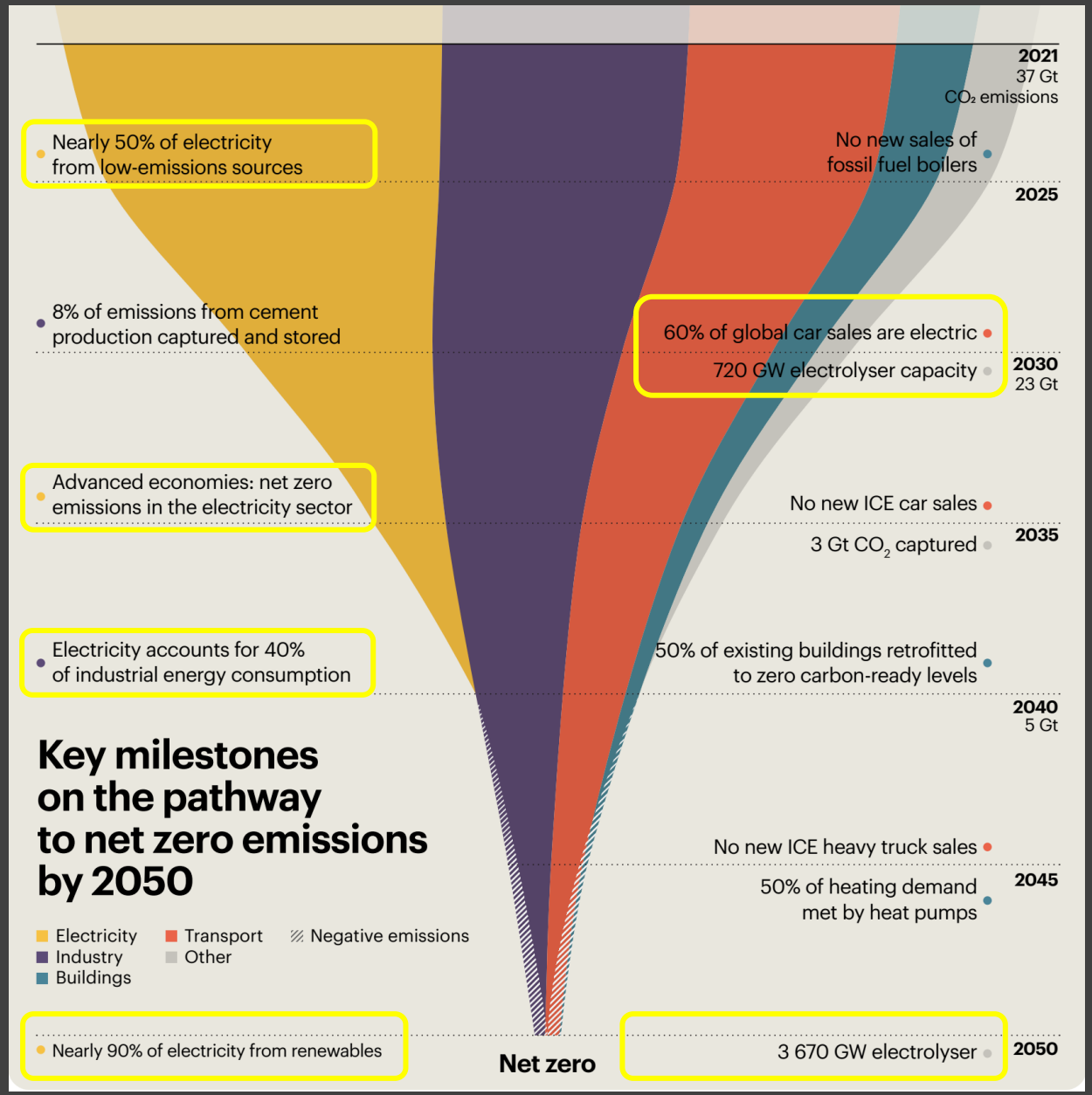


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The Energy Transition

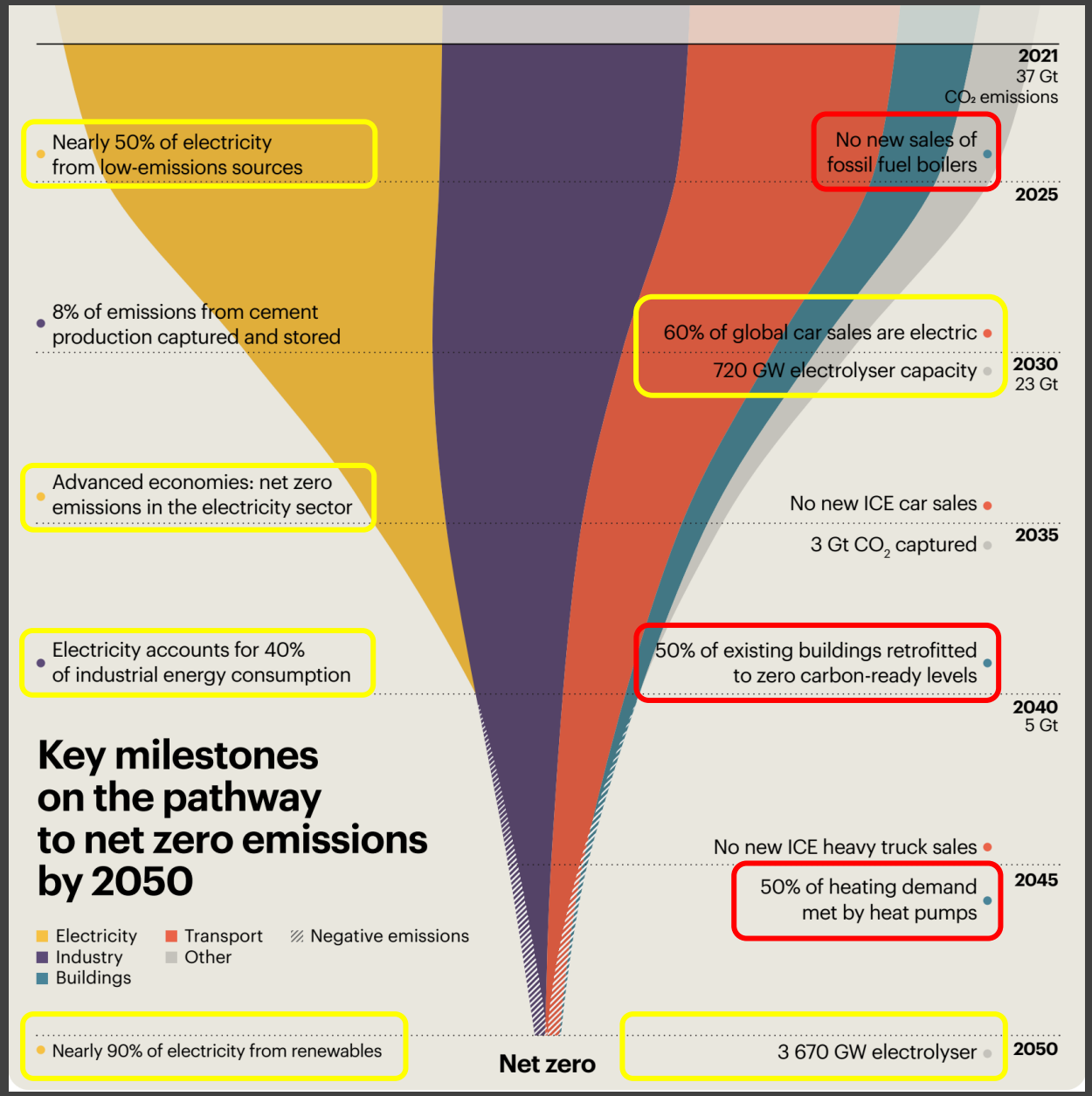


IEA, 2022



Electricity

IEA, 2022

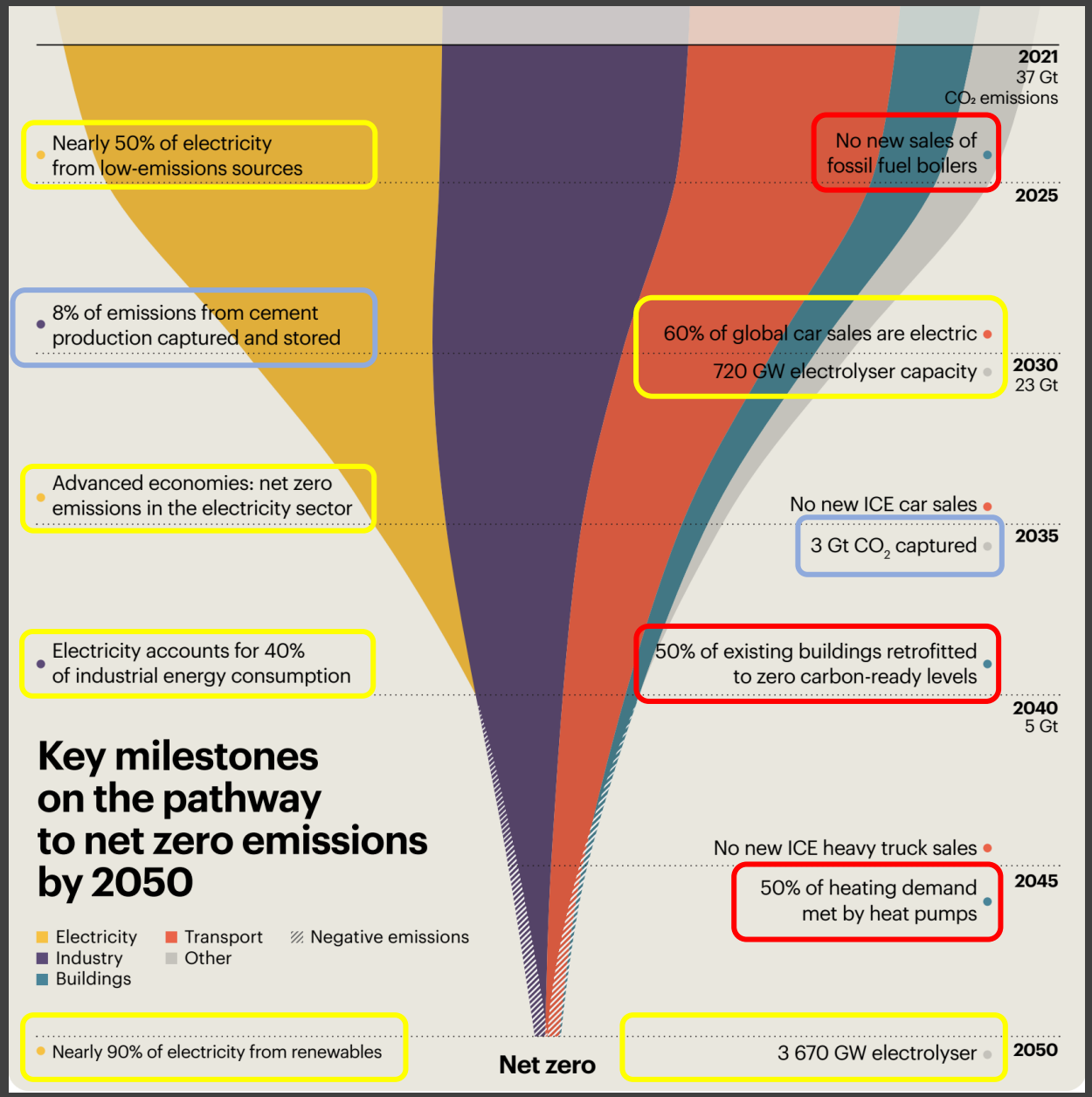


Electricity

→

Heat

IEA, 2022



Electricity

Heat

Carbon Capture and Storage

IEA, 2022

Electricity

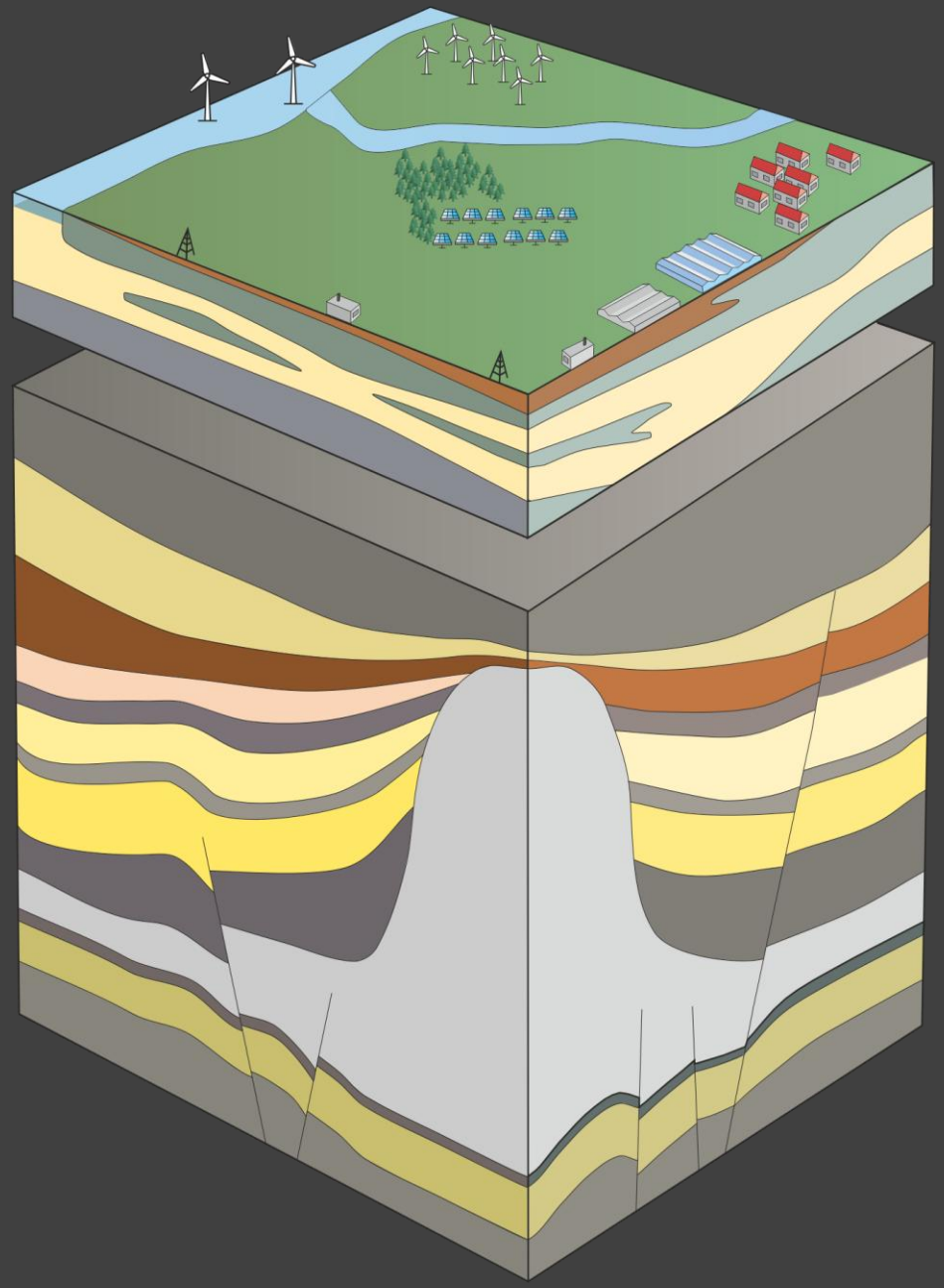
Heat

?

Carbon Capture and Storage



Electricity ⟷



Is there electricity production linked to the subsurface in the Netherlands?

Yes - only non-renewable

No

Yes - also renewable

Start the presentation to see live content. For screen share software, share the entire screen. Get help at **pollev.com/app**

Is there electricity production linked to the subsurface in the Netherlands?

Yes - only non-renewable

0%

No

0%

Yes - also renewable

0%

Start the presentation to see live content. For screen share software, share the entire screen. Get help at **pollev.com/app**

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0%

No

0%

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0%

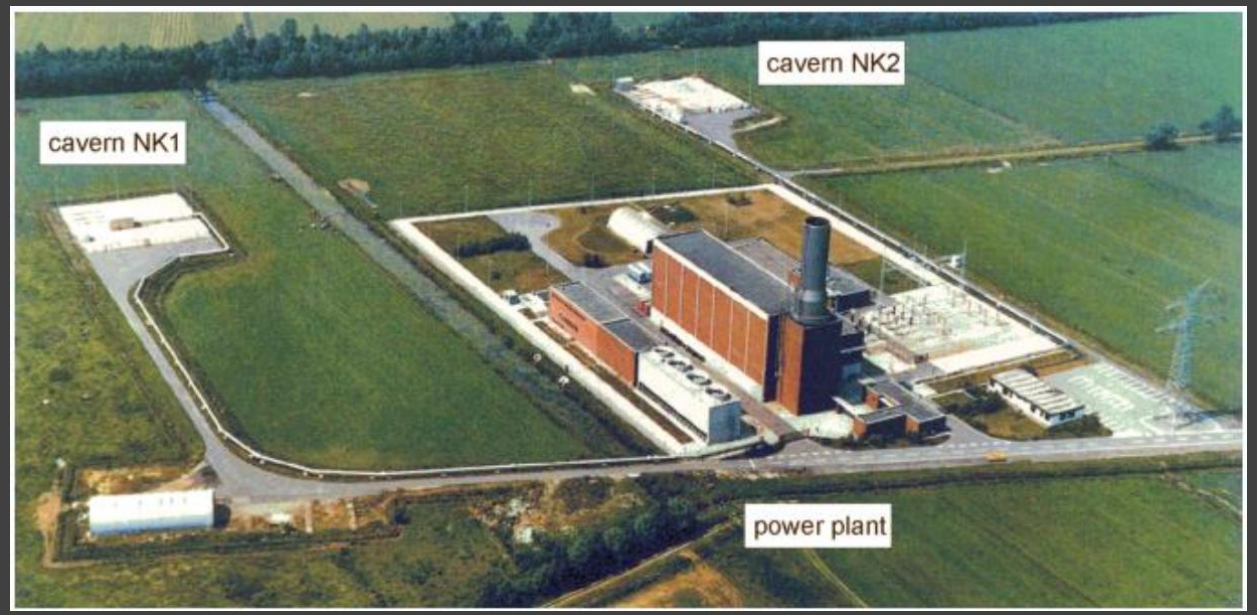
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Electricity

Production

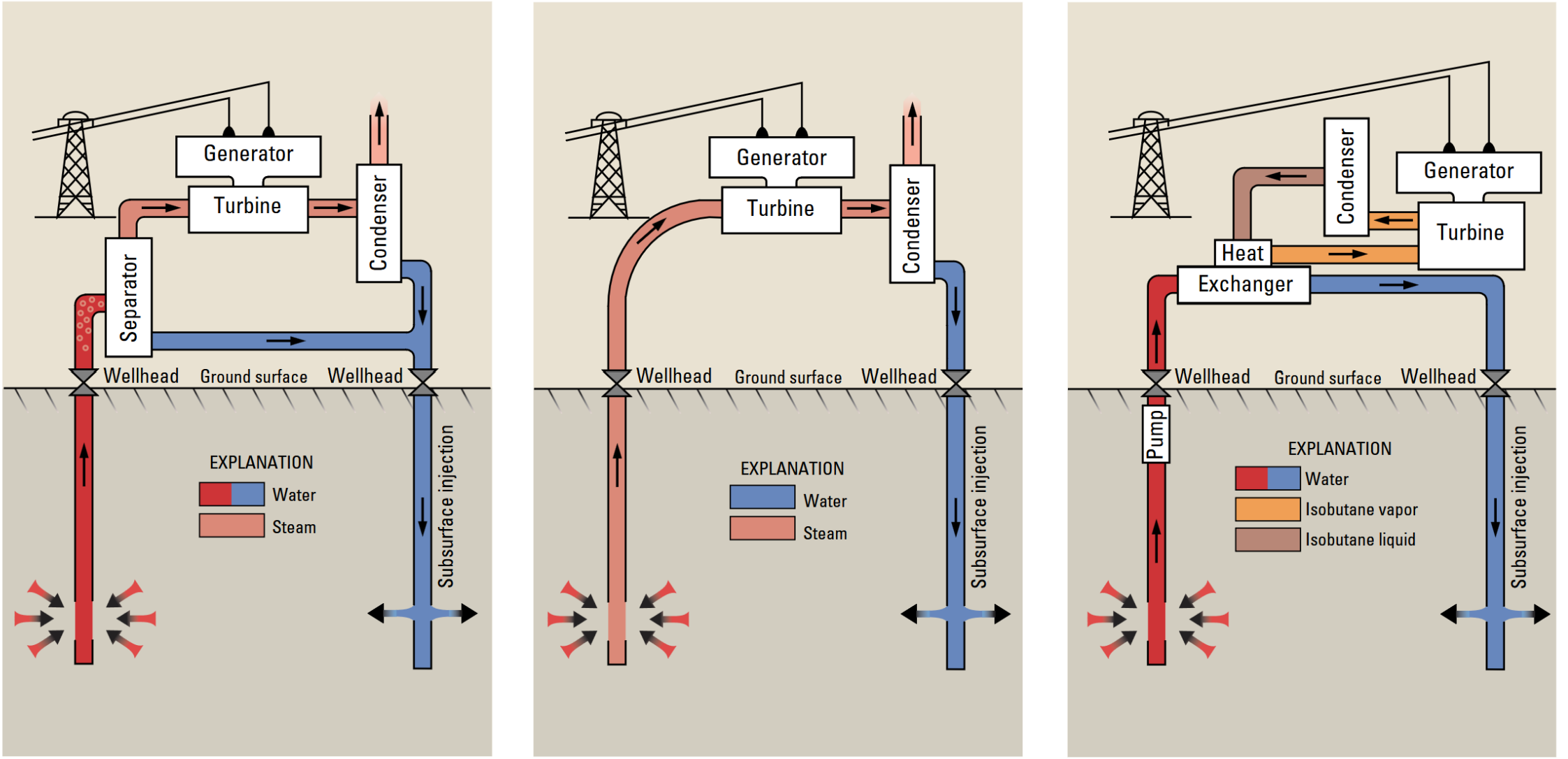


Storage



Ivarson, 2006; Crotogino et al., 2001

Geothermal electricity production



Duffield & Sass, 2003

Geothermal electricity production

$$P_{ideal} = m * h_{steam}$$

m = mass flow
h = enthalpy

$$h = U(T) + pV$$

U: internal energy, p: pressure, V: volume

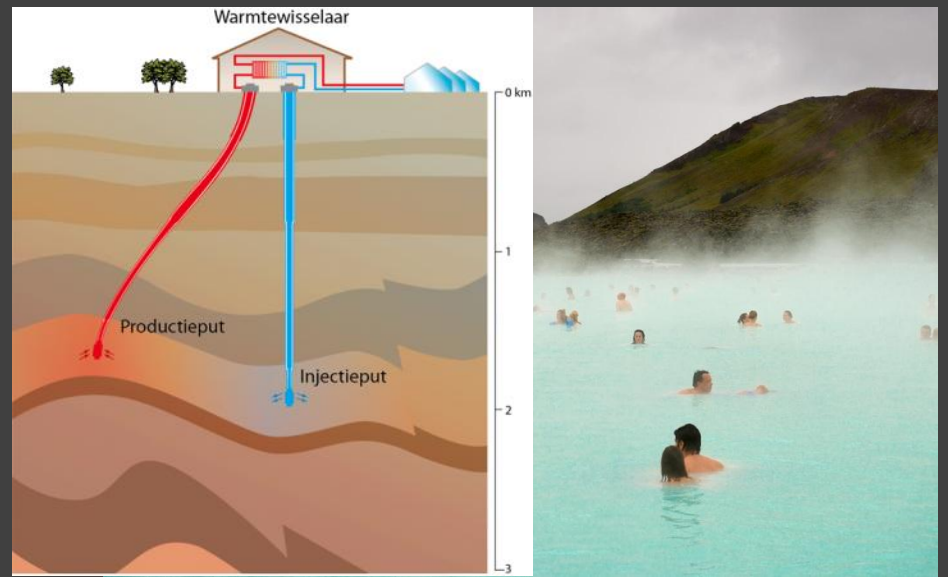
High enthalpy (>150°C)

Suitable for electricity production

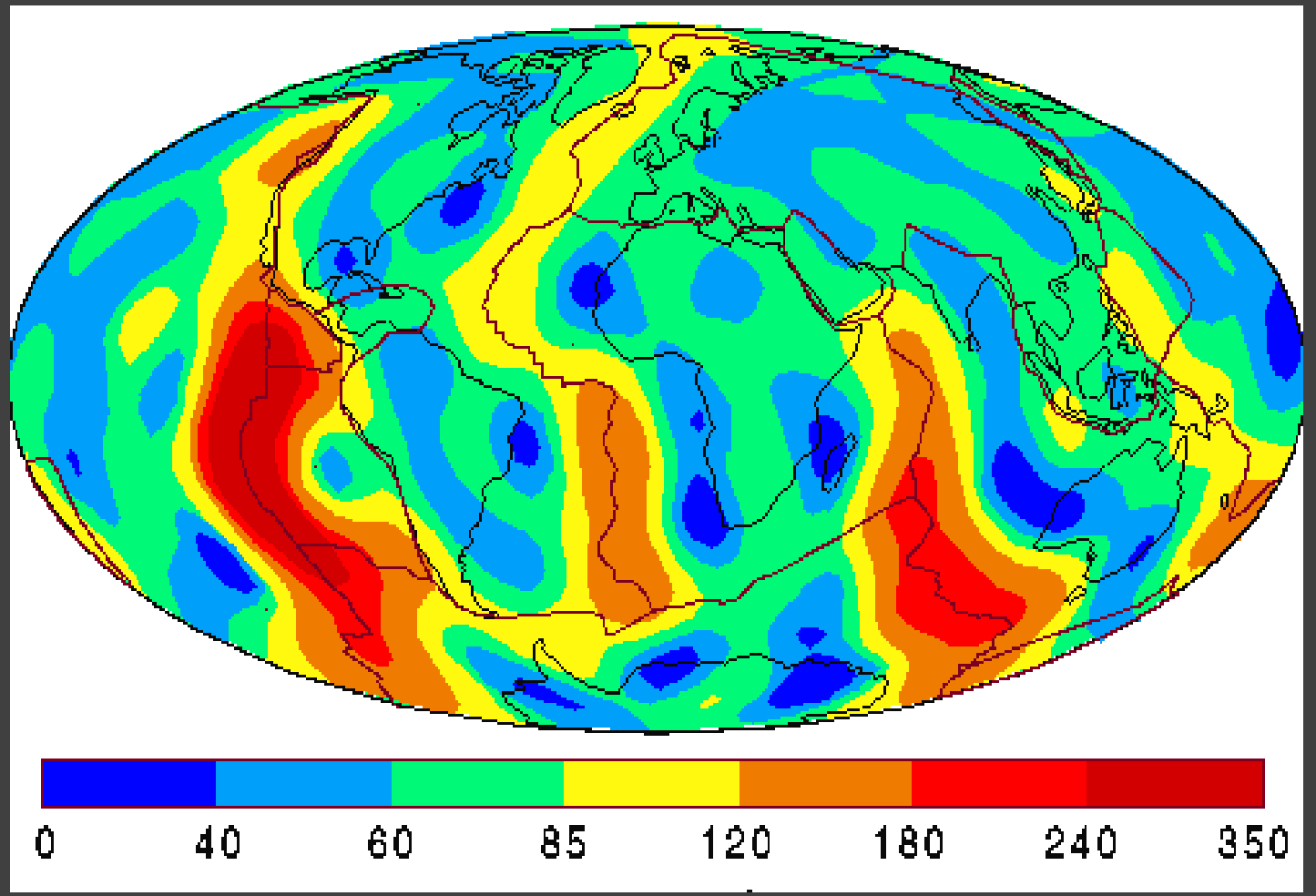


Low enthalpy (<150°C)

Direct heat uses (district heating, greenhouses, etc)



Global heatflow



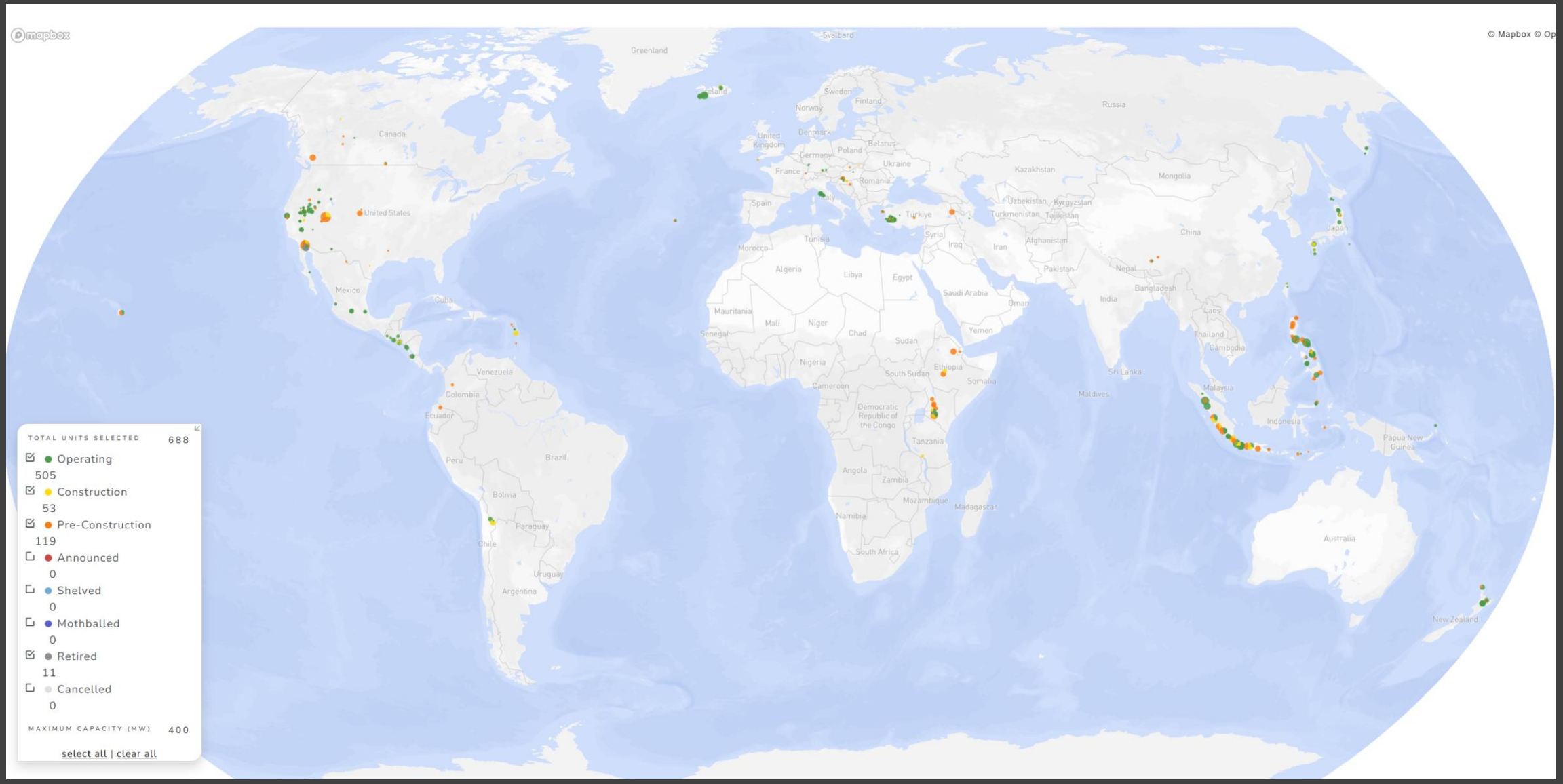
Average Heatflow:
Continental: 65 mW/m²
Oceanic: 101 mW/m²

Global weighted average: 87 mW/m²

Total heat loss of the Earth: 44.000.000 MW

Pollack et al., 1993

Global geothermal electricity production



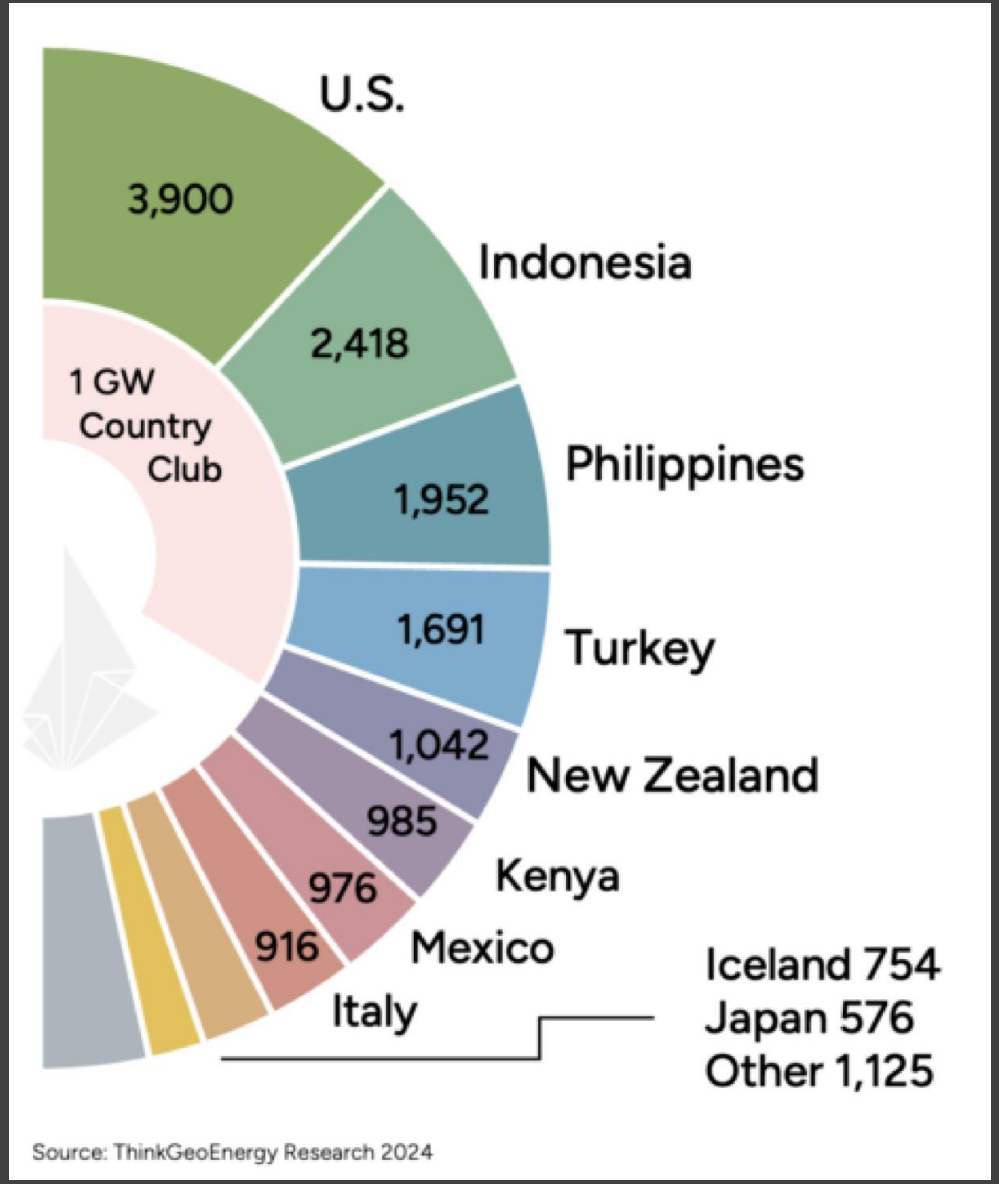
https://globalenergymonitor.org/projects/global-geothermal-power-tracker

Global geothermal electricity production

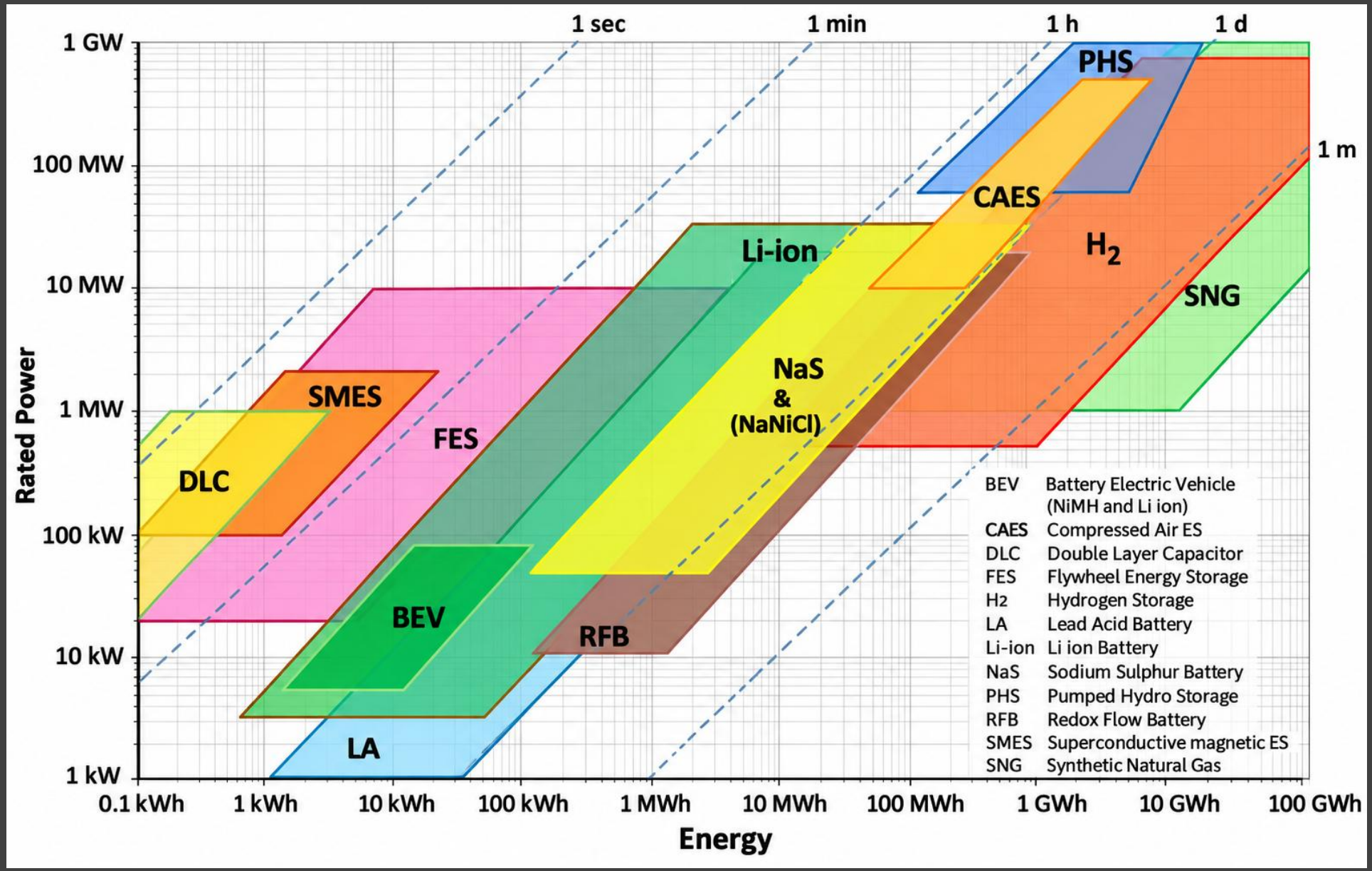
- 16.6 GW capacity
- 14.3 GW prospective

- 2020: 95.000 GWh production

- NL consumption: 132.000 GWh (2025)

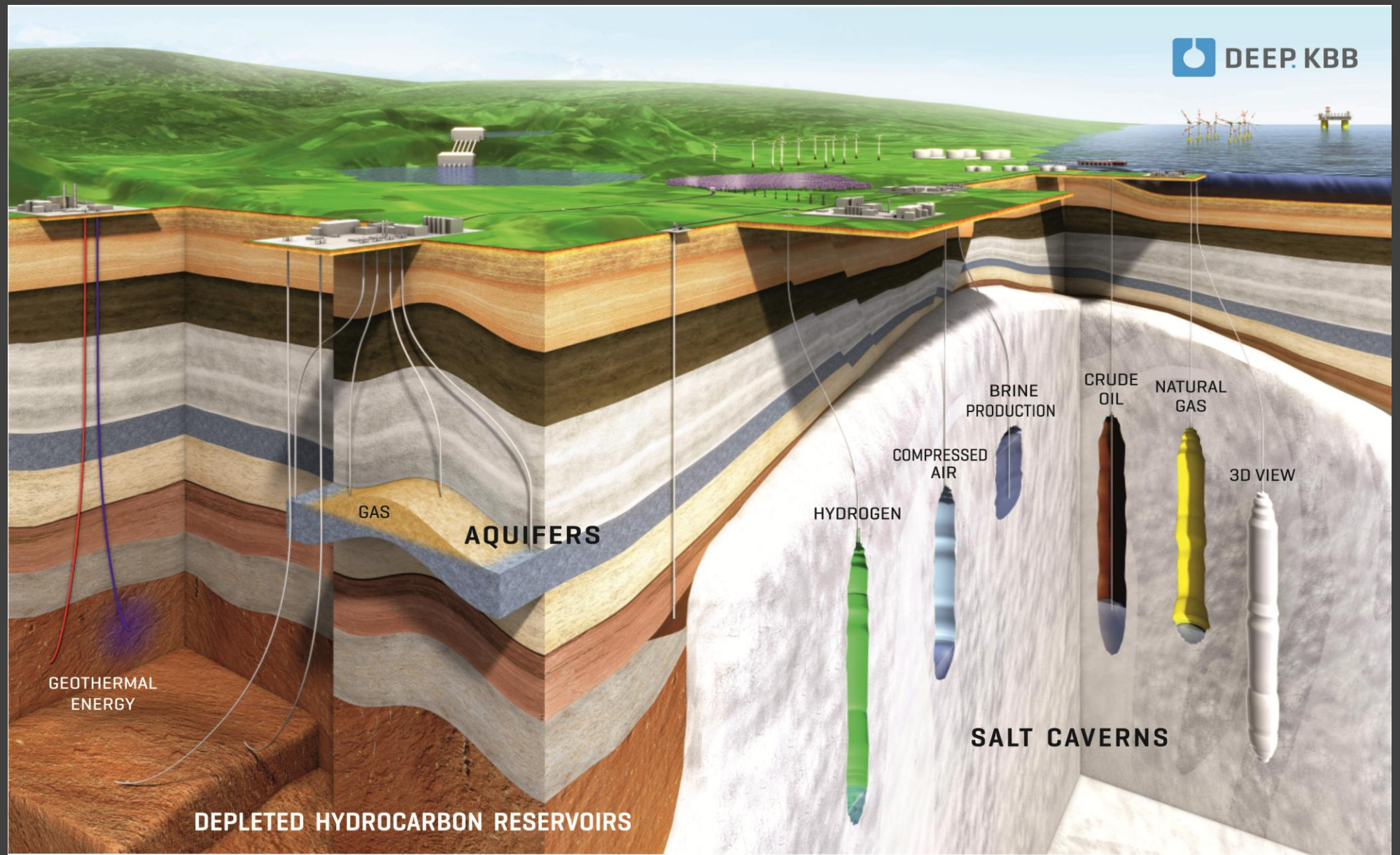


Electricity/energy storage options

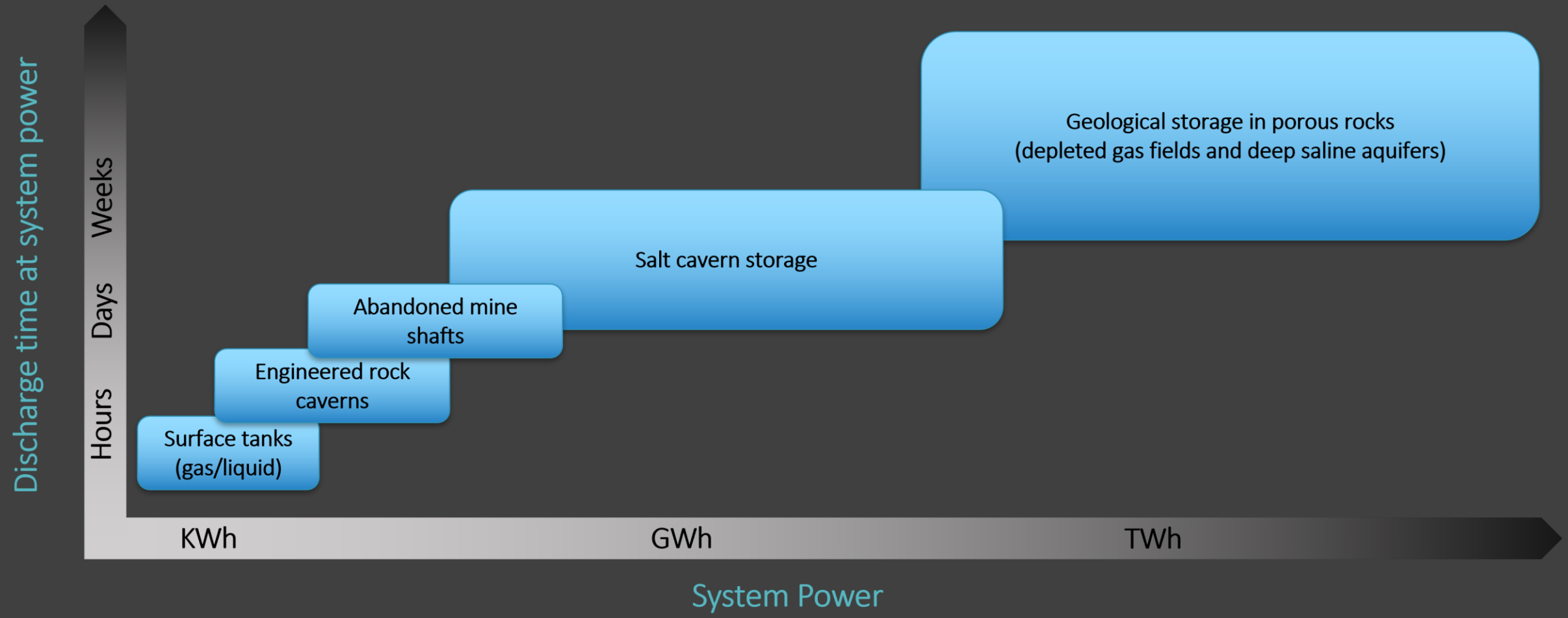


After IEC, 2011

Geological storage options

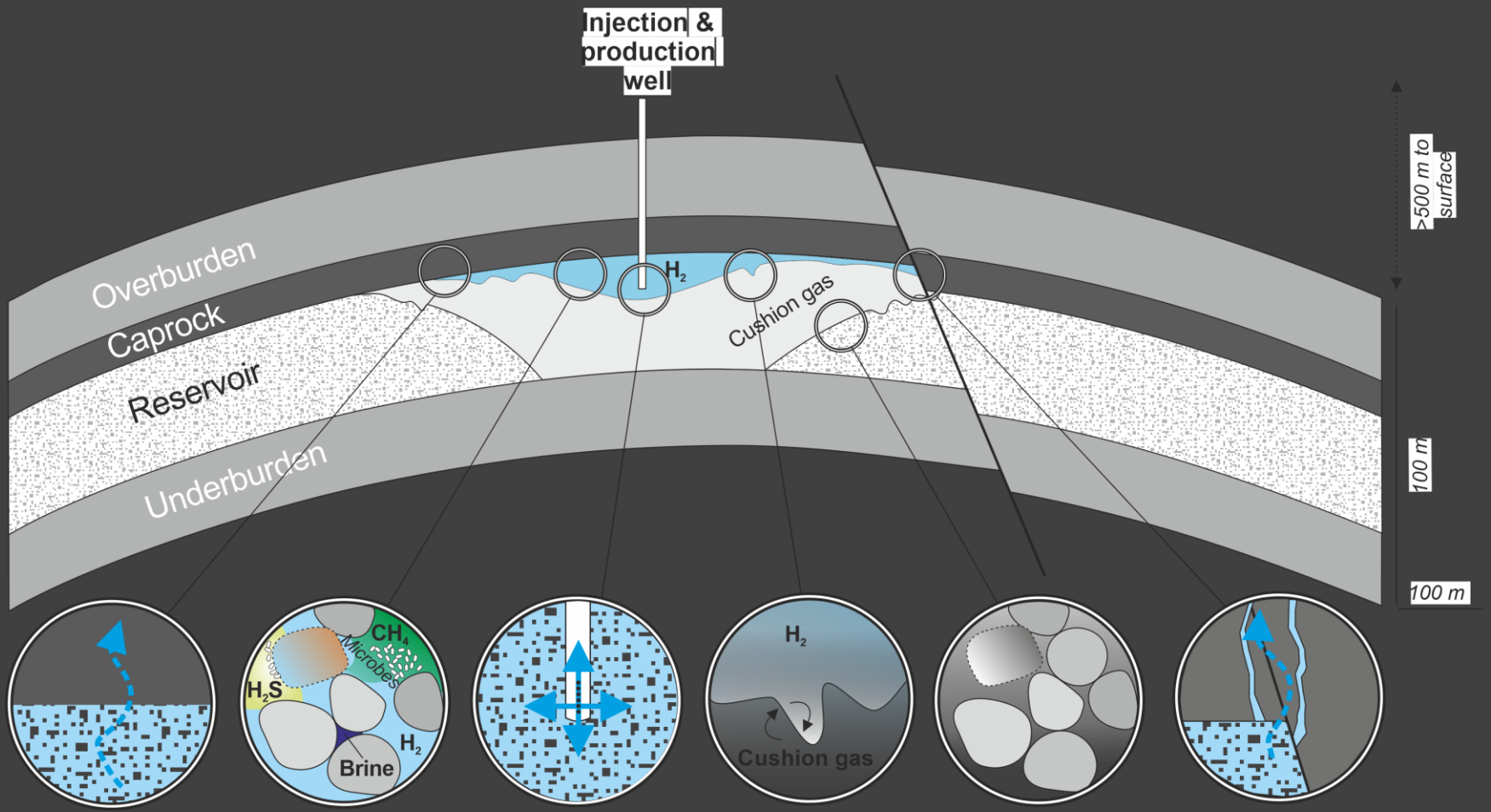


Hydrogen storage options



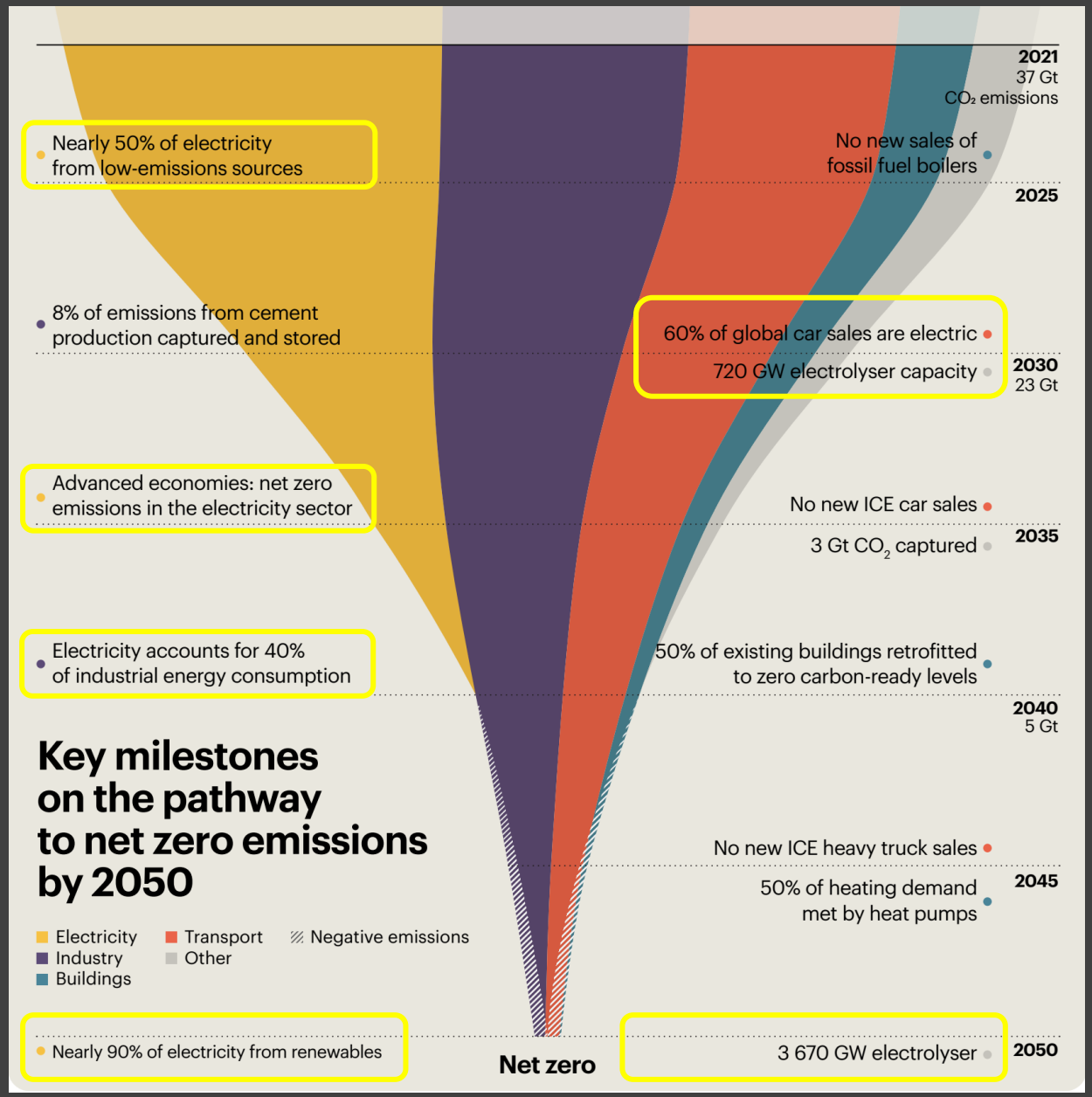
Miocic et al., 2023

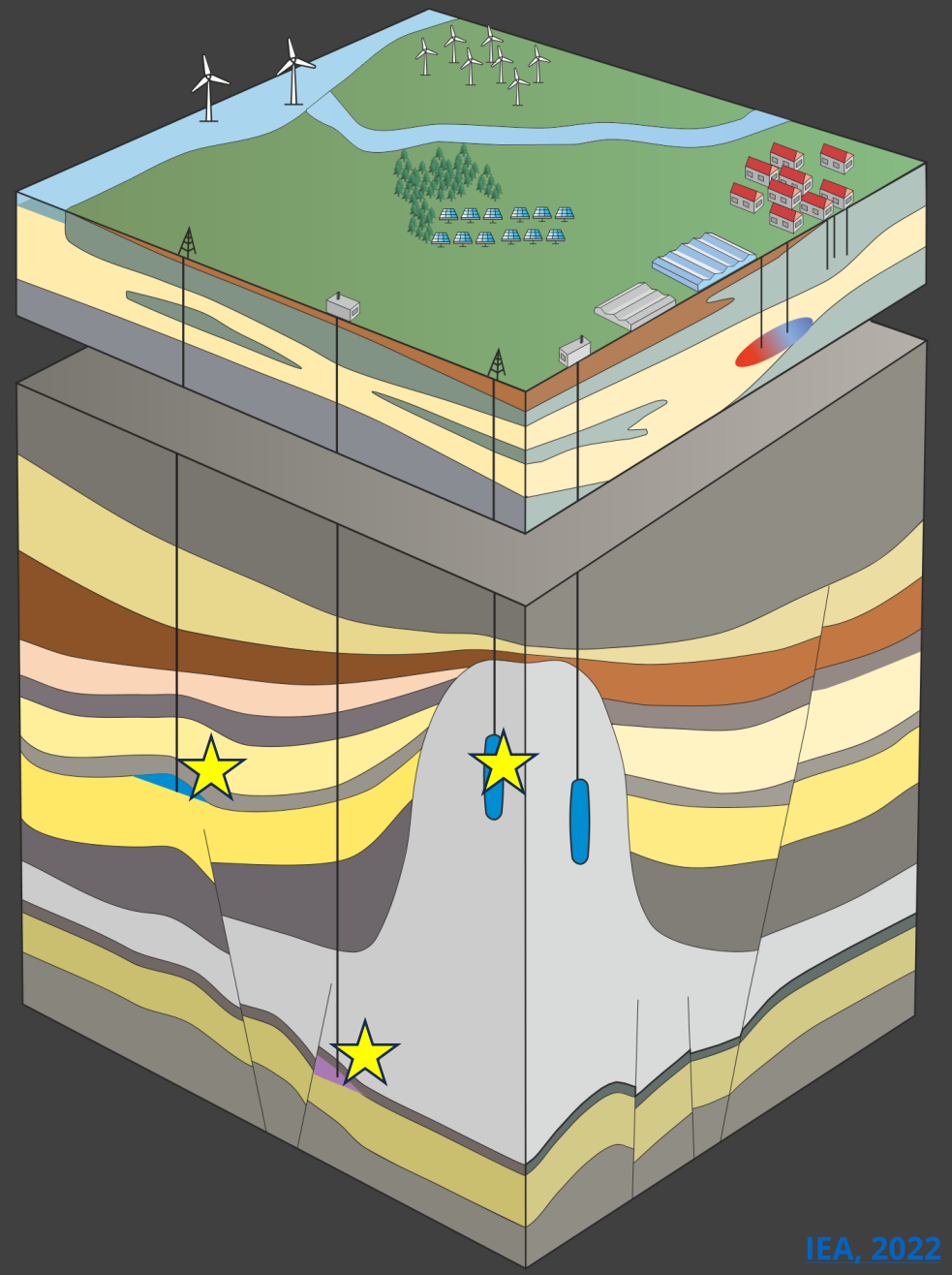
Hydrogen storage challenges



Caprock:	Hydrogen plume	Injection/production:	H_2 - cushion gas:	Cushion gas- brine	Structural geology:
• Diffusion • Capillary leakage • Fracturing • Buoyancy pressure	• Fluid-rock interaction • Microbial activity • Dissolution & residual trapping	• P/T change • Multiphase processes • Stress/strain changes	• Unstable displacement & uncrontrolled lateral spreading • Gas mixing	• Fluid-rock interaction • Unstable displacement • Dissolution & residual trapping	• Fault leakage • Far and near field stress changes • Reactivation • Overpressure

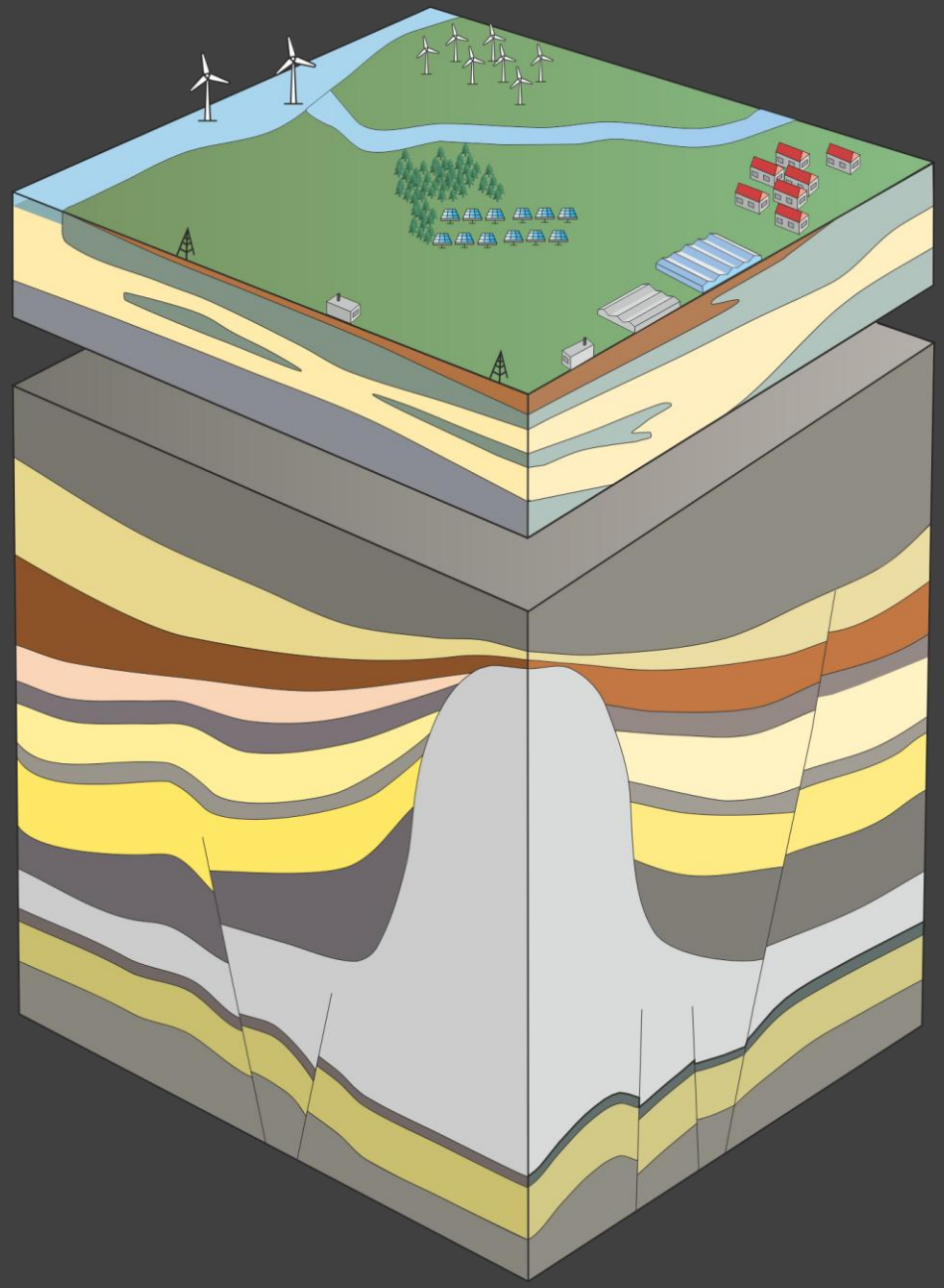
Heinemann et al., 2021


2021
37 Gt
CO_2 emissions
Nearly 50% of electricity from low-emissions sources
No new sales of fossil fuel boilers
2025
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Other
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3 670 GW electrolyser
2050



IEA, 2022

Heat



Heating and cooling: the elephant in the room

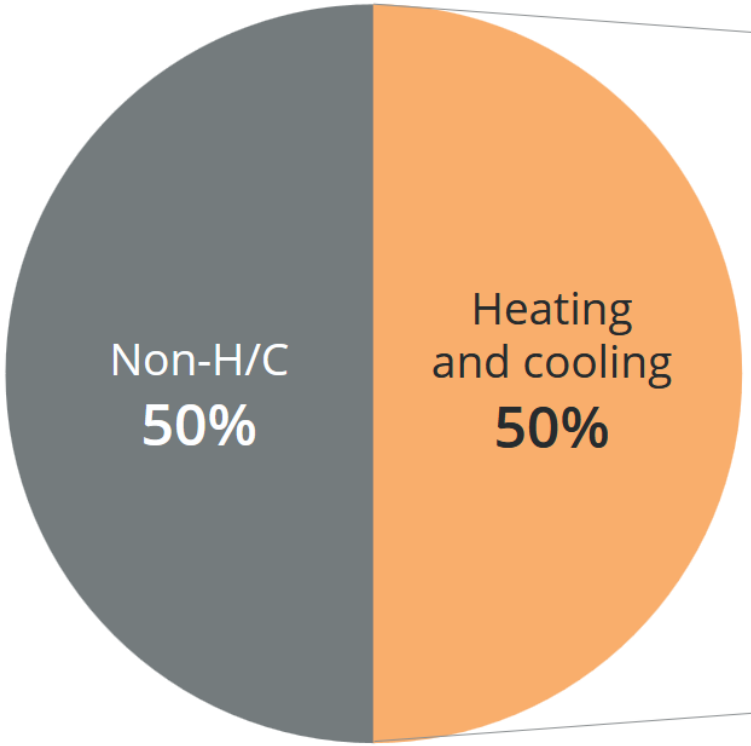


Figure 1:
Total final energy in 2015 (EU28)

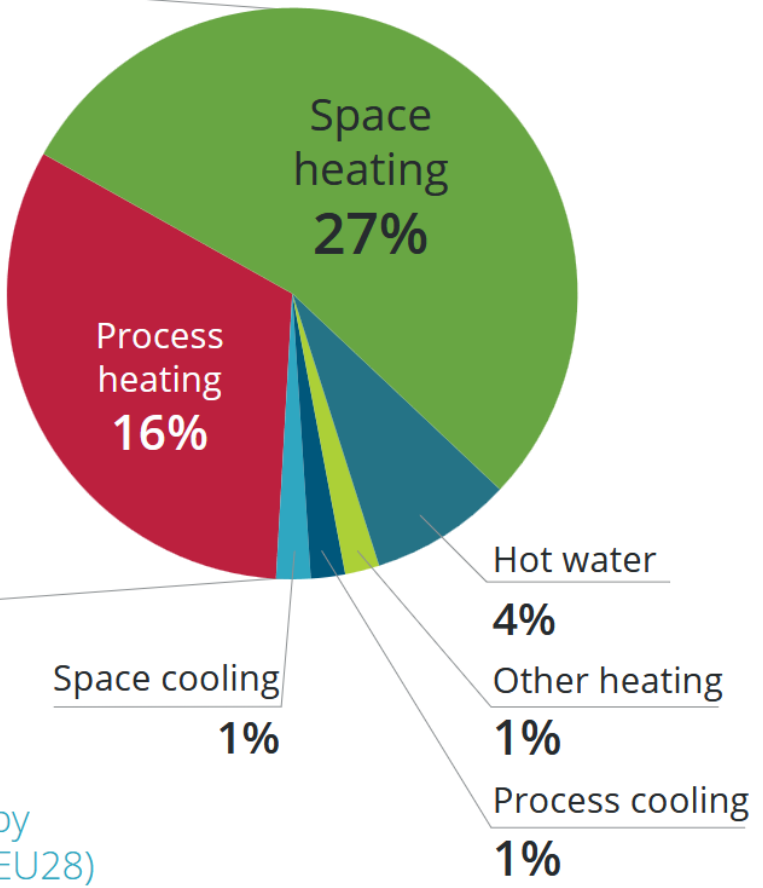


Figure 2:
H&C final energy by end-use in 2015 (EU28)

Is the subsurface used for heat purposes in NL?

No

0%

A little

0%

More than anywhere in the world

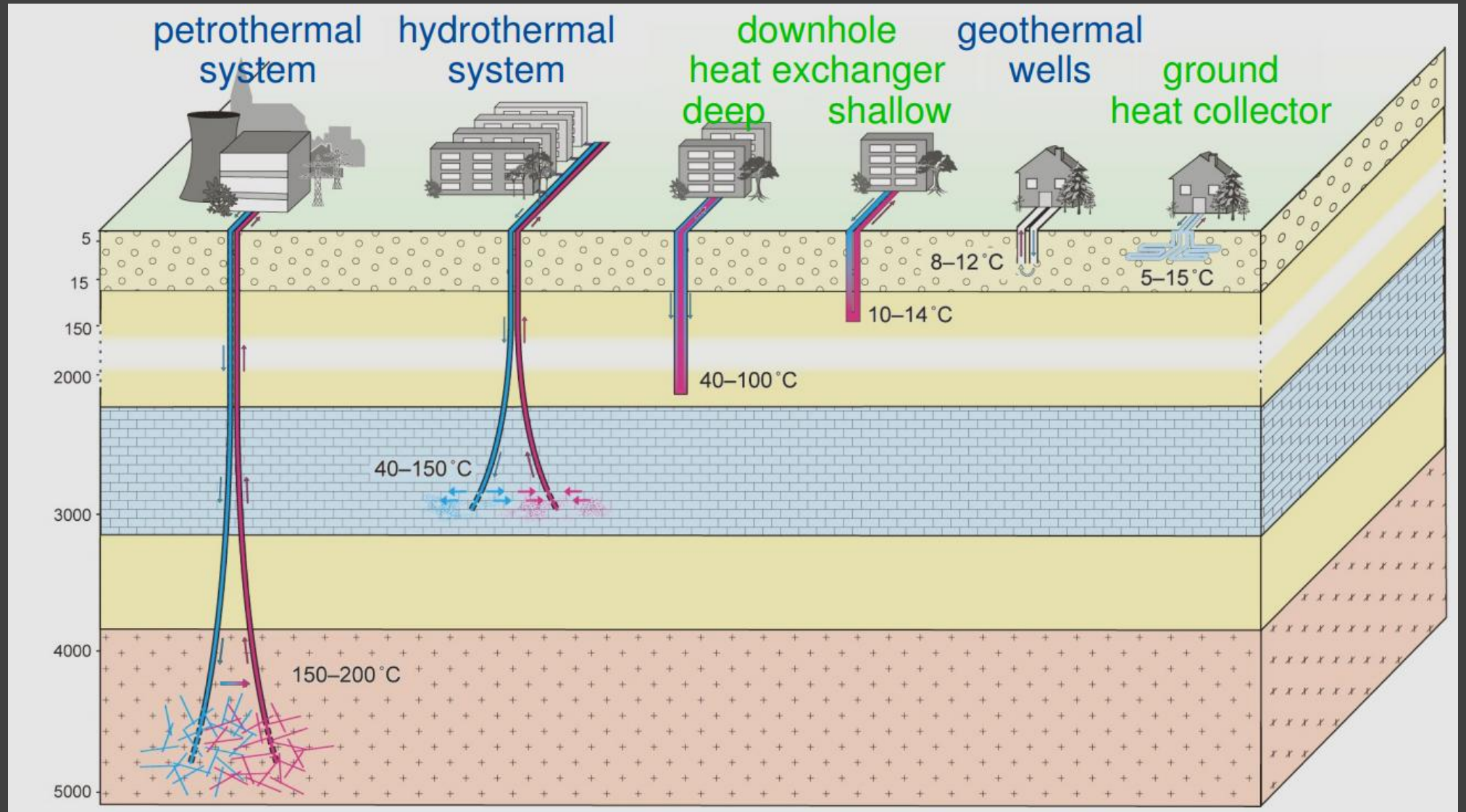
0%

Yes

0%

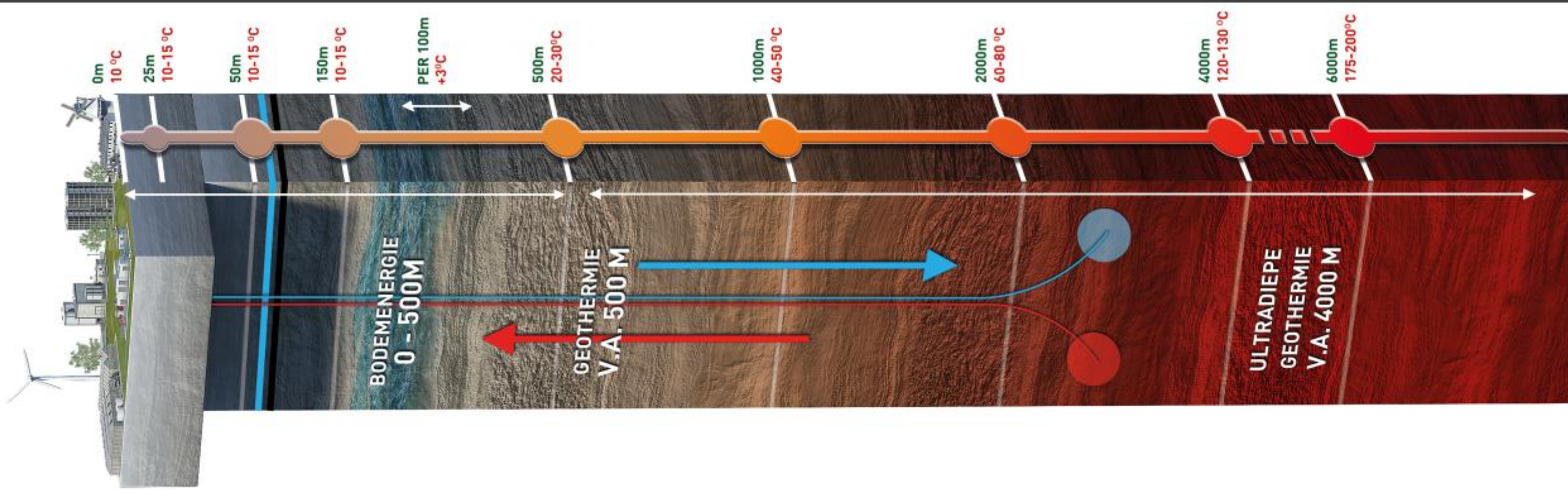
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Geothermal heating and cooling options



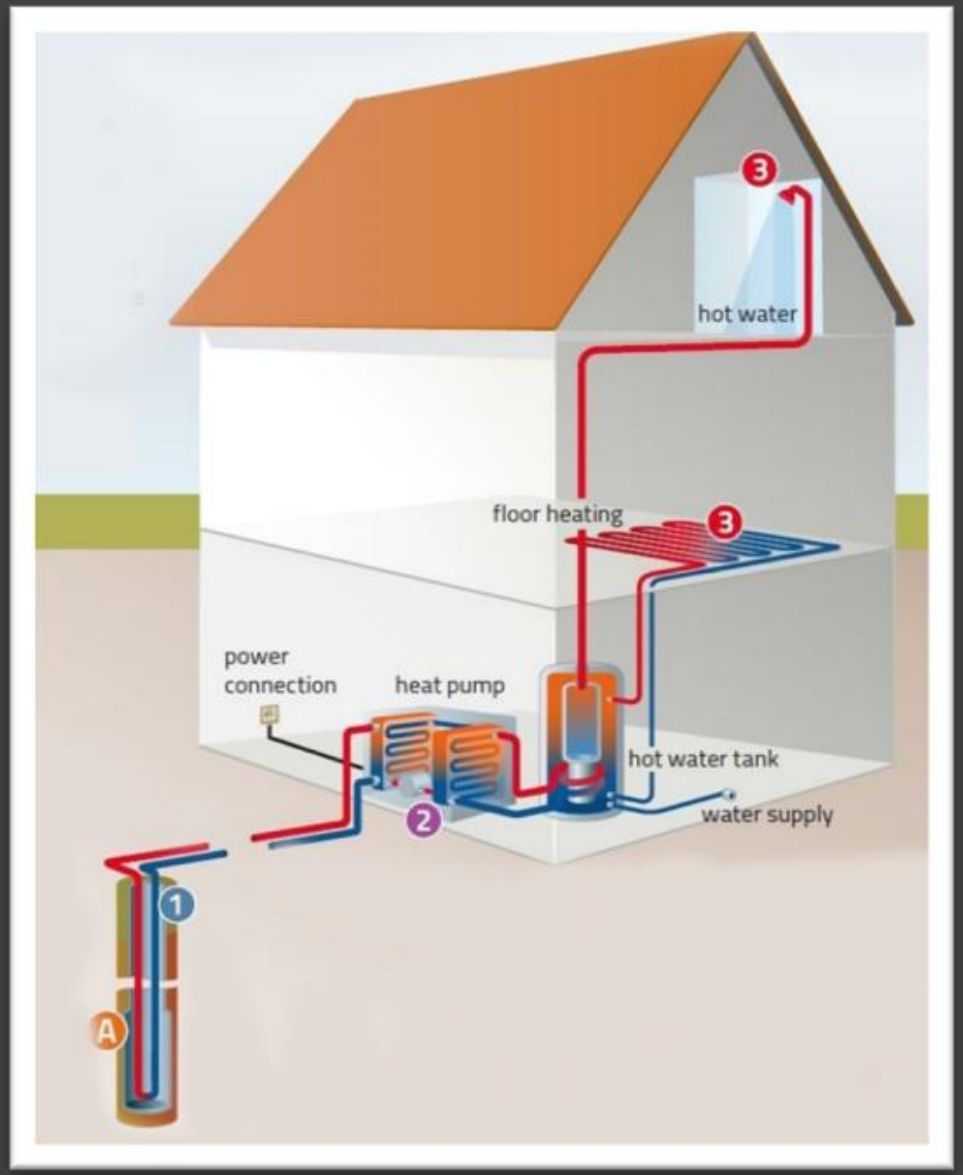
Source: Ingolstädter Kommunalbetriebe (modified)

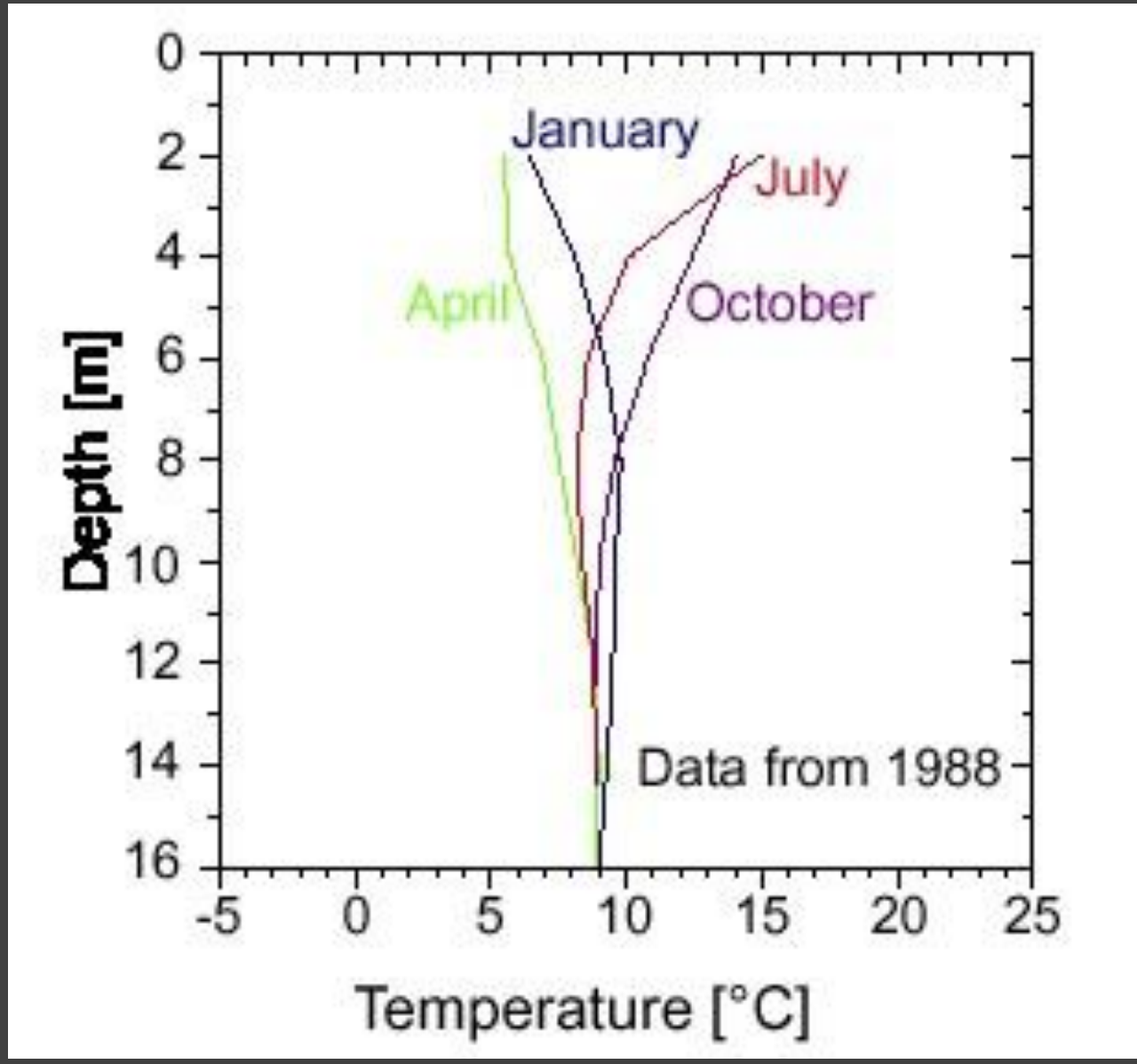
Geothermal heating and cooling options



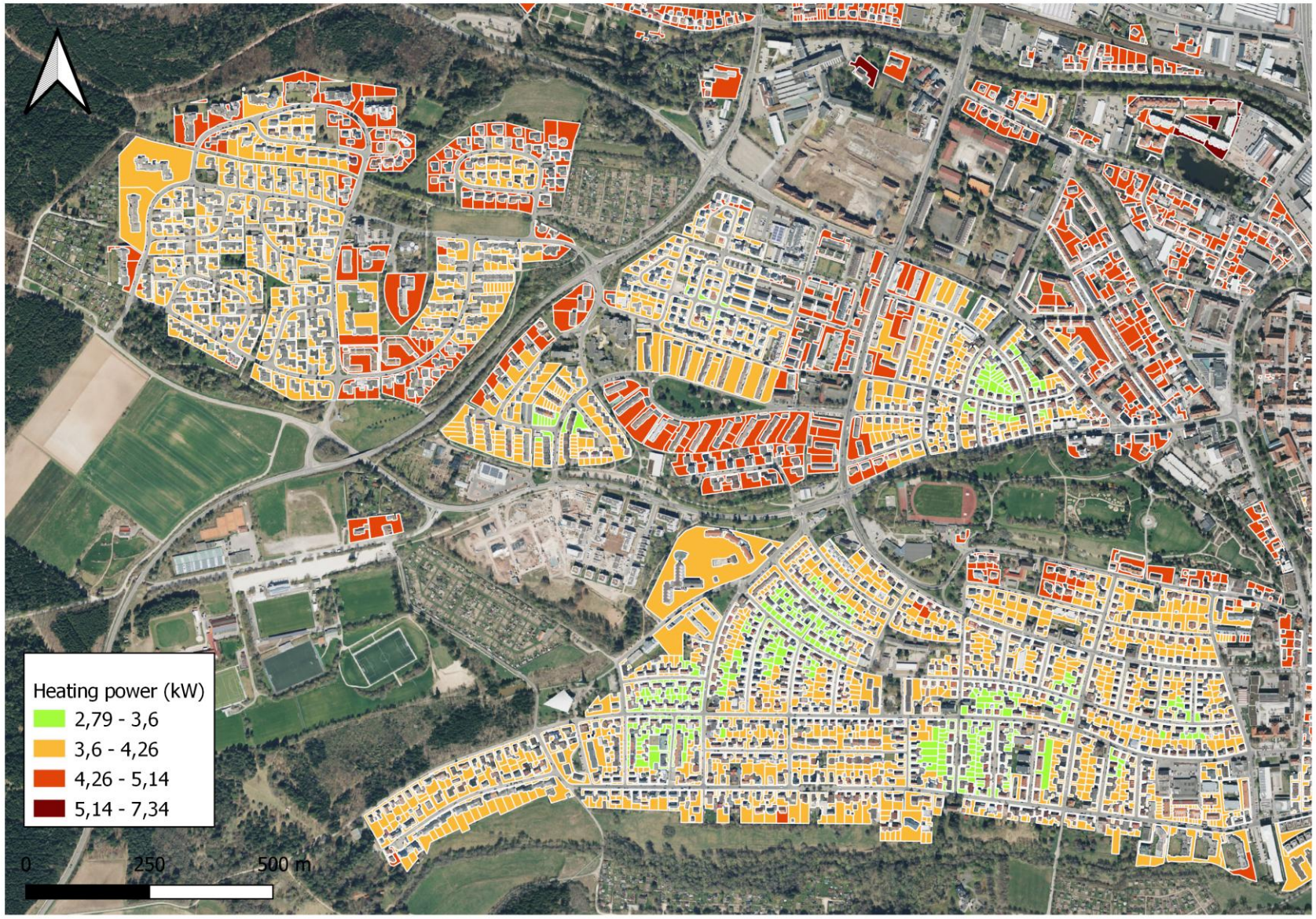
Geothermie.nl

Shallow geothermal energy

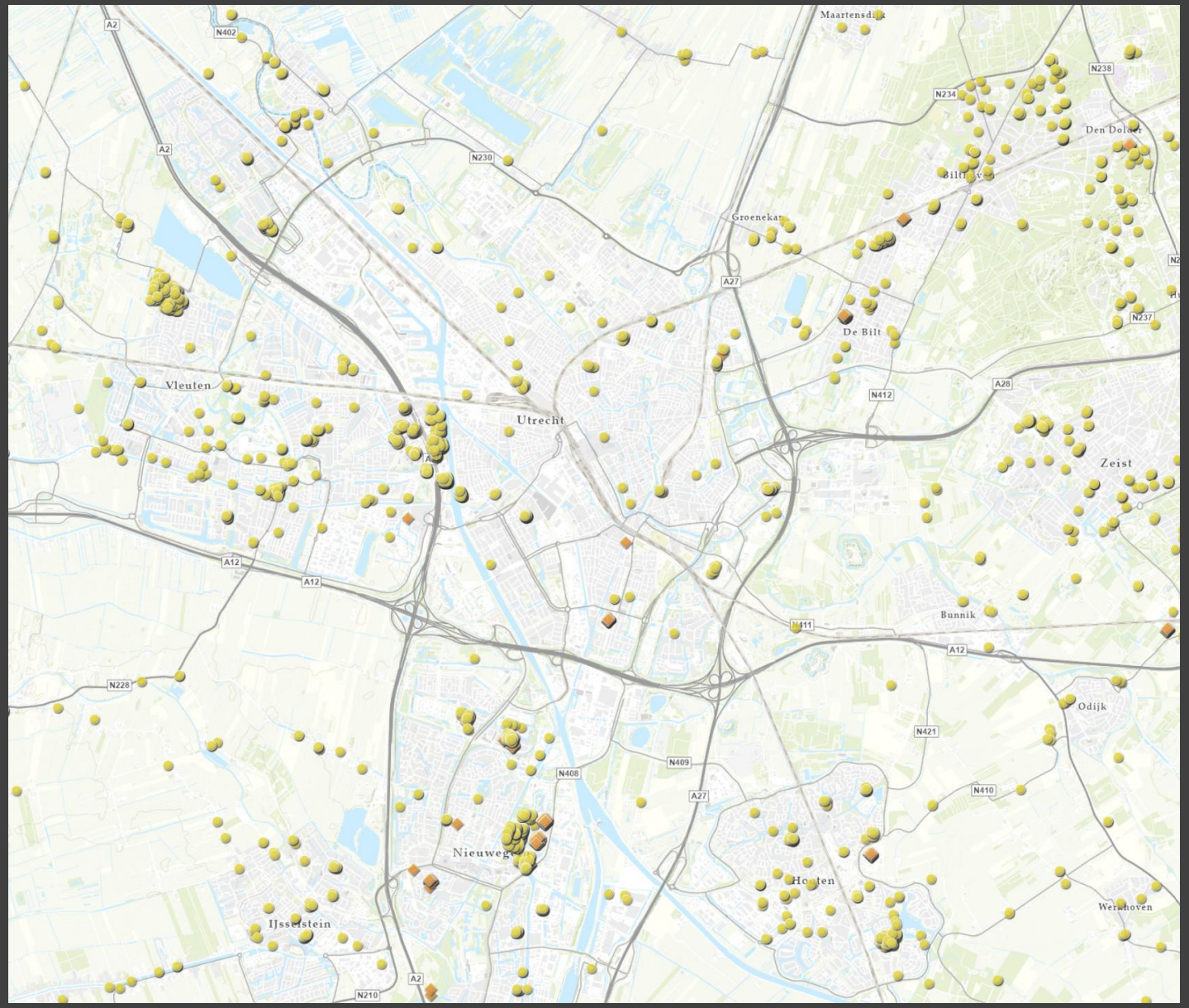




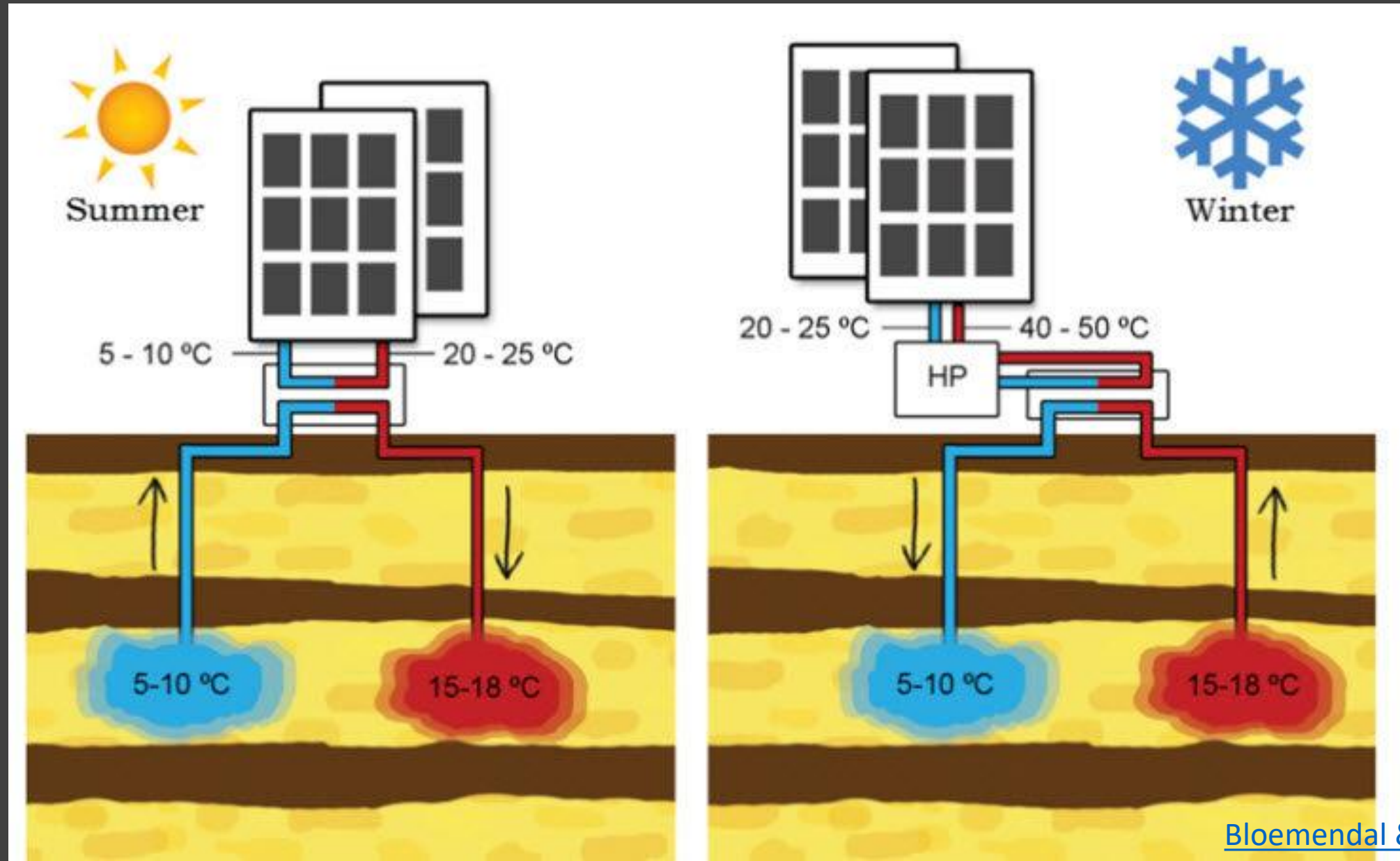
Shallow geothermal energy potentials



Shallow geothermal energy - Utrecht

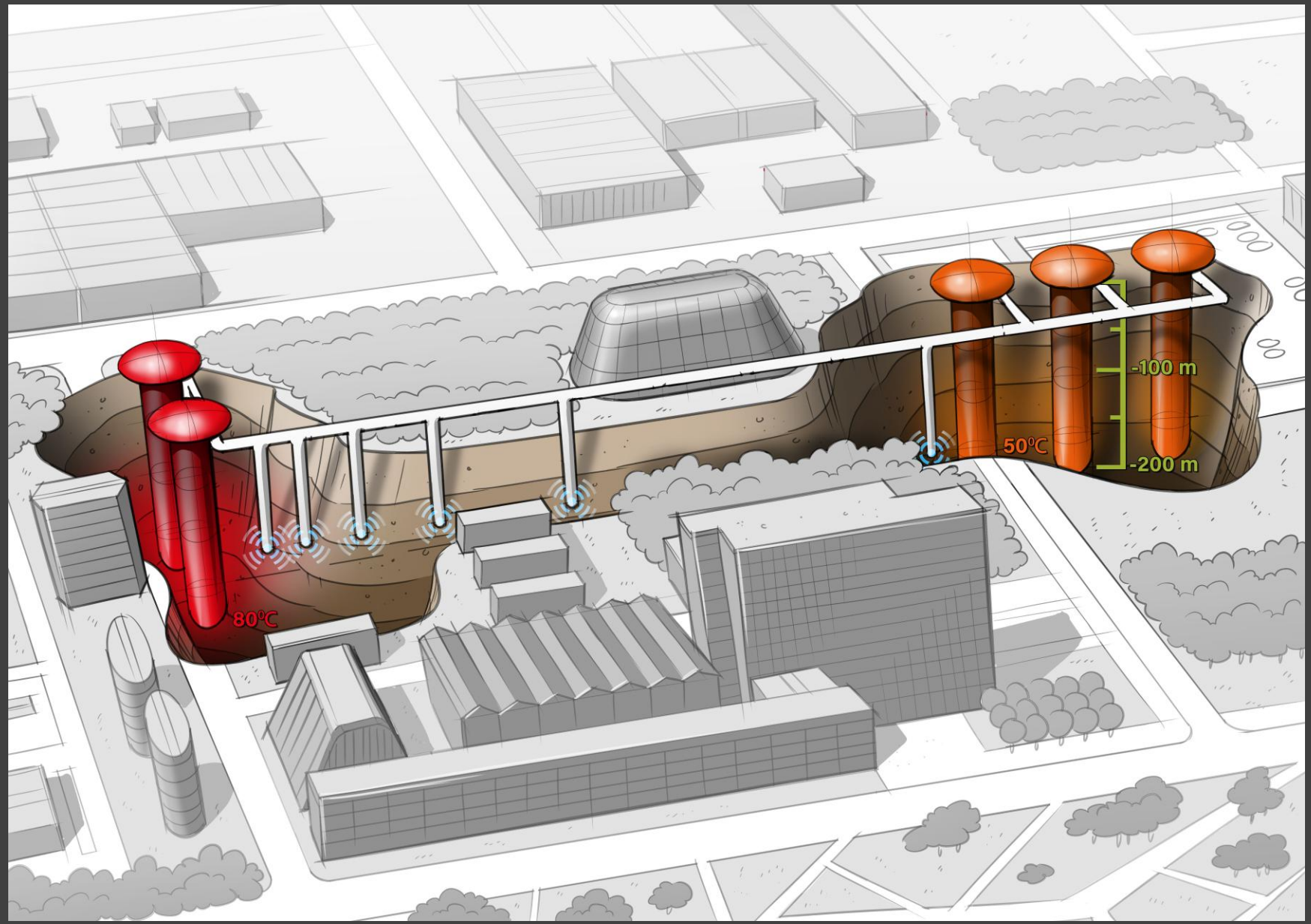


Aquifer thermal energy storage (ATES)

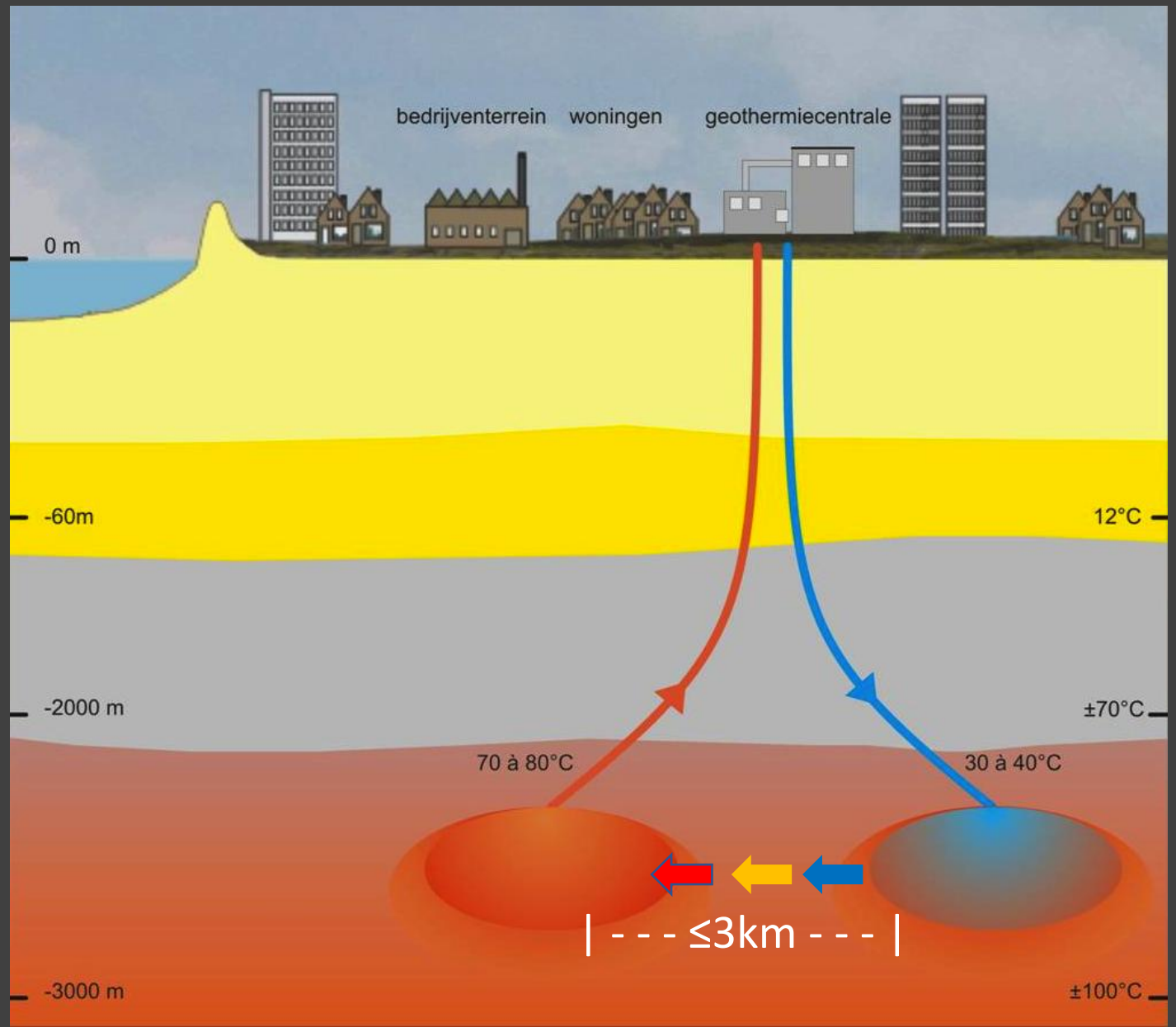


Bloemendal & Hartog, 2018

Hight Temperature ATES



Deep Geothermal Heat – Geothermal doublets



Geothermal doublets in NL

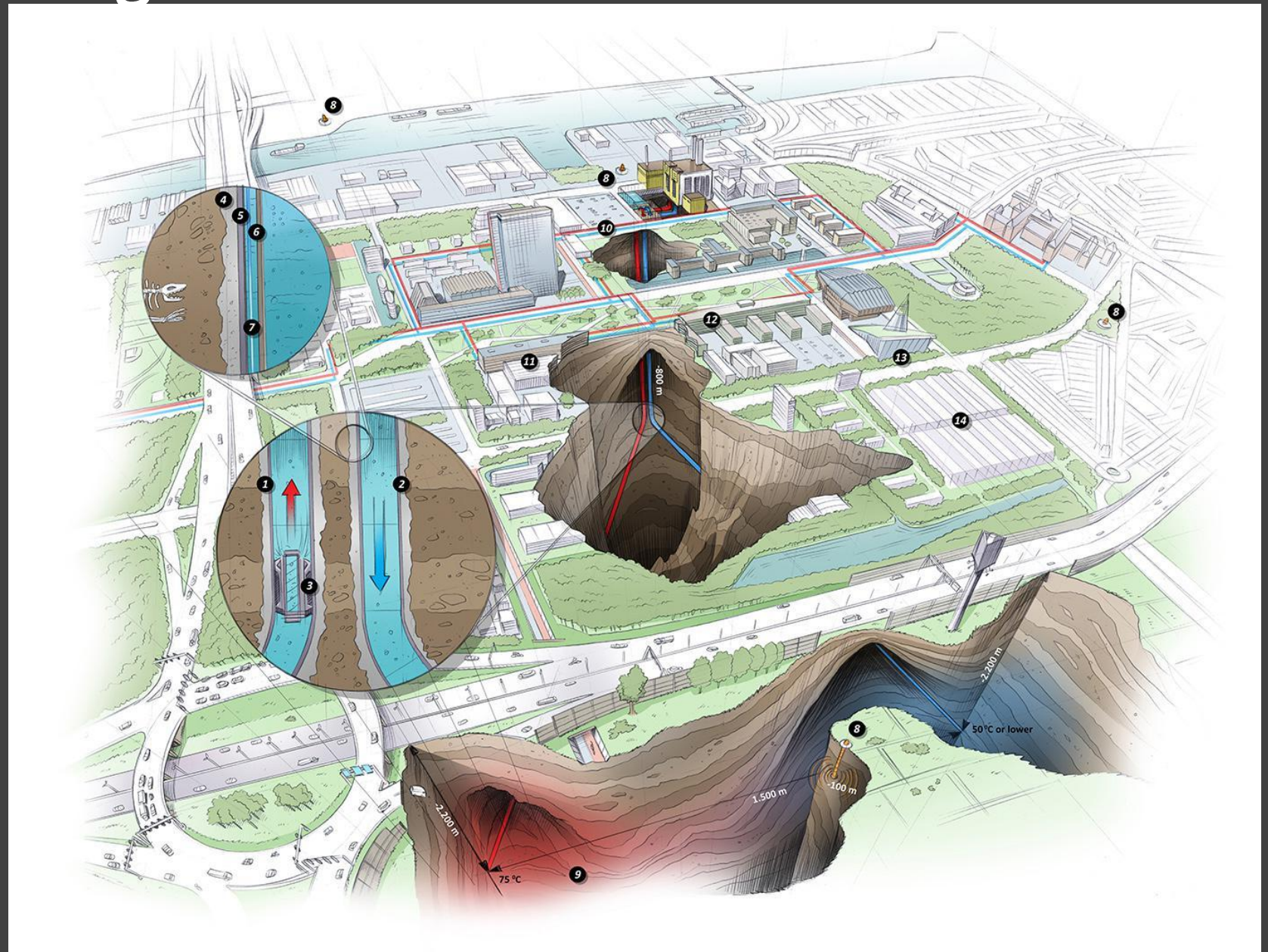


https://geothermie.nl/geothermie/locaties-op-kaart/

Geothermal doublets in NL



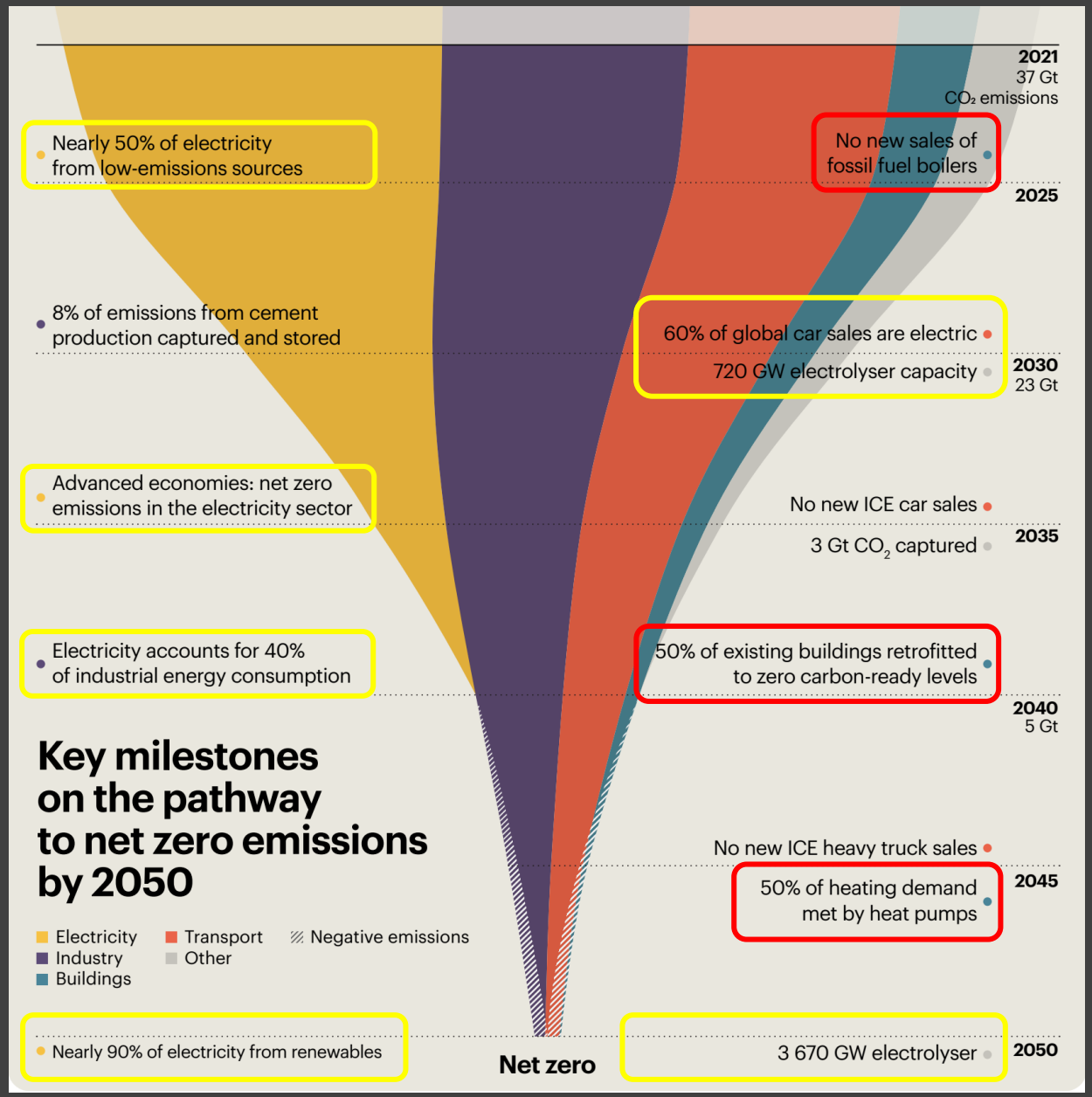
TU Delft geothermal doublet

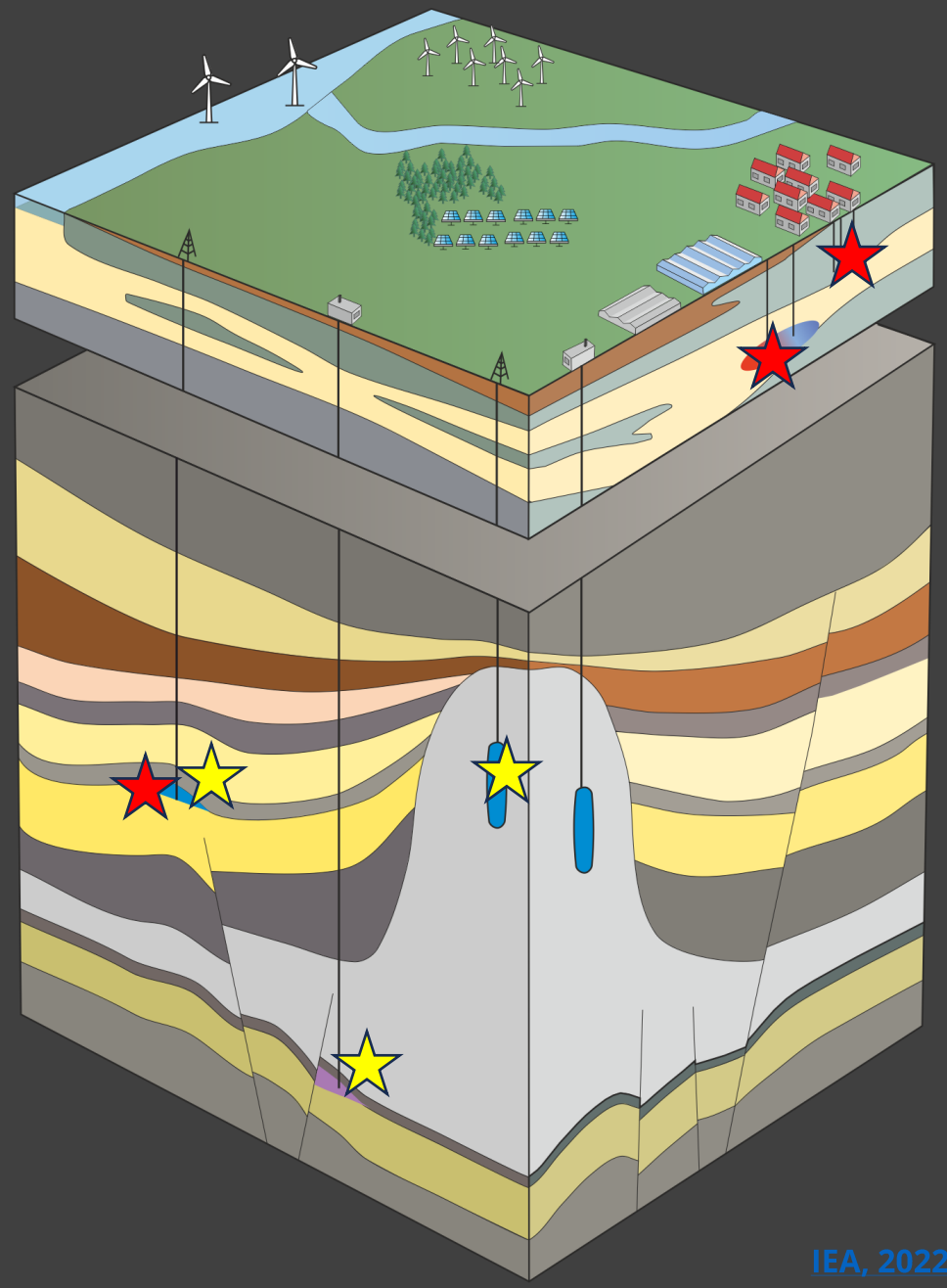


Most Dutch geothermal energy users...



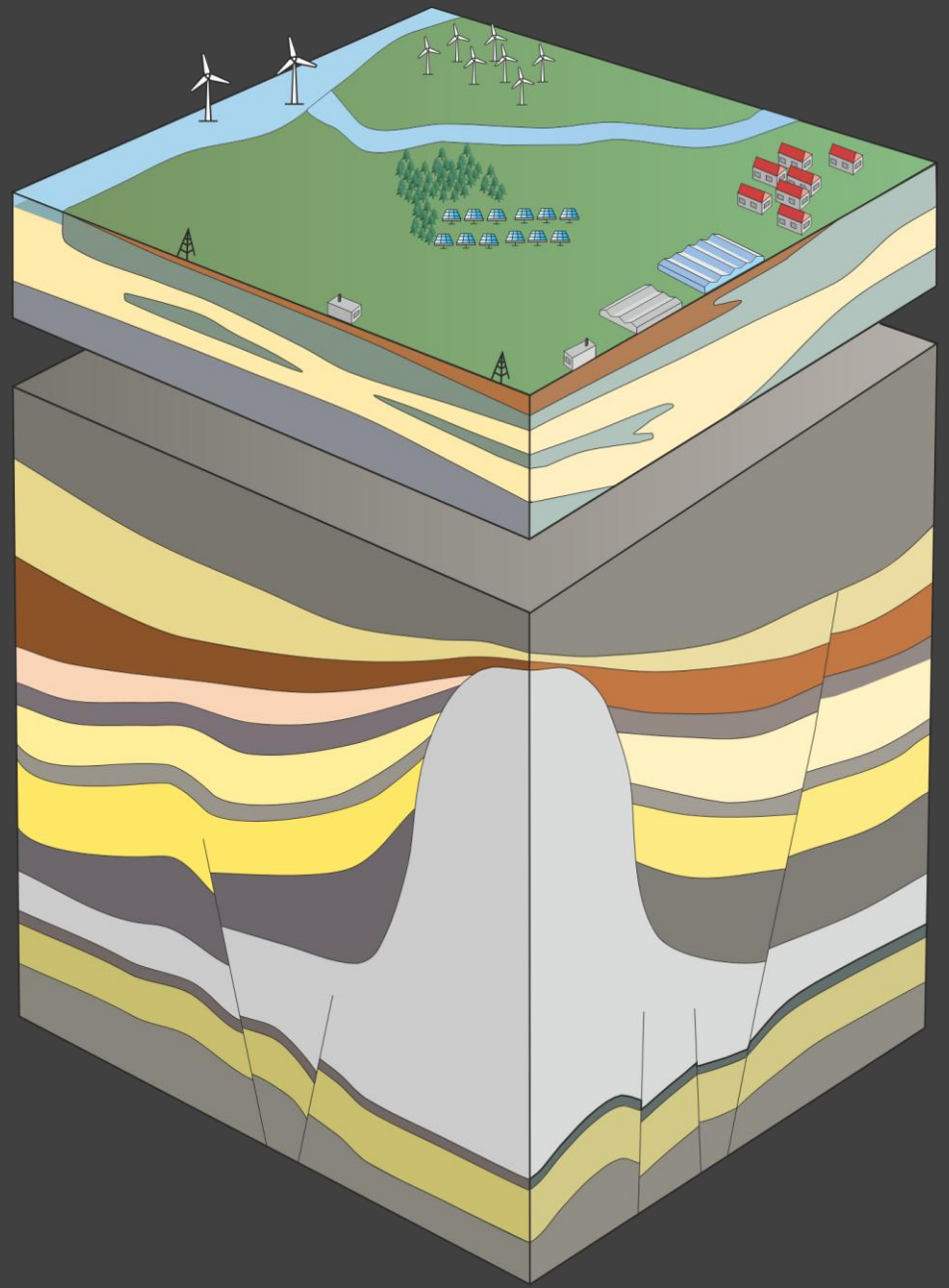
Geothermie.nl


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2050



IEA, 2022

Carbon Capture and Storage



Is CCS happening in the Netherlands?

Yes

0%

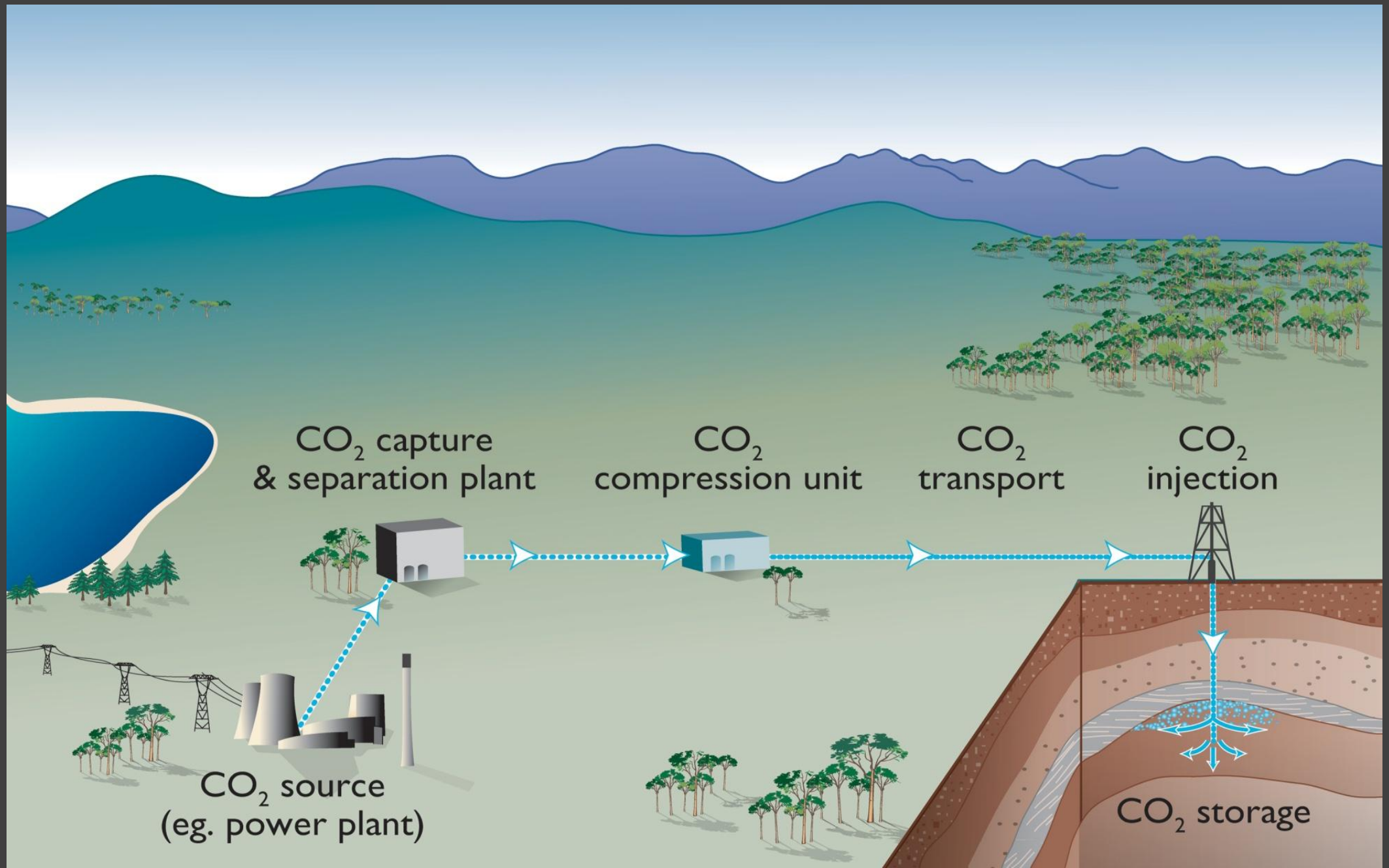
No

0%

Soon

0%

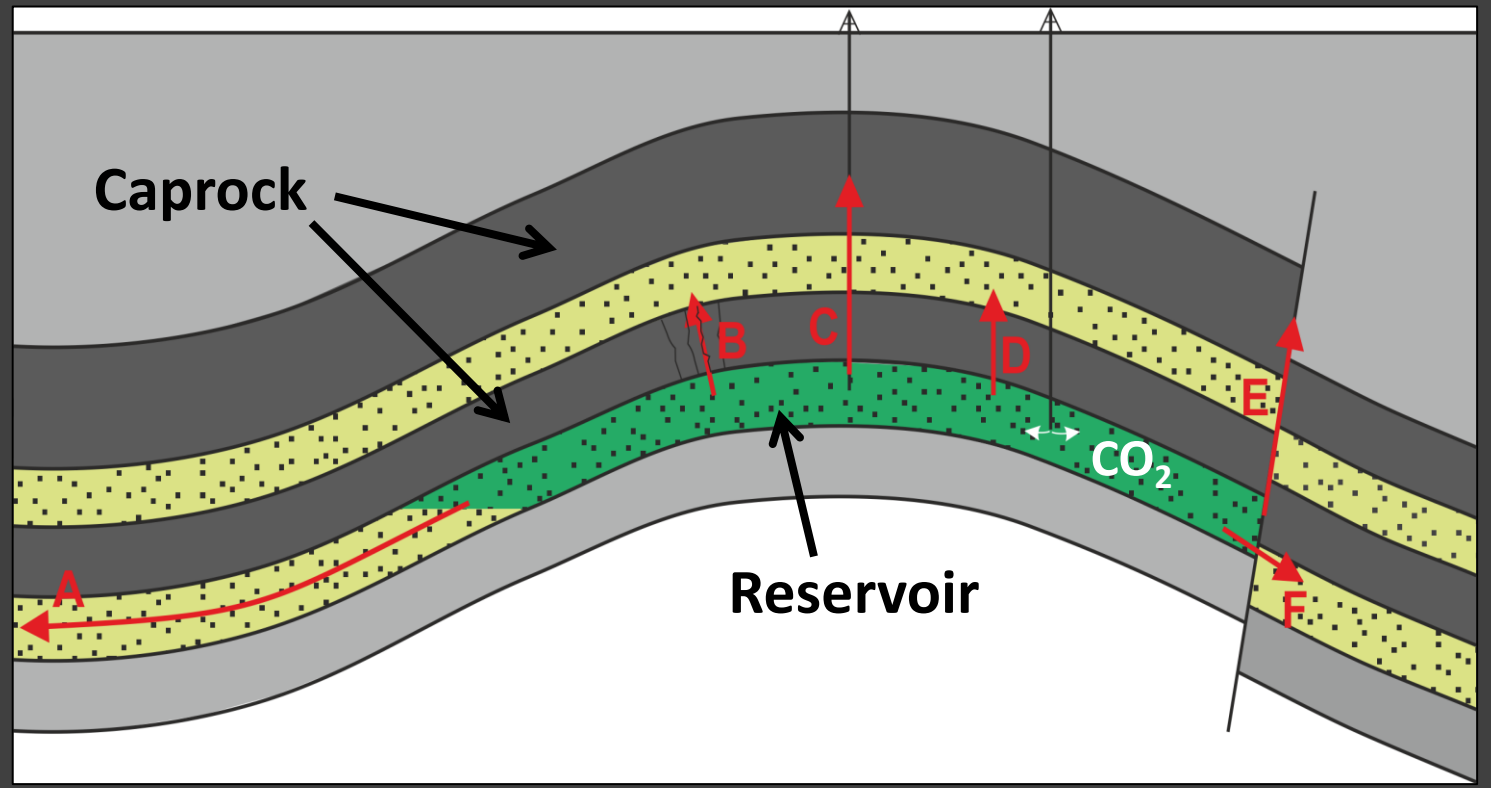
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CO_2 capture & separation plant
CO_2 compression unit
CO_2 transport
CO_2 injection
CO_2 source (eg. power plant)
CO_2 storage

CO2CRC, 2008







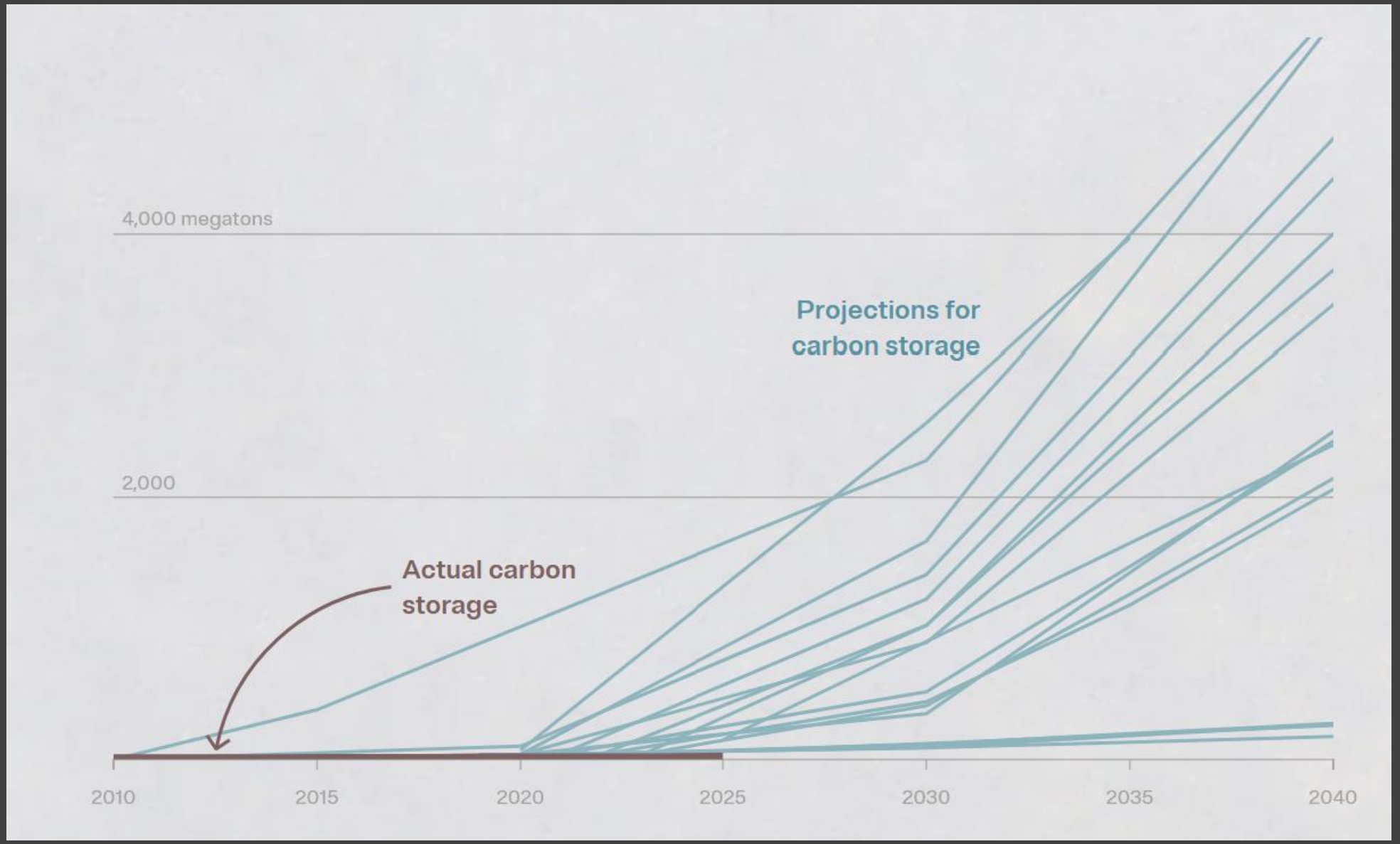
Carbon Visuals 2014; Miocic, 2016; Hrkac, 2021

Sleipner project



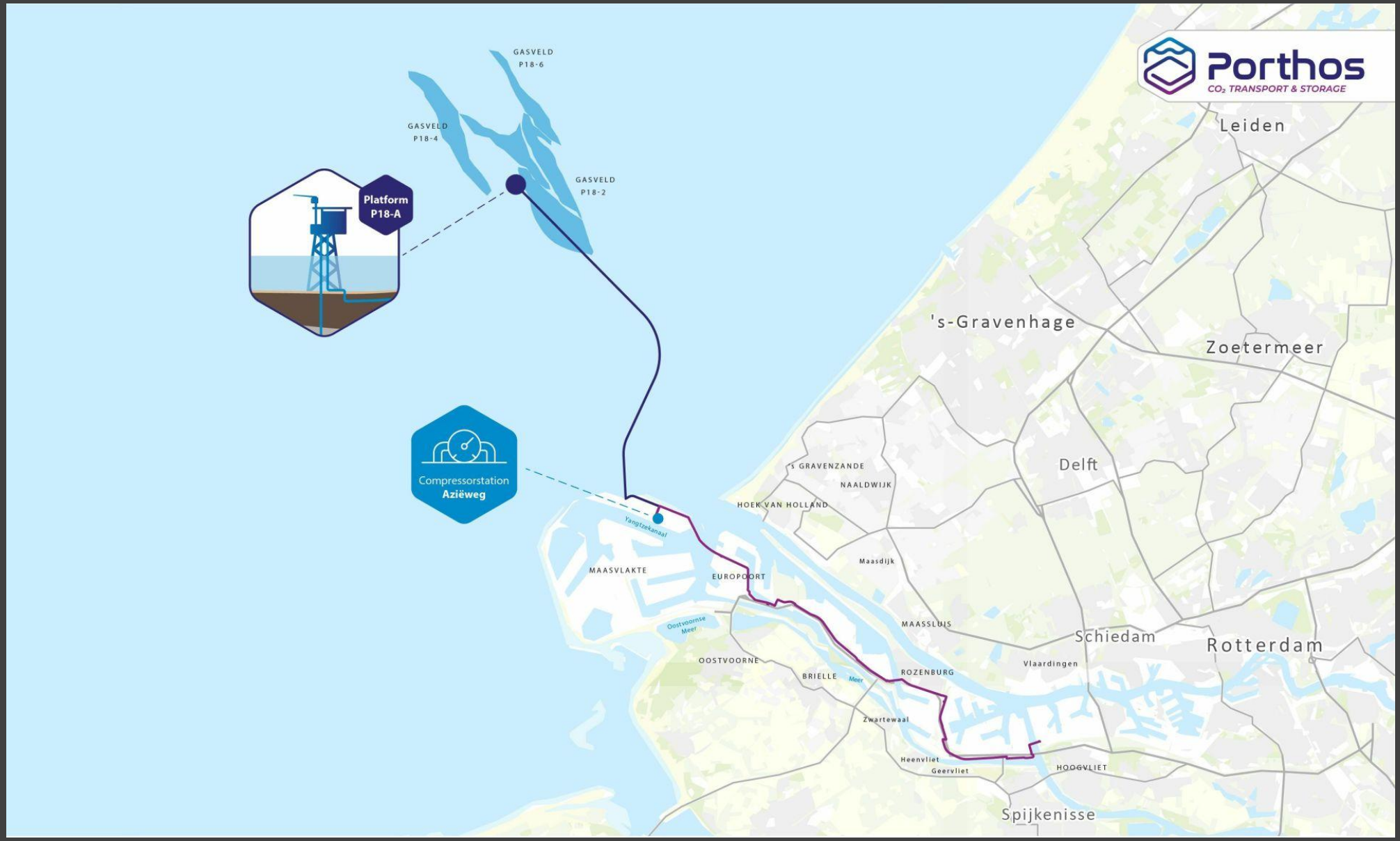
Sleipner, Norway

Global CO2 storage

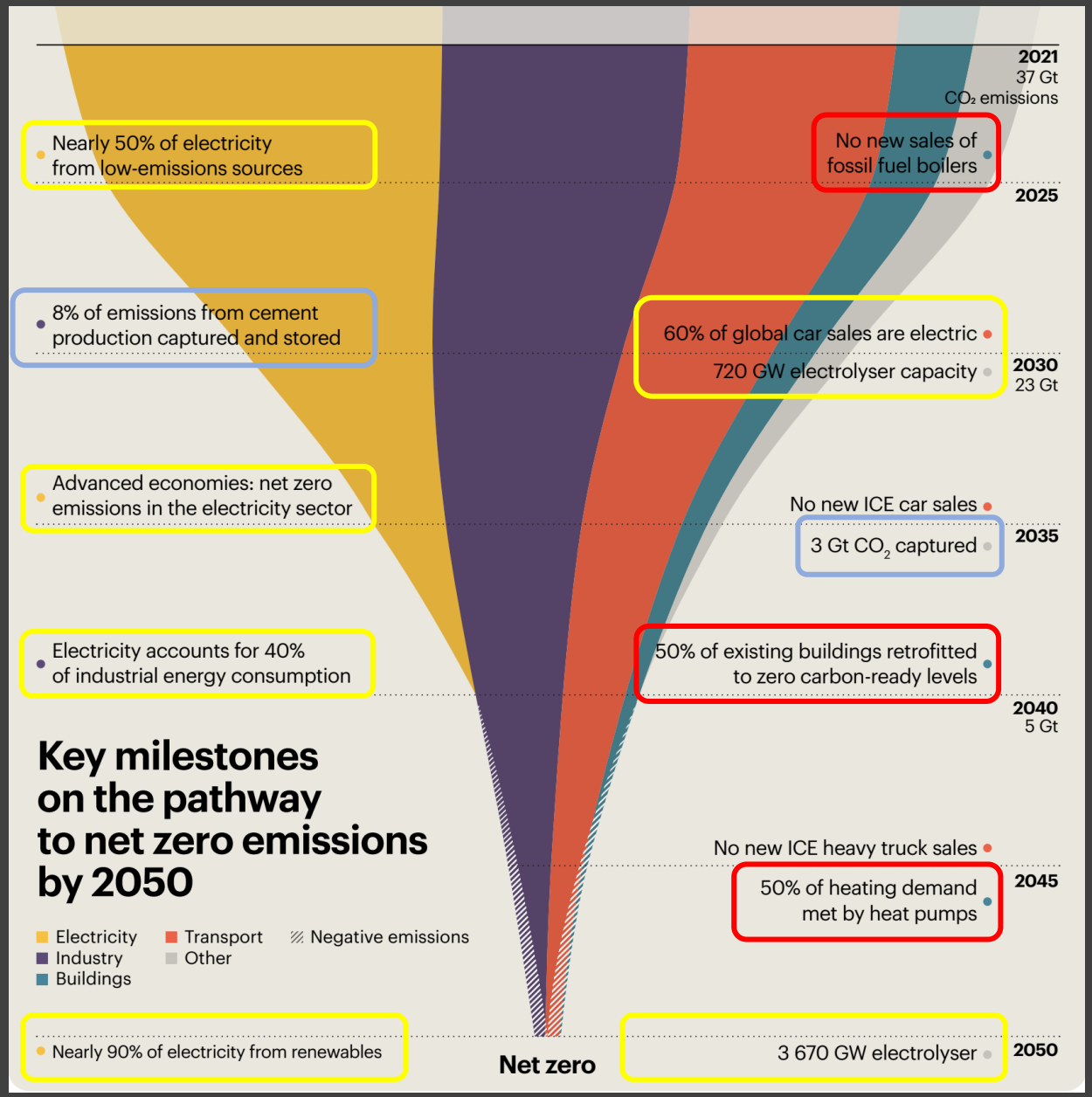


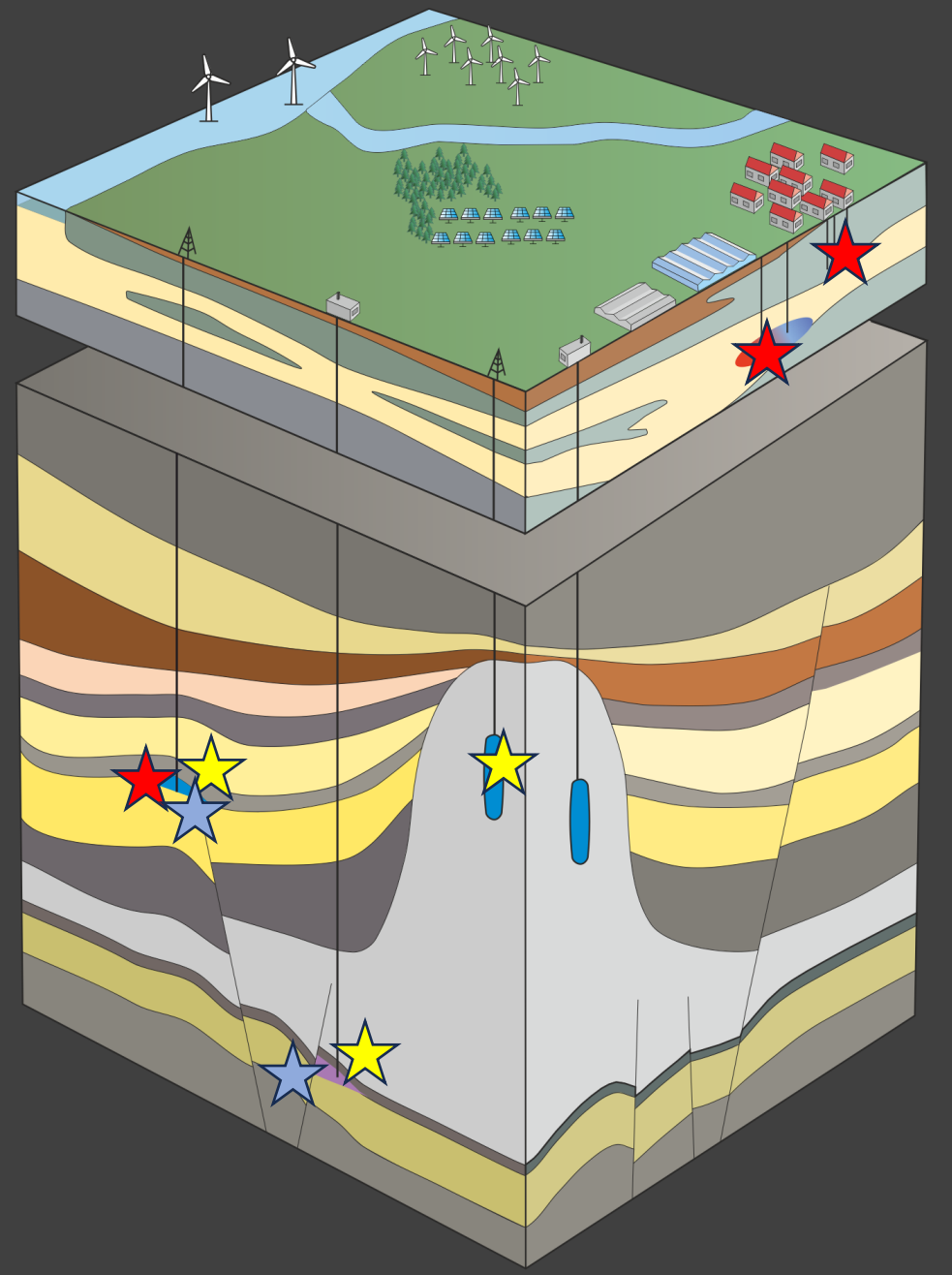
Worth & Waldron, 2026

Global CO2 storage



gasunie


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The subsurface can play an important role in the energy transition by:

- **Generating and storing electricity**
- **Producing and storing heat**
- **Storing CO2**

