GEAN
Geothermal Energy Association of Norway

EAPOLAB INITIATIVE
TO REALIZE ADVANCED GEOTHERMAL SYSTEMS (AGS)

1. Holistic Considerations: Geothermal and the “Energy Transition”
2. Deep Geothermal: Expanding the Application Spectrum to Geothermal Anywhere
3. AGS Designs and Low-Hanging Fruits for Faster Deployment
4. EAPOLAB Initiative Scope | EAPOLAB Svalbard-Longyearbyen

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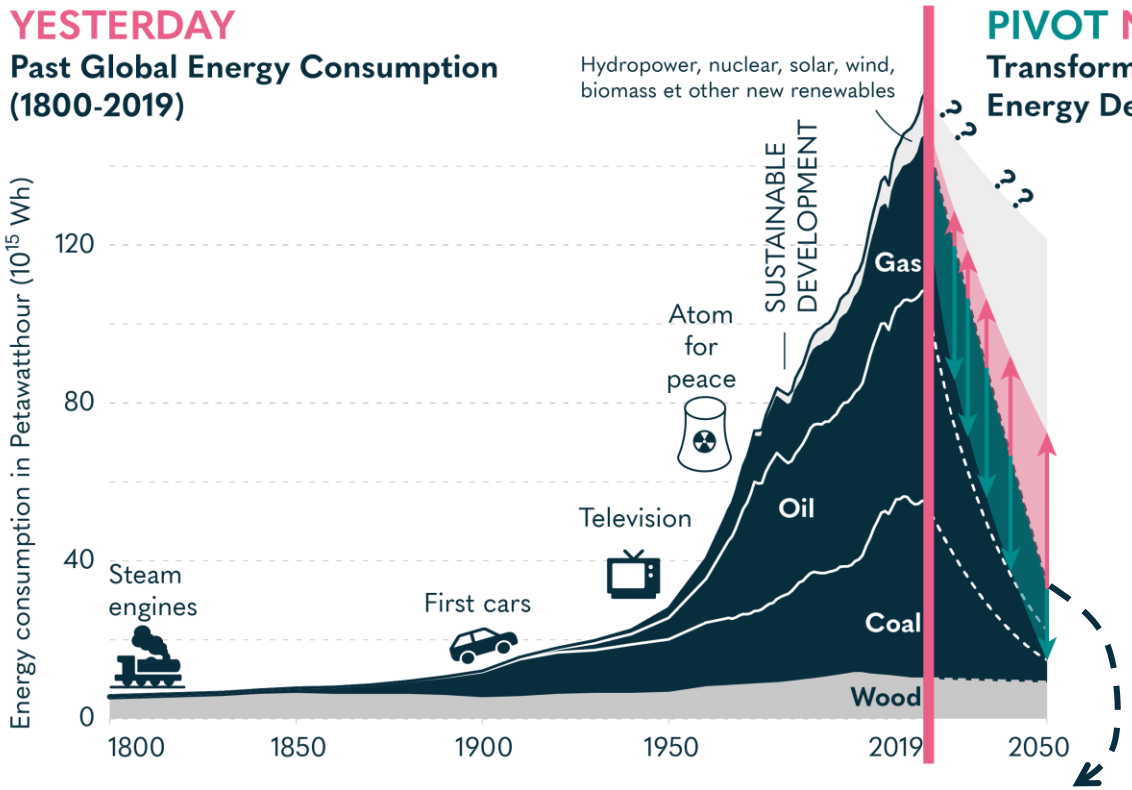
Energy-Climate Scenario for the ~~"Transition"~~ Transformation

Geothermal potential to TRANSFORM our energy future is twofold



Emission reduction slope for a 1.5°C Planet

Ubiquitous Energy Source

Low carbon, local, sovereign, baseload, dispatchable, minimal land footprint, can supply heating/cooling and/or electricity

De-escalating *Oil&Gas*

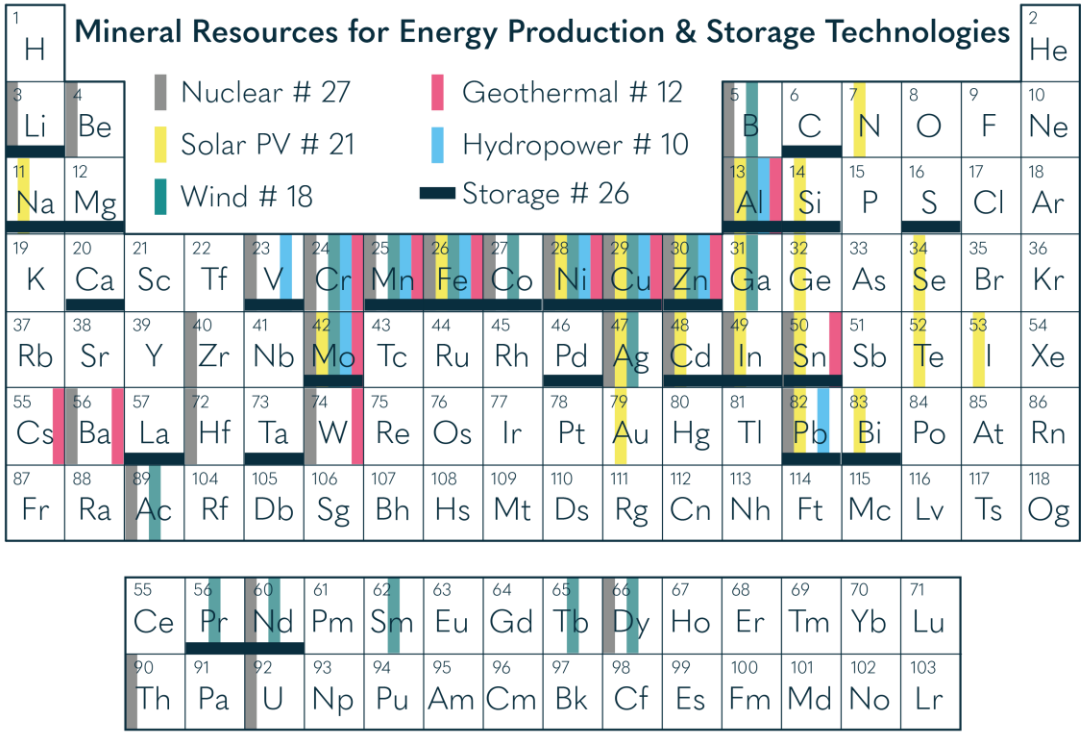
Deep geothermal is realized by transferring assets and technologies from the Oil and Gas Industry:

➔ Drill ➔ Produce heat ➔ Repeat*

Sources: Global Energy Consumption: BP Statistical Review of World Energy (2020), adapted from Vaclav Smil (2017); Icons | Freepik – flaticon.com. The fossil energy reduction slope is copied on the emission reduction slope required to keep global warming below 1.5°C (IPCC). * Project InnerSpace tag line.

Geothermal: Lower Critical Material Dependency

Compared to other Energy Generation Technologies, Geothermal has low rare minerals intensity



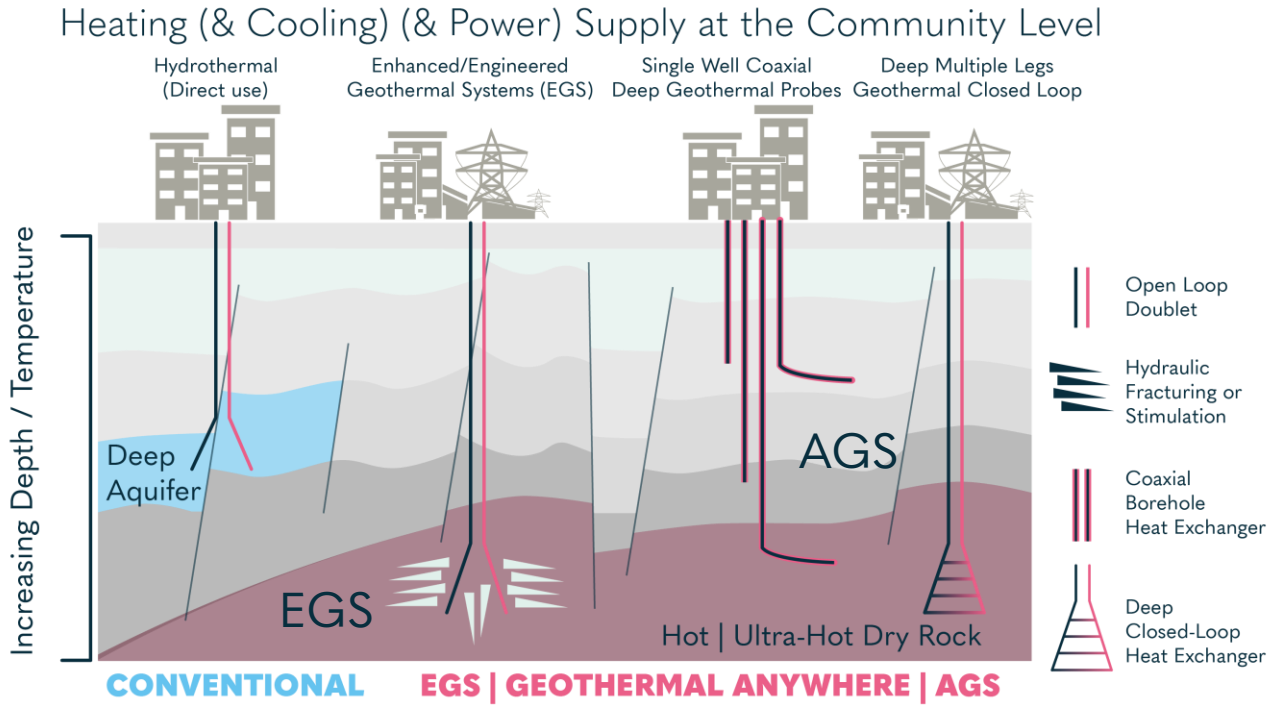
Sources: Periodic table from SystExt.org 2023 in prep., presented at the University of Lausanne, Sept. 26, 2023 by Aurore Stéphan; Based on Bihouix & Guillebon (2010): Quel futur pour les métaux?; Christmann (2016) Développement économique et croissance des usages des métaux; Marscheider-Weidemann et al. (2016) Rohstoffe für Zukunftstechnologien - *Auftragstudie DERA Rohstoffinformationen;* SystExt (2022) Entretien Thinkerview du 25 janvier 2022 - Sources et complements; KU LEUVEN & Eurométaux (2022) Metals for Clean Energy-Pathways to solving Europes raw materials challenge.
Note: EAPOSYS added Cs & Ba (drilling muds) and W (deep drill bit alloys) for geothermal.

IN A WORLD OF GROWING INSTABILITIES, SIMPLICITY AND ROBUSTNESS ARE KEY ATTRIBUTES!

- ✓ Geothermal produces heat by circulating water in underground pipes
- ✓ Geothermal assets are underground: less of a security risk
- ✓ **Geothermal increases energy autonomy and reshapes the geopolitical landscape**

➔ #GEOTHERMAL FOR PEACE

Deep Geothermal Systems: A Spectrum of Applications



99.9% of the estimated recoverable heat is stored into Hot Dry Rocks*

➔ PETROTHERMAL ENERGY IS UBIQUITOUS

BOTH EGS & AGS PURSUE GEOTHERMAL ANYWHERE

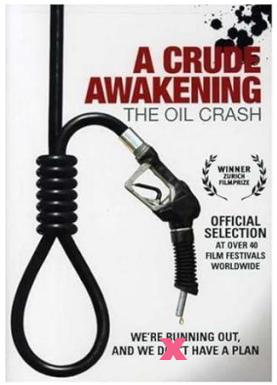
Geothermal systems archetypes | Illustration adapted from Causeway Energies (2023) and Abesser (2020) BGS.
* Brown et al. (2012), *Mining the Earth's Heat: Hot Dry Rock Geothermal Energy*, Chapter 2, Fig. 2-2.

Spectrum	Hydrothermal	Petrothermal
Coverage	Geological Niches (0.01%)*	Ubiquitous (99.9%)*
Design	Open (Brines)	Closed-Loop (Working Fluid)
Heat Recovery	Advection/Convection (Faster)	Conduction Only (Slower)
Induced Seismicity	May hold significant risk (Stimulation/Fracking)	Reduced (Pressure Balanced)
Challenges	Reservoir permeability/Pumping/Scaling	Deep Long Directional Drilling

Geothermal Anywhere: Low Hanging Fruit for Faster Deployment

USA – The Case for EGS

- Target: 60-90 GW_e by 2050
  i.e. > 3 doublets with 2 MW_e to be deployed per day
- DoE Energy Earthshots™ Initiative
  US$264 M for Basic Research (Nov. 2023)
- UTAH FORGE Laboratory
  Project InnerSpace, Fervo Energy…
- Amortizing the collapse of the existing Shale Oil&Gas Industry



The Permian Basin Is Depleting Faster Than We Thought

06/30/2023

GOEHRING & ROZENCWAJG | Natural Resource Investors

Beginning of the End for the Permian

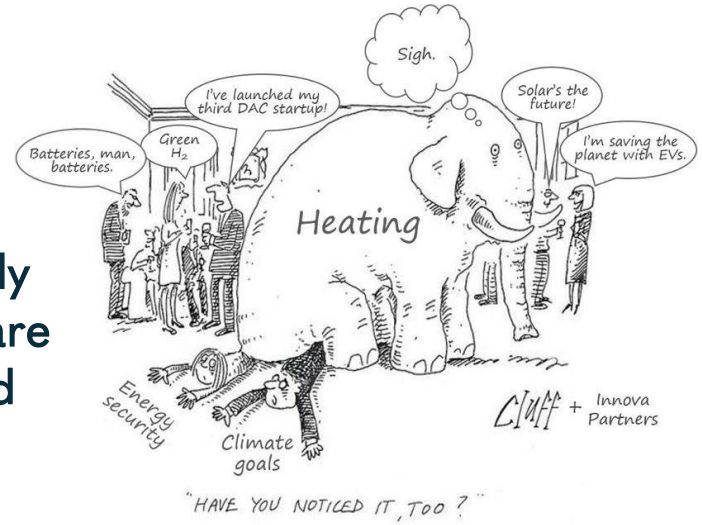
January 4, 2024 | Art Berman

Europe – The Case for AGS

- +10’000 existing District Heating Network (DHN), mostly running on gas (USA ~ 660 DHN)
- DHN require lower operational temperature
  ➔ AGS can be deployed at lower (easier) depth
- AGS require no fracking and are tailorable
  ➔ can be deployed withing communities to match the local demand

DHN = Natural entry market for AGS

Electricity can gradually increase its energy share as experience is gained



Sources: USA targets: DoE GeoVision (2019); NREL Enhanced Geothermal Shot Analysis (2023); Permian Basin Depletion: https://blog.gorozen.com/blog/the-permian-basin, https://www.artberman.com/blog/beginning-of-the-end-for-the-permian/; DHN in EU: https://map.mbfsz.gov.hu/geo_DH/; DHN in USA: DoE District System Overview; Cartoon: “Heating has been the elephant in the room for too long” by *Cluff* (John Longstaff) & Innova Partners in a Tweet from Jan Rosenow 23.03.2023. All websites last visited March 9, 2024.

Multiple Legs Closed Loop AGS Designs

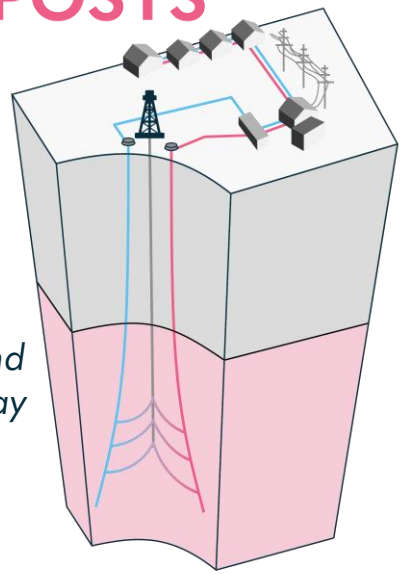
Incremental & Parallel

Legs are deployed from a service well and connected to injection and production wells.

EAPOSYS

WEP work well together

Not at scale
Patent pending
Number of wells and well trajectories may vary

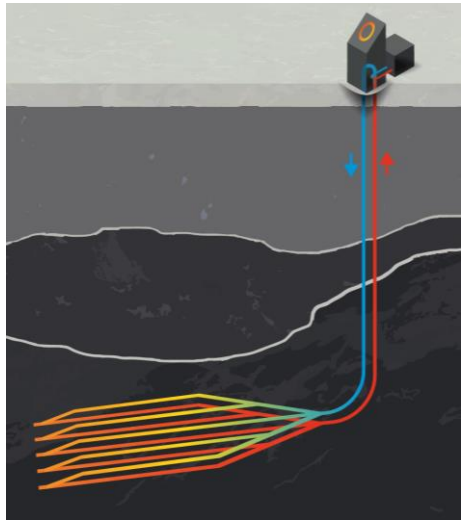


Plant can start operation as soon as the first loop is completed.

Series

Legs are drilled in parallel and simultaneously from the injection and production wells.

Eavor™



Plant must be fully drilled before starting operation.

Thermal Data Summary

Host rock: ~ 150°C @ 5 km

ΔT inlet-outlet: ~60-70°C

Well diameter: 8 ½ inches

Flow rate: max $\frac{1}{2}$ l/s per km of lateral*
* To keep T_{out} > 115°C | ~ 1 l/s for direct use only

Thermal output: 0.2 MW_{th} / km lat.*
* Enabling co-generation of heat + electricity

Reference unit (+100 years)
- 50 km of laterals
- 10 MW_{th} / 1 MW_e

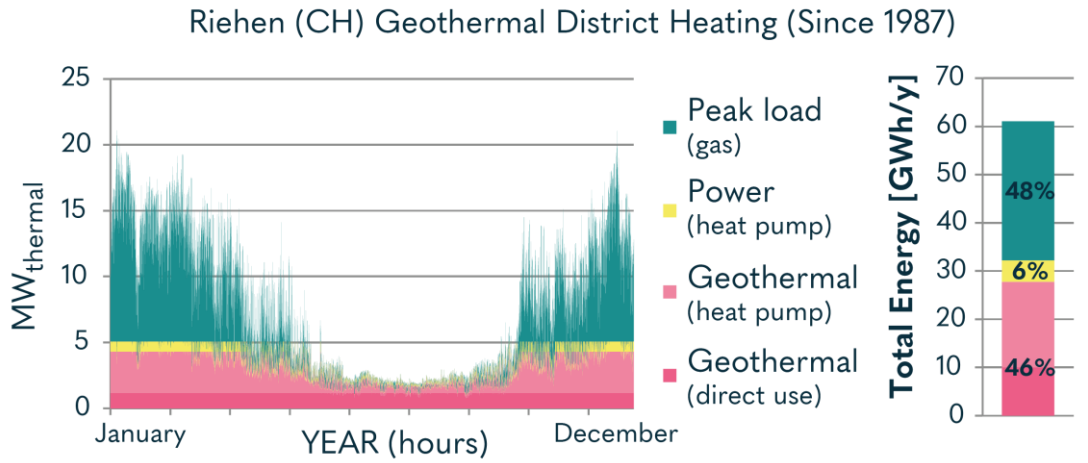
Supply for ~ 10'000 persons
(Current Swiss electricity and heating consumption)

Longfield et al. (2022): Eavor Loop™ Commercial Project at Geretsried, Molasse Basin, Germany. In European Geothermal Congress. Perrochet & Vouillamoz (2023) Advanced Geothermal System Thermodynamical Analyses – EAPOSYS SA report to Innosuisse.

District Heating Network – AGS Equivalent

RIEHEN GEOTHERMAL INSTALLATION

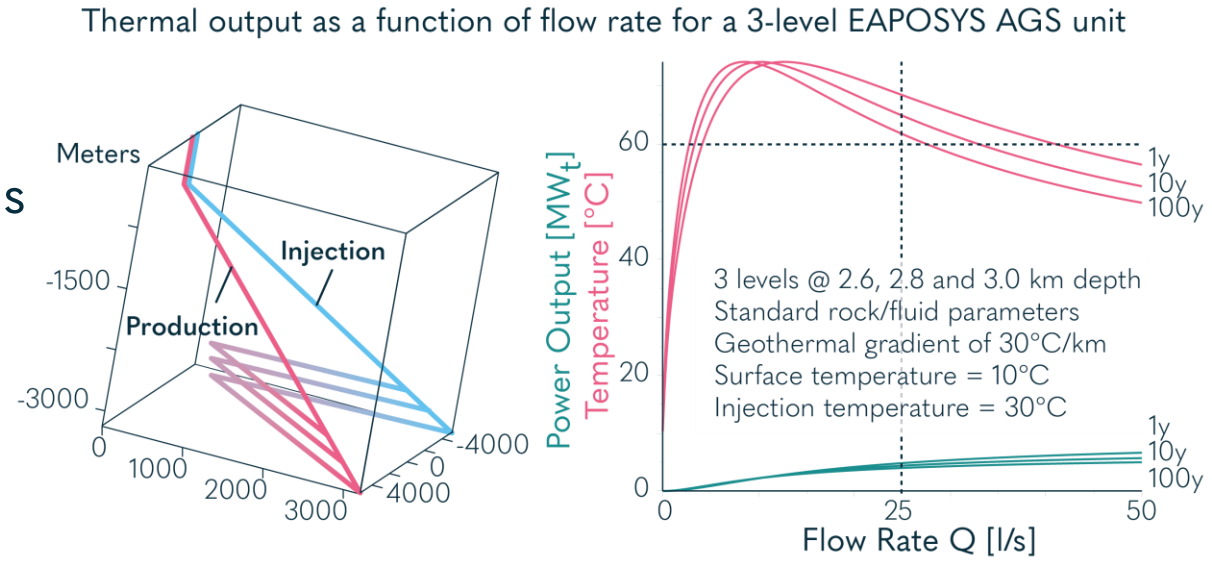
- Hydrothermal System (Muschelkalk)
- Heat & hot water DHN for 8'500 people
- 1 doublet (depth ~ 1600 m)
- 25 l/s @ 66°C
- 1 heat pump



RIEHEN EAPOSYS AGS EQUIVALENT

- 3-level, each leg ~ 4 km ➔ 24 km of laterals
- Depth between 2600-3000 m
  (30°C/km gradient, Surface T=10°C)

➔ 25 l/s @ +60°C for +100 years



Data source: Fassler J. 2022. Geothermie Schweiz. P4 CAD – Riehen Fact Presentation; Fassler J. & Quiquerez L. (2016). GeoCAD DH Simulation Tool. Geneva University and SIG; AGS Simulation: Pr. Perrochet Pierre, Neuchâtel University for EAPOSYS SA (2023).

EAPOLAB Initiative and Initial Core Partners

Initiative

A DEEP GEOTHERMAL ALLIANCE IS NEEDED!

➔ Public-private alliance network to develop and accelerate the adoption of AGS relevant technologies, know-whys and know-hows

EAPOSYS targets the deployment of 10 EAPOLABs by 2030, acting as a catalyst, using a non-vertical, distributed business model

EAPOLAB delivers

- ✓ AGS ENERGY PRODUCTION SITE
- ✓ AGS REFERENCE DEPLOYMENT GUIDE for HOST COUNTRY
  (Best advanced drilling and subsurface technologies for AGS; Optimal AGS setup for enhanced EROI/LCIA*; Suitable financial instruments for AGS deployment)

GOVERNMENT

- Ministry of Finance
- Ministry of Energy
- Ministry of Natural Resources

RESEARCH

- Universities
- Engineering Schools
- Rock Laboratories...

INDUSTRY

- Oil & Gas Field Services
- Energy Companies
- Technologies & Innovation

FINANCE/ECONOMICS

- Sovereign State Funds
- Banks
- Institutional investors

EAPOLABS INITIAL CORE PARTNERS

EAPOSYS
CH-Deep Geothermal Catalyst & AGS Reference Guide

NL-EAPOSYS AGS
WEP work well together
Well Design
Well Delivery
Sequence & Exec.

HALLIBURTON
International-Drilling Services Provider
Credibiliy - Review - Validation & Execution

NORCE
GEAN Geothermal Energy Association of Norway
NO-Geothermal Energy Research

Canopus
NL-New Deep Directional Steel Shot Drilling

Rijswijk Centre for Sustainable Geo-energy
NL-New Drilling Validation in Lab

GEOTHERMIE SCHWEIZ SUISSE SVIZZERA
CH-Geothermal Knowledge Transfer

unine Université de Neuchâtel
Centre d'hydrogéologie et de géothermie (CHYN)
CH-AGS Thermodynamics & Deep Rock-Geo-Mechanics

EAPOLAB – Svalbard | Longyearbyen

EAPOLAB Svalbard-Longyearbyen

Consortium Scope

✓ Umbrella for AGS pilots by/with local partners

Reasons

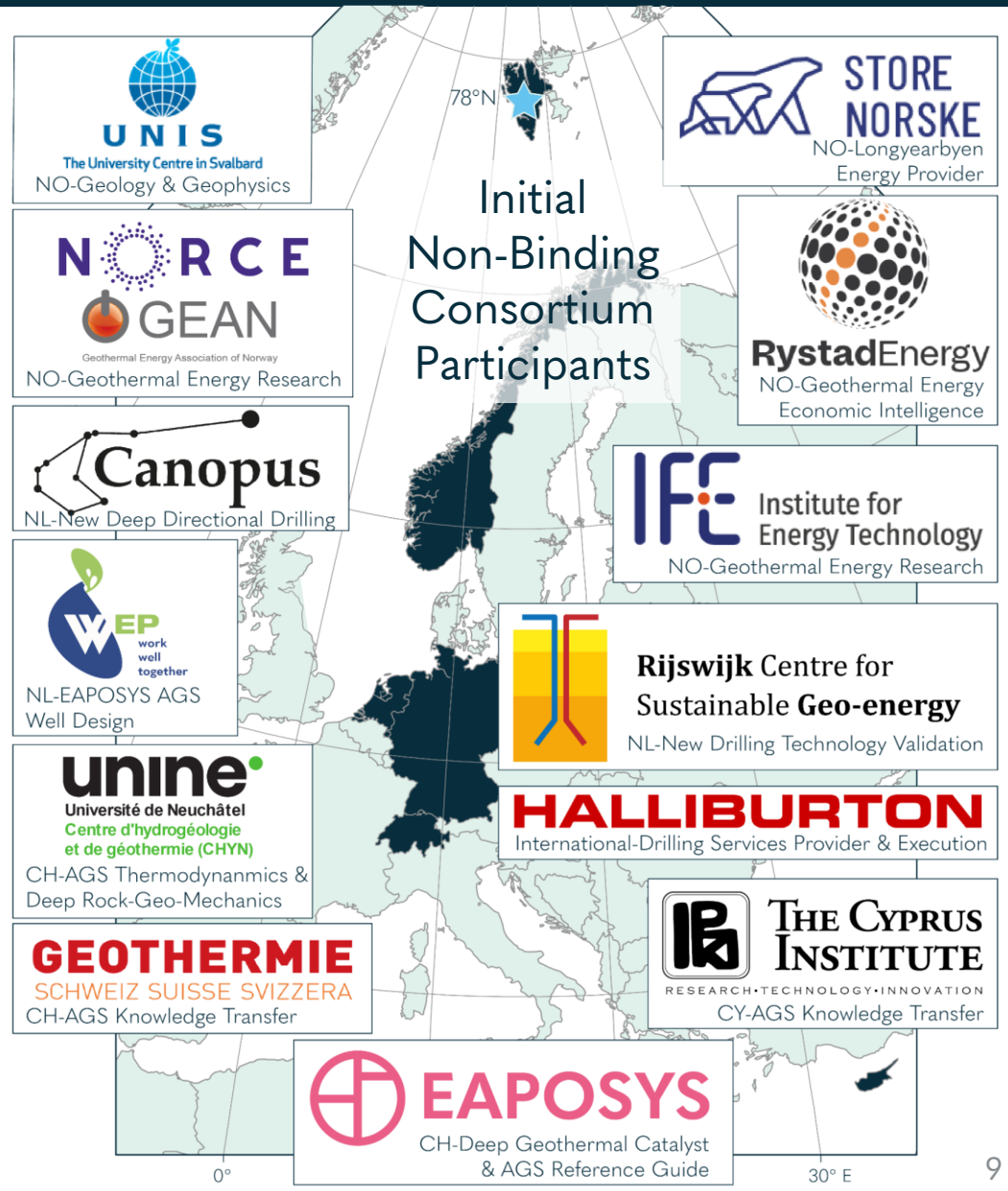
✓ Political will to phase out fossil-fueled energy supply
✓ Moderate peak-load need (few MW) both for heating and electricity supply
✓ Remote and constrained context calling for reliable solutions ➔ geothermal is a good candidate

Impact

✓ Norway takes a leading position in O&G pivot to Geothermal Anywhere
✓ Direct transfer to artic/insulated communities

Envisaged Funding

➢ EU Innovation Fund Very Large Scale Project (CAPEX>100 M€)
➢ Foundations, UHNWI, Sovereign State Funds



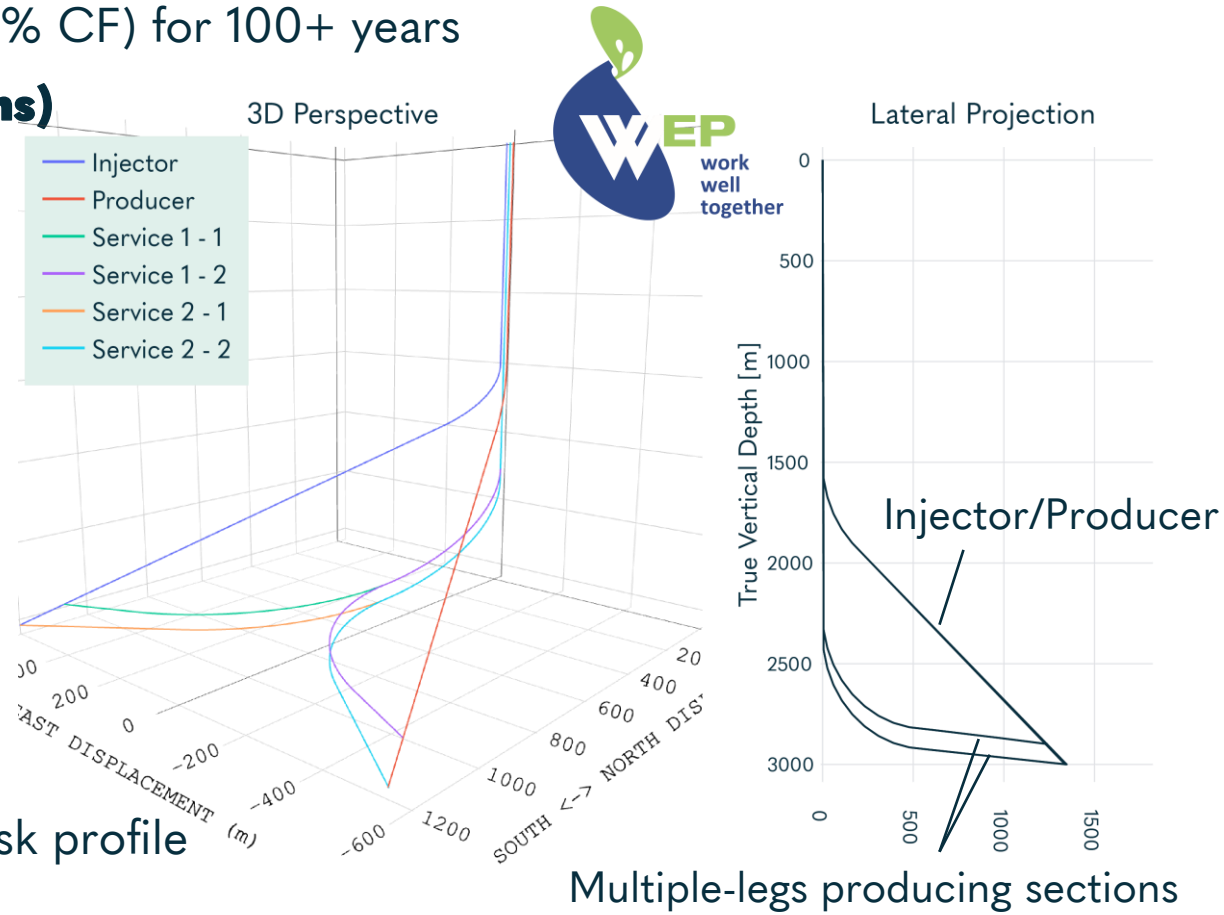
EAPOLAB – Svalbard | Longyearbyen

2-Level EAPOSYS AGS Unit

- "Eavor-Lite™ equivalent" ➔ 2 levels with 1.5-2 km cumulated lateral legs deployed between 2.5-3 km depth
- Potential thermal output ~ 0.8 MW_{th} ~ 6 GWh/y (90% CF) for 100+ years

Drilling cost evaluation (without surface installations)

Case	Pessimistic	New Tech
ROP – Sedim. [m/h]	10	30
ROP – Metam. [m/h]	3	20
Bit life – Sedim. [m/bit]	1000	1000
Bit life – Metam. [m/bit]	200	640
Tot. CAPEX + 50% contingency	60 M€	40 M€
Price per meter (15 km AH drilling)	3'500 €	2'800 €
Duration [Days]	300	140



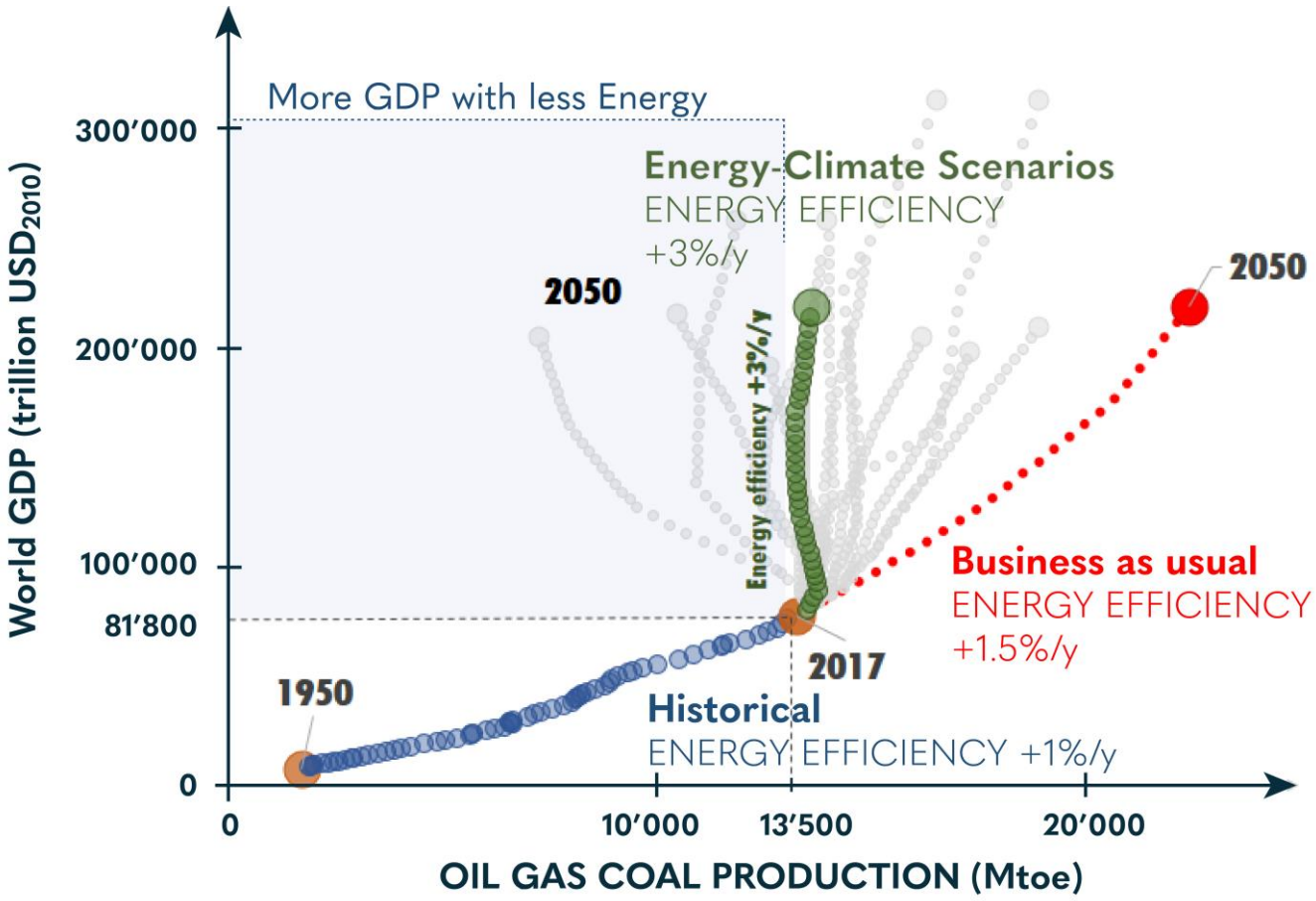
Realization Strategy

- AGS construction = Engineering problem with low risk profile
- AGS optimization = R&D and transfer

Backup Slides

Phasing-Out Fossils – A Difficult Imperative

GDP as a Function of Energy Consumption



HISTORICAL

GDP tightly coupled to fossils

➔ Fossils fuels ~ GDP growth engine

FUTURE

Business as usual dilemma

➔ How much recoverable Oil & Gas left in a cooking planet?

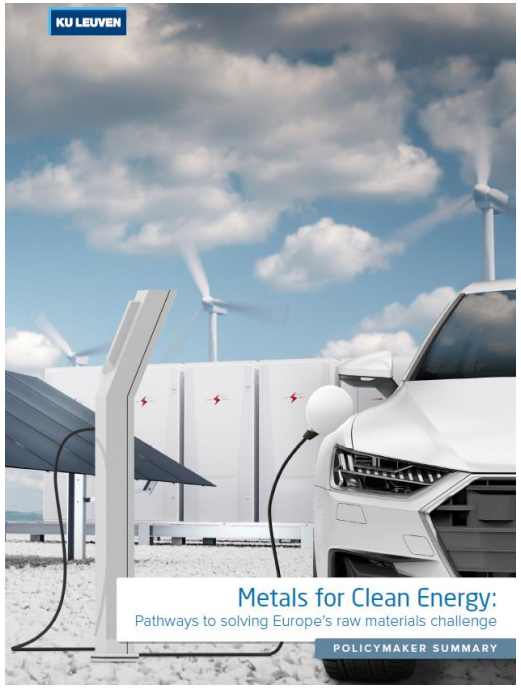
Energy-Climate scenarios

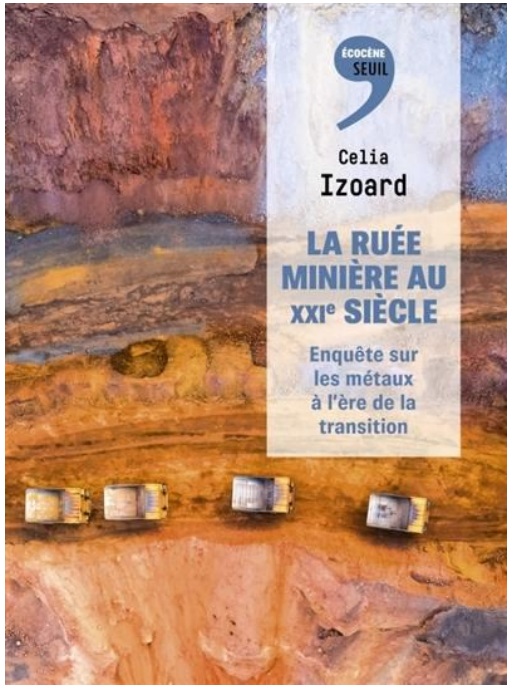
➔ Require NEVER-OBSERVED TRENDS of +3% energy efficiency increase per year!

Source: Energy-Climate Scenarios: Evaluation and Guidance": New report by The Shift Project with AFEP (France).

The Energy Transition Tale - Electrifying the World with Metals

➔ RESOURCES DEPLETION ➔ SUPPLY CHAIN VULNERABILITY ➔ GEOPOLITICAL CONFLICTS





EU TRANSITION METAL DEMAND:
(steel excluded)

- 10-fold increase on top of an already exploding demand for "everyday use" (look around you!)

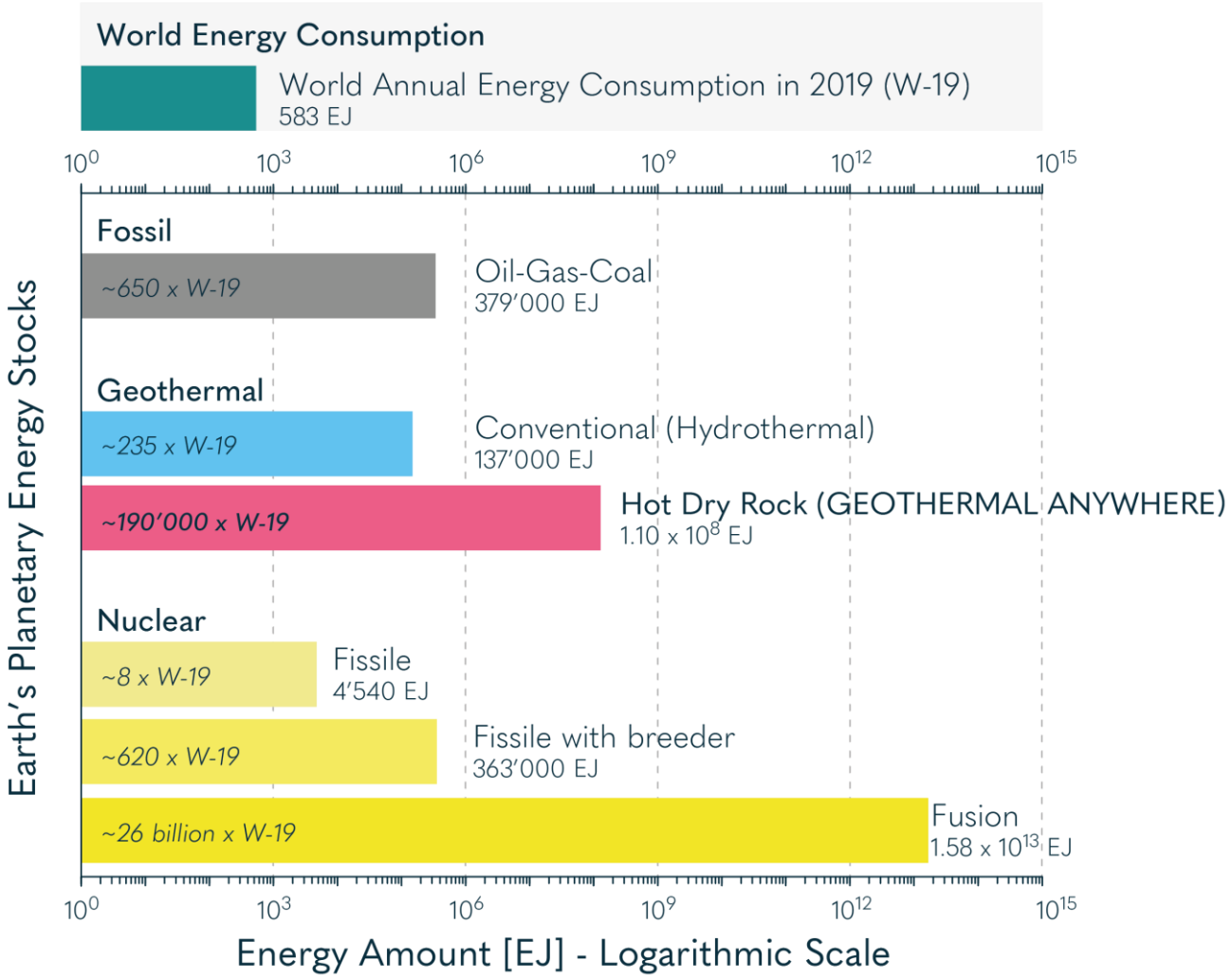
MINING INDUSTRY:

- By essence, the most polluting (liquid, solid, gas wastes) and controversial (human rights) industry worldwide.
- Requires cheap & abundant fossils to be affordable

Sources: KU LEUVEN & Eurométaux (2022) *Metals for Clean Energy-Pathways to solving Europe's raw materials challenge*; Celia Izoard (2024) *La ruée manière au XXIe siècle* & Systext.org.

Deep Geothermal Tremendous Potential – Earth's Energy Stocks

Geothermal Anywhere potential is exceeded only by Fusion



- **Conventional** (hydrothermal) geothermal represents **0.01%** of recoverable geothermal energy.
- **99.9%** recoverable geothermal energy stored in ***HOT DRY ROCK***, 'hence the claim that it is **UBIQUITOUS**.
- *THE AIM IS TO REALIZE GEOTHERMAL ANYWHERE*

Sources: Based on Brown et al. (2012): Mining the Earth's Heat: Hot Dry Rock Geothermal Energy. Springer Berlin Heidelberg. Fig. 2-2. Note that geopressured geothermal (oil/gas/water mixed reservoirs, 570'000 EJ) potential has been removed from the graphic for clarity purposes.

District Heating: Potential and Challenges

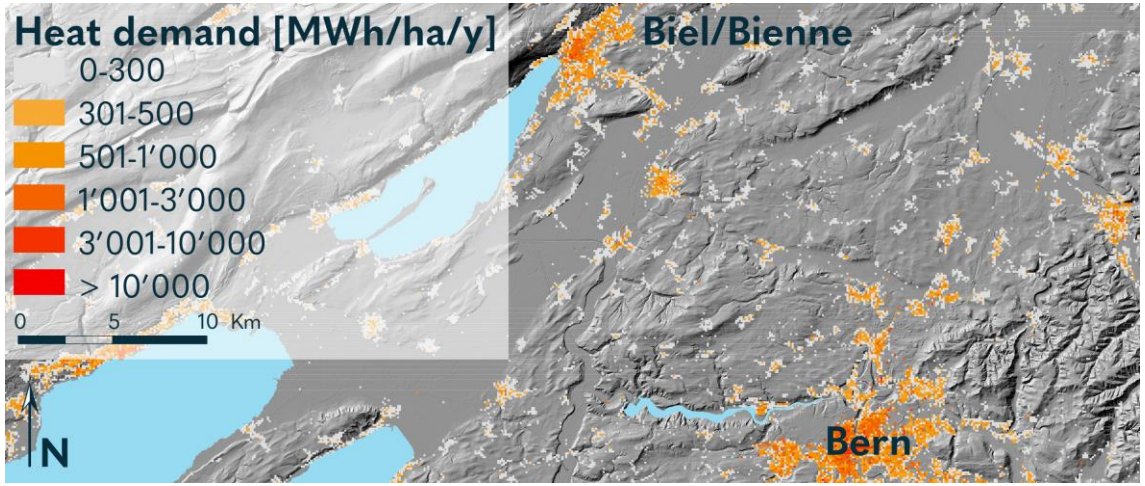
POTENTIAL

District heating sourced on renewable is key to decarbonate heating/cooling supply in cities

(E..g. Quiquerez et al. (2017): The role of district heating in achieving sustainable cities: comparative analysis of different heat scenarios for Geneva.)

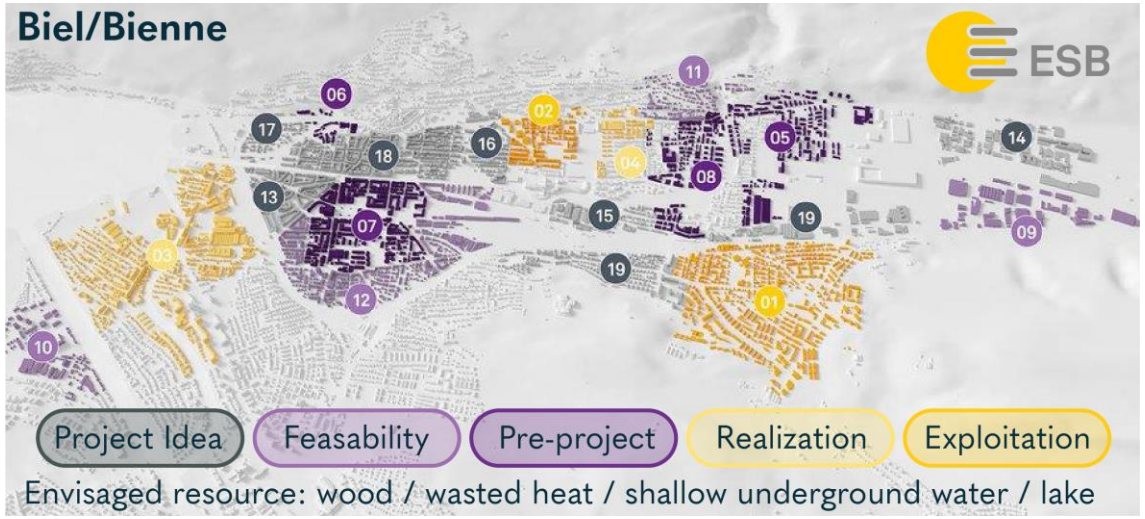
About 1/3 of the total heating demand is suited for residential district heating application

(E..g. Geothermie Schweiz - Positionspapier Wärmepotenzial Geothermie 02.10.2020)



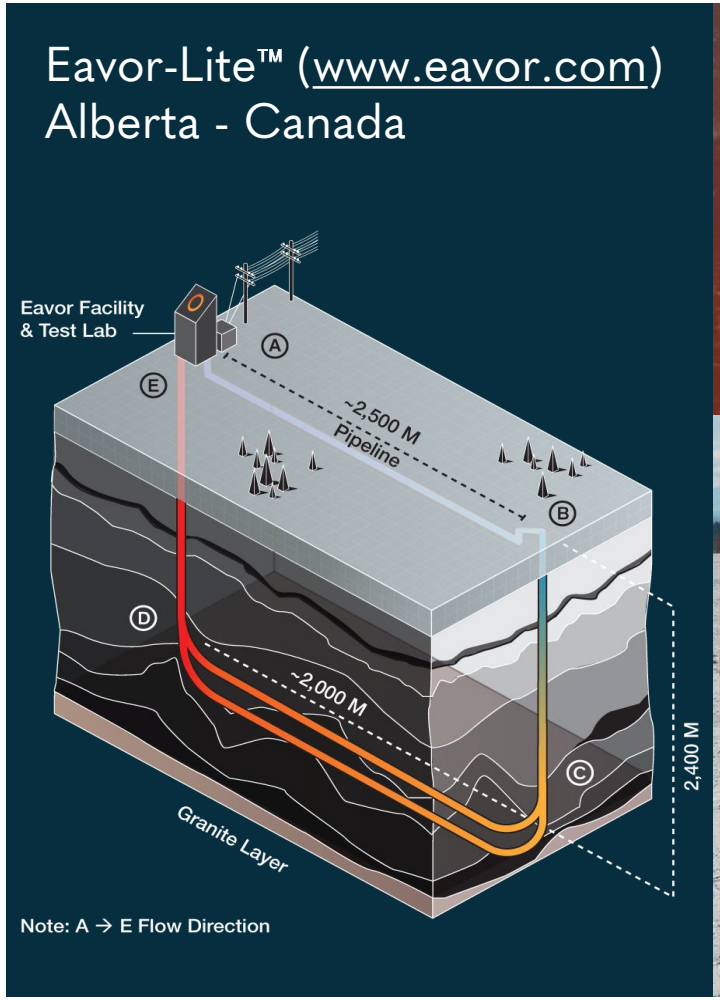
CHALLENGES

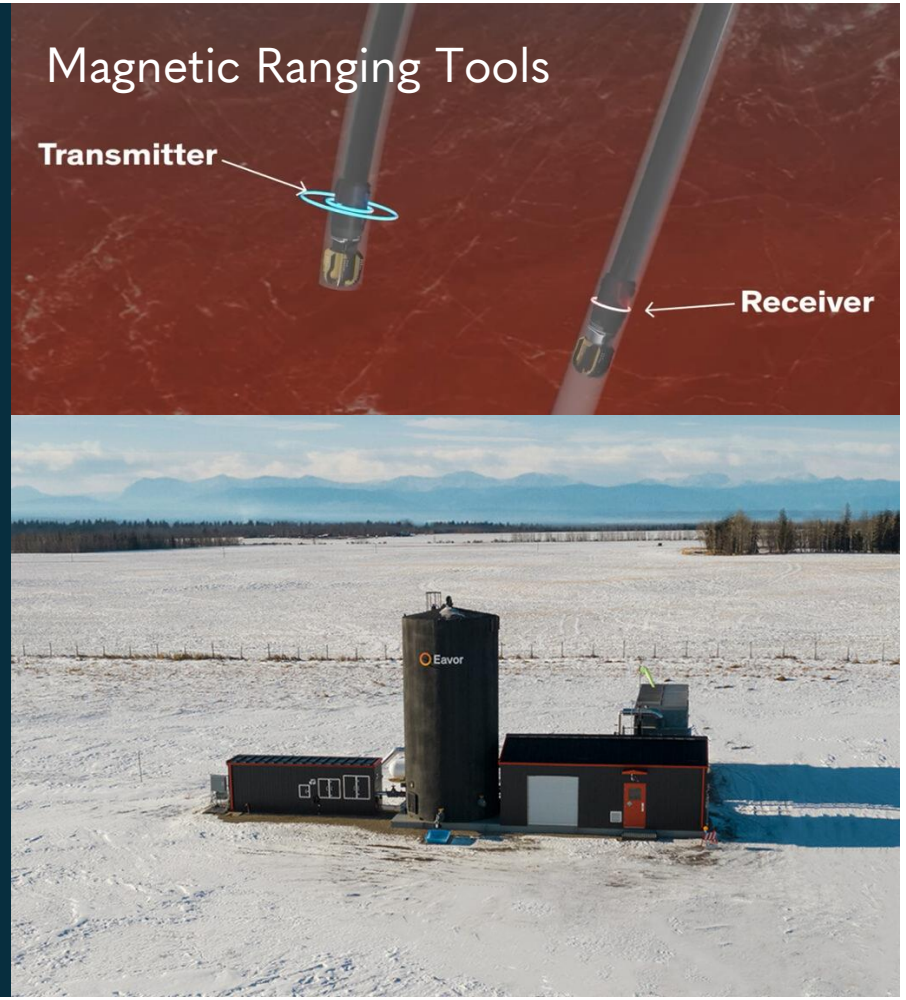
- Limited renewable heat sources availability
  E.g.: Fribourg Canton raising alert on wood
  Staat Freiburg | 12 Mai 2023 | Aktualisierte Berechnung des Nutzungspotenzials von Energieholz in den Wäldern des Kantons Freiburg.
- Usage conflicts
  E.g.: Dense heat resources should be kept in priority for HT industrial applications



Data source (Top) map.geoadmin.ch swisstopo Residential heat/cooling demand | swissALTI3D multidirectional hillshade | Lakes (Bottom) Illustration adapted from Energie Service Biel/Bienne (2022) Conférence Chaleur/Froid à distance. https://www.esb.ch/de/

Eavor-Lite™ Demonstration Pilot





- **Drill & Intersect:** Multilaterals deviated and connected on horizontal section (Eavor-Lite™)
- **Horizontal Completion**: «bare foot» and coating with «self-sealing fluid» (RockPipe™).

PREDICTABILITY

- **Thermodynamics**: Simulated performances validated by 4 years of data (2019-2023) 20 GWh_{th} delivered.
- **Thermosiphon effect:** Demonstrated ➔ pumps are required only on surface to start the system.

Illustration credits: Eavor™. Toews & Schwarz (2020), *Eavor-Lite Demonstration Project. Final Confidential Report prepared for Alberta Innovates and Emissions Reduction Alberta*; Zatonski & Brown (2023), *Eavor-Lite Update After Four Years Of Operation*, GRC Transactions 47.