Triple N Talks

Geological CO_2 Storage: the Technology and the Austrian Potential

The Challenge
CCS and Geological CO_2 Storage
Aspects of Storage Safety
CCS Projects
CCS in Austria?

Leoben, Mey 15 2025
online

CARBON CAPTURE, TRANSFORMATION, UTILIZATION & STORAGE

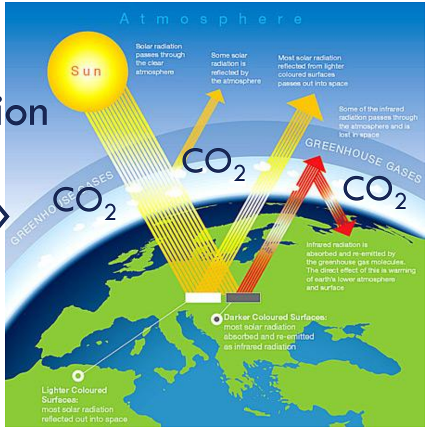
The Challenge

The Problem

CO_2 CO_2

combustion
→ electrical energy

CO_2
Emission

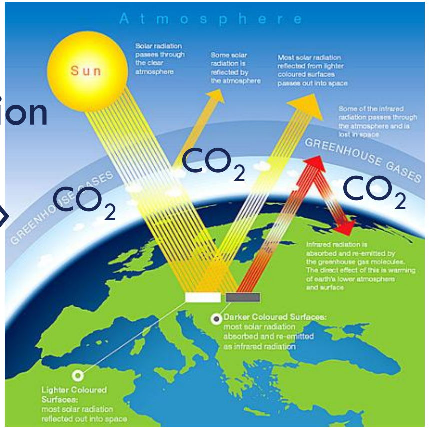


Greenhouse gas effect
→ global warming

The Problem

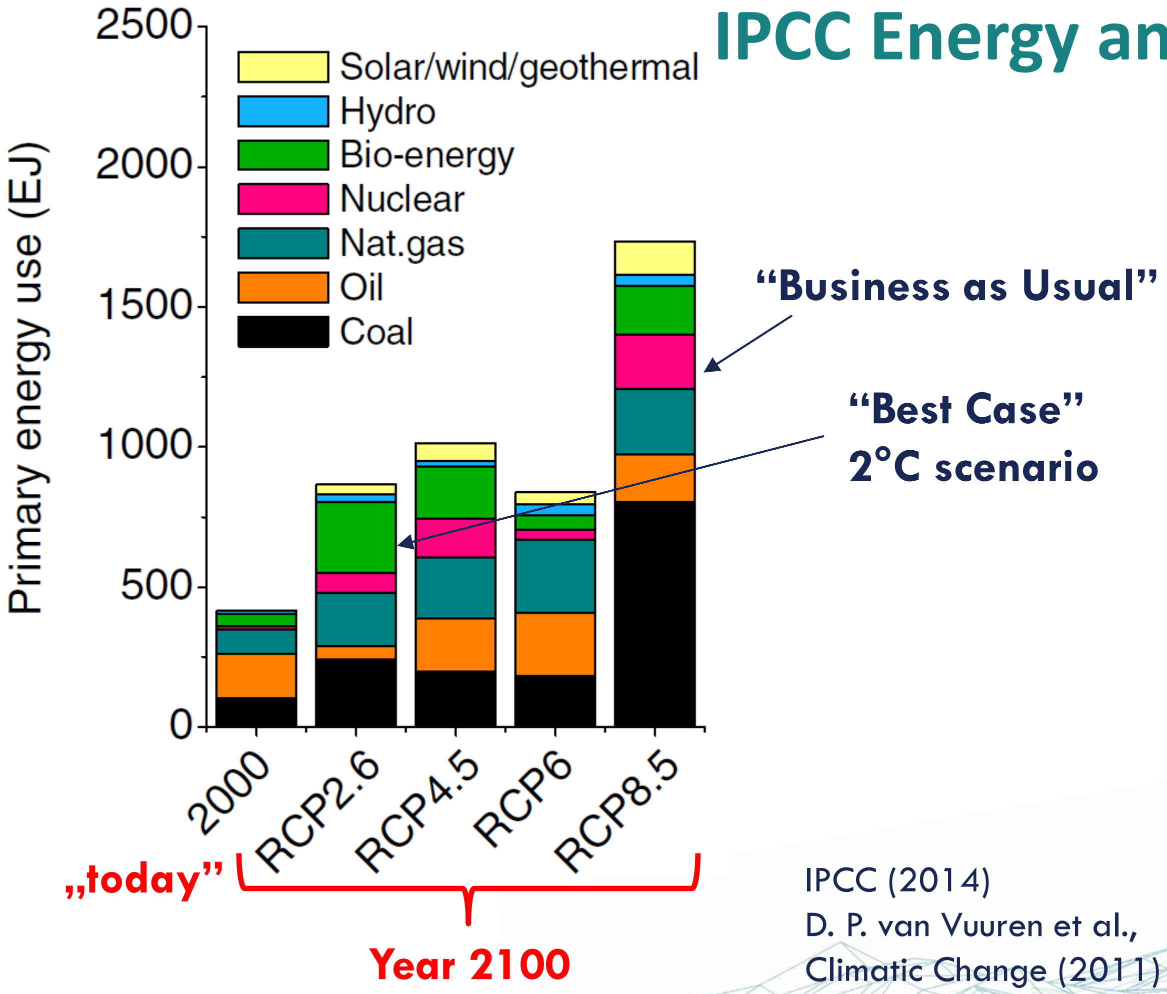
CO_2 CO_2

CO_2
Emission



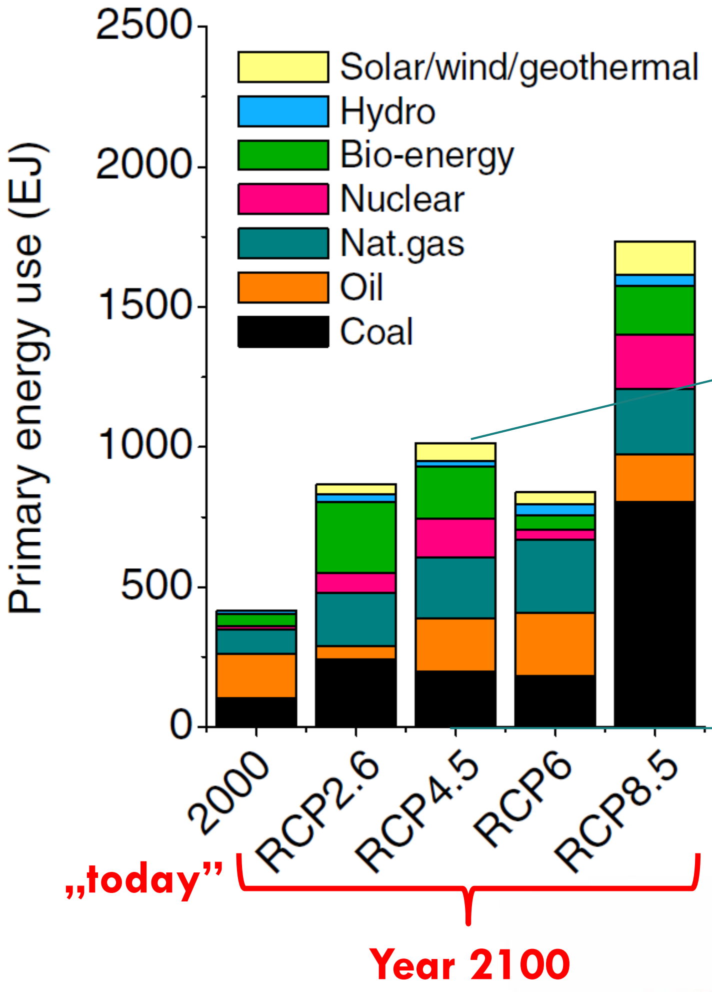
Greenhouse gas effect
→ global warming

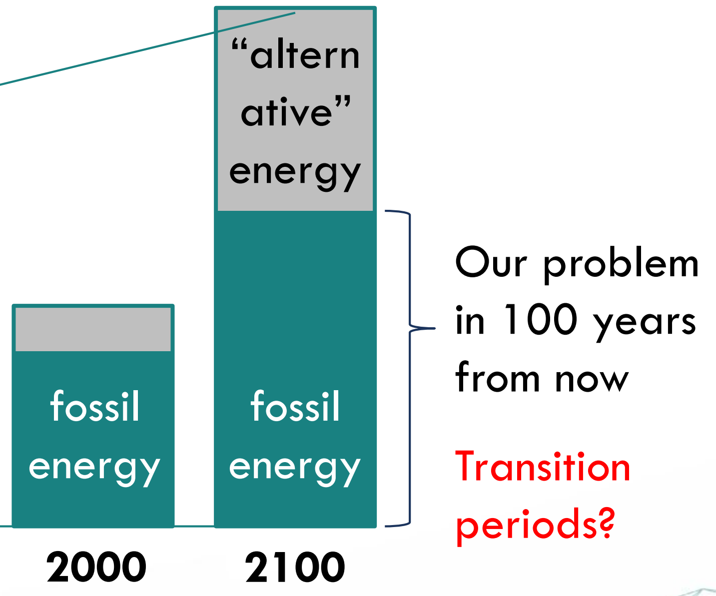
IPCC Energy and Climate Scenarios



IPCC (2014)
D. P. van Vuuren et al.,
Climatic Change (2011)

IPCC Energy and Climate Scenarios



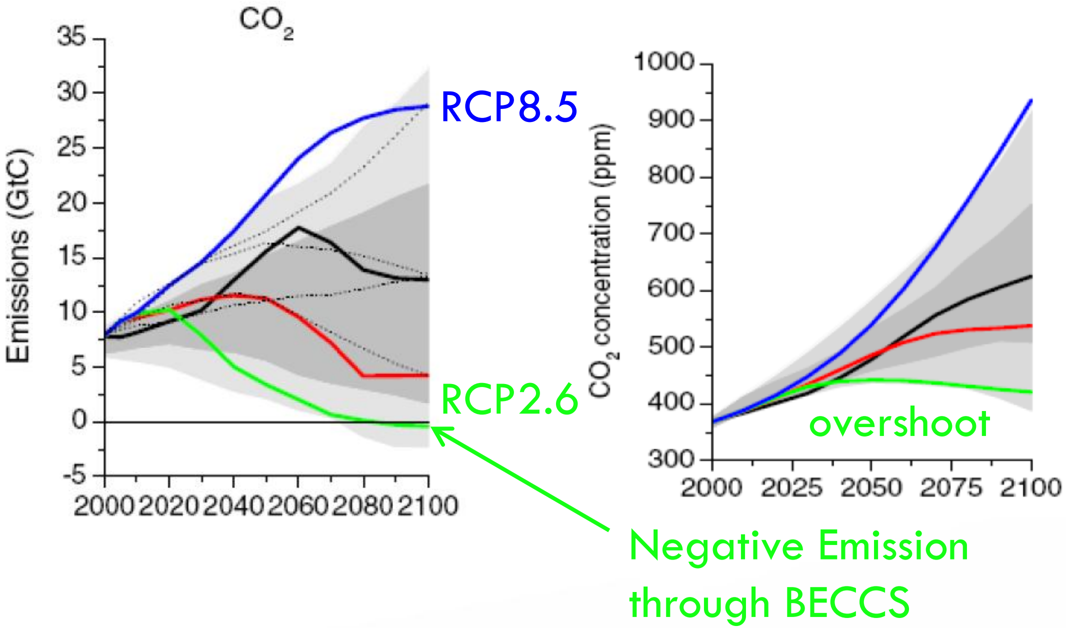


IPCC (2014)
D. P. van Vuuren et al., Climatic Change (2011)

The Role of CCS and BECCS

CCS plays a role in all mitigation scenarios [IPCC 2023, IIASA]

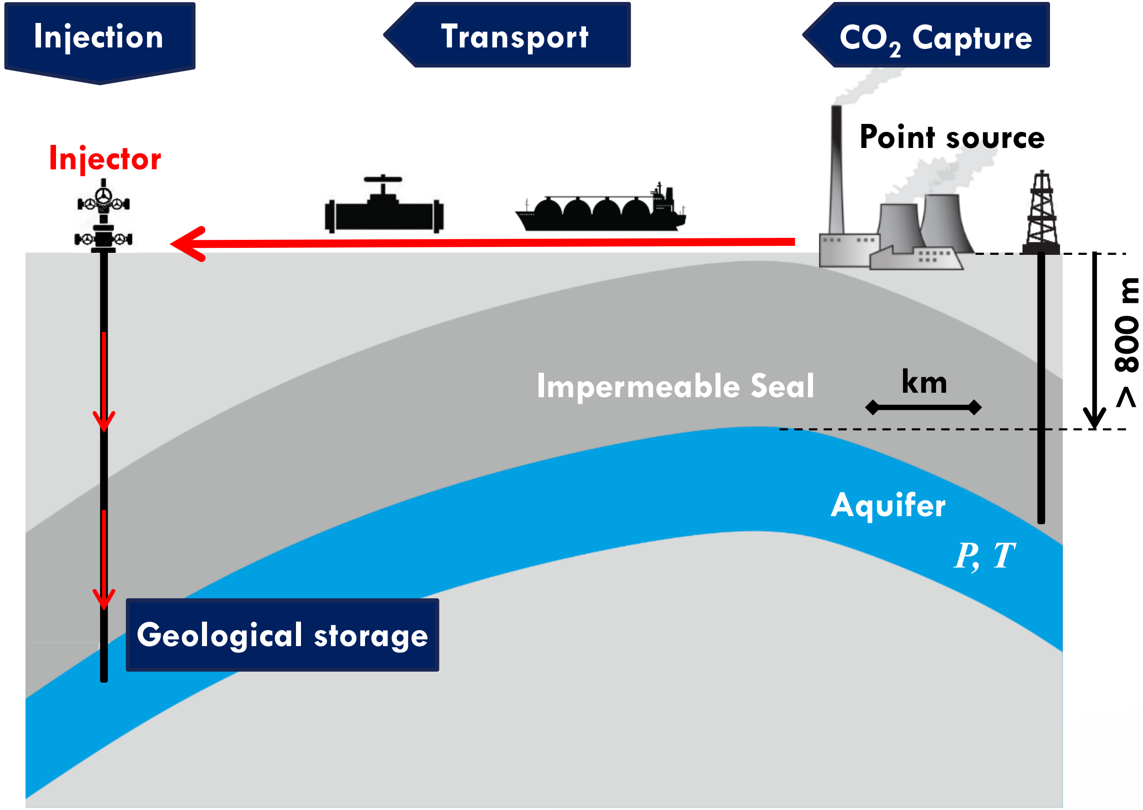
"**Overshoot scenarios** - require **extensive development of BECCS** - a combination of geological carbon sequestration and bioenergy – and afforestation in the second half of the century" [IPCC, 2014]



IPCC (2014)
D. P. van Vuuren et al., Climatic Change (2011)

What is CCS?

Carbon Capture and Storage



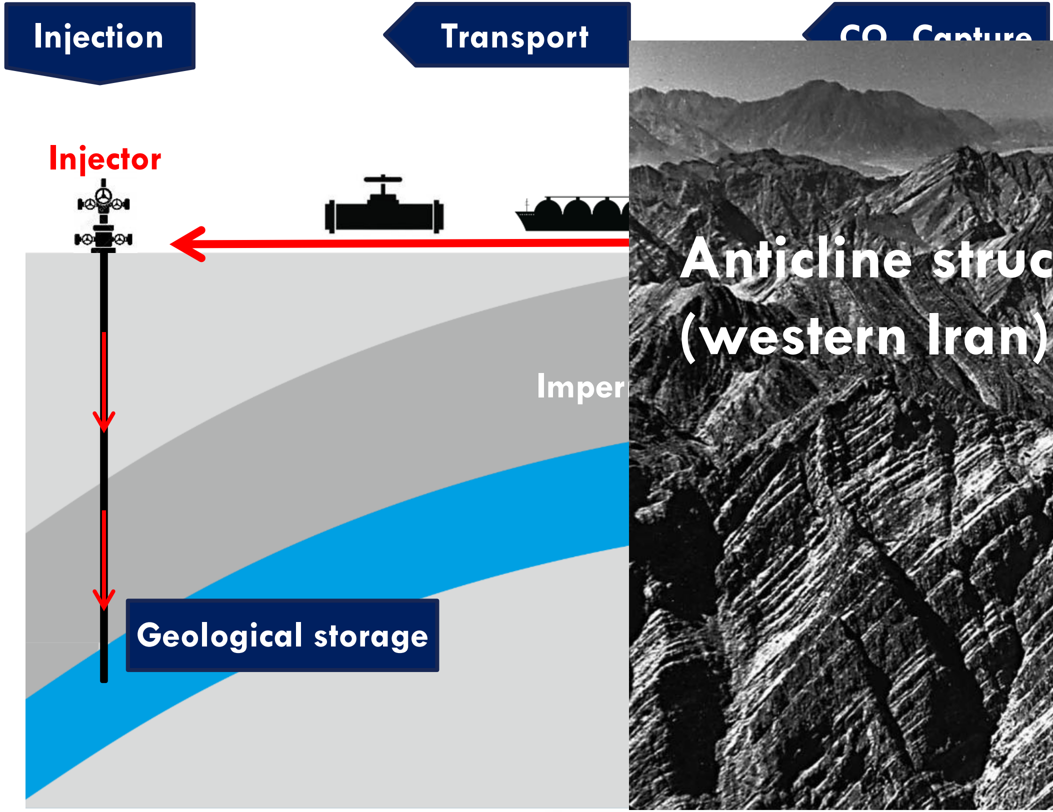
Point sources:

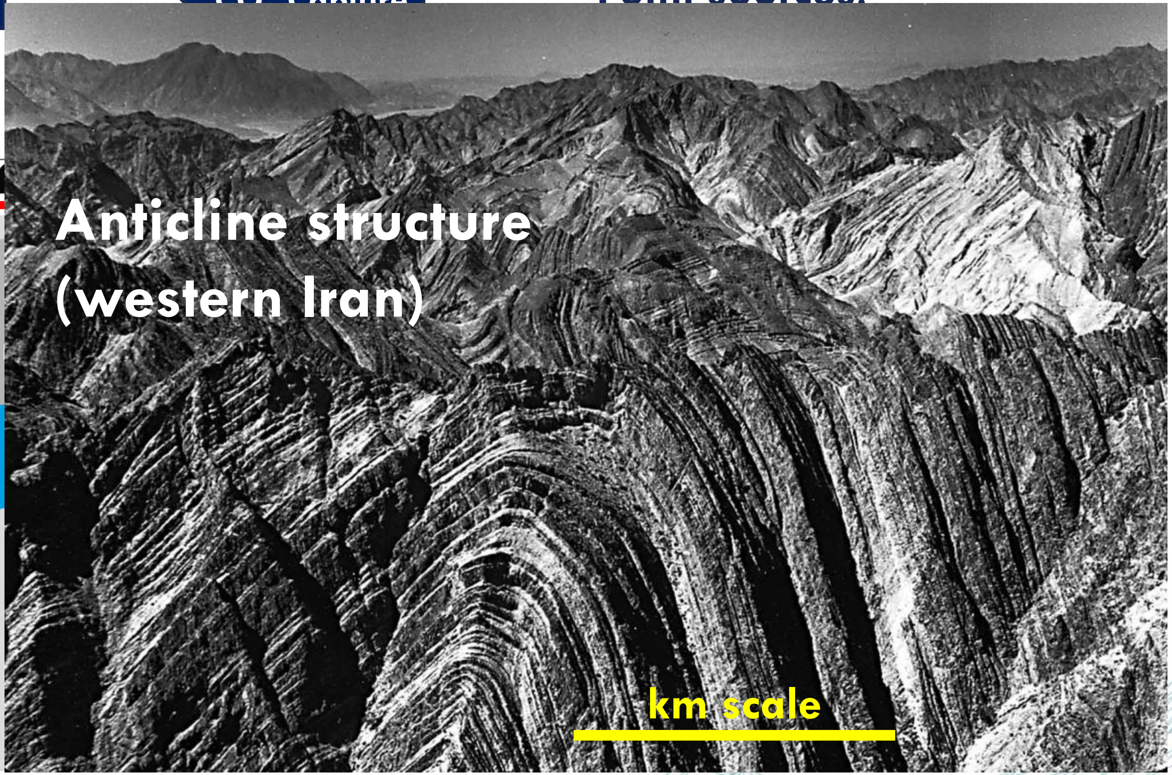
- ❑ Power plants
- ❑ HC production
- ❑ Hard-to-abate Emissions: Steel/cement industry
- ❑ …
- ➢ >0.1Mt CO_2/a

Geological Targets:

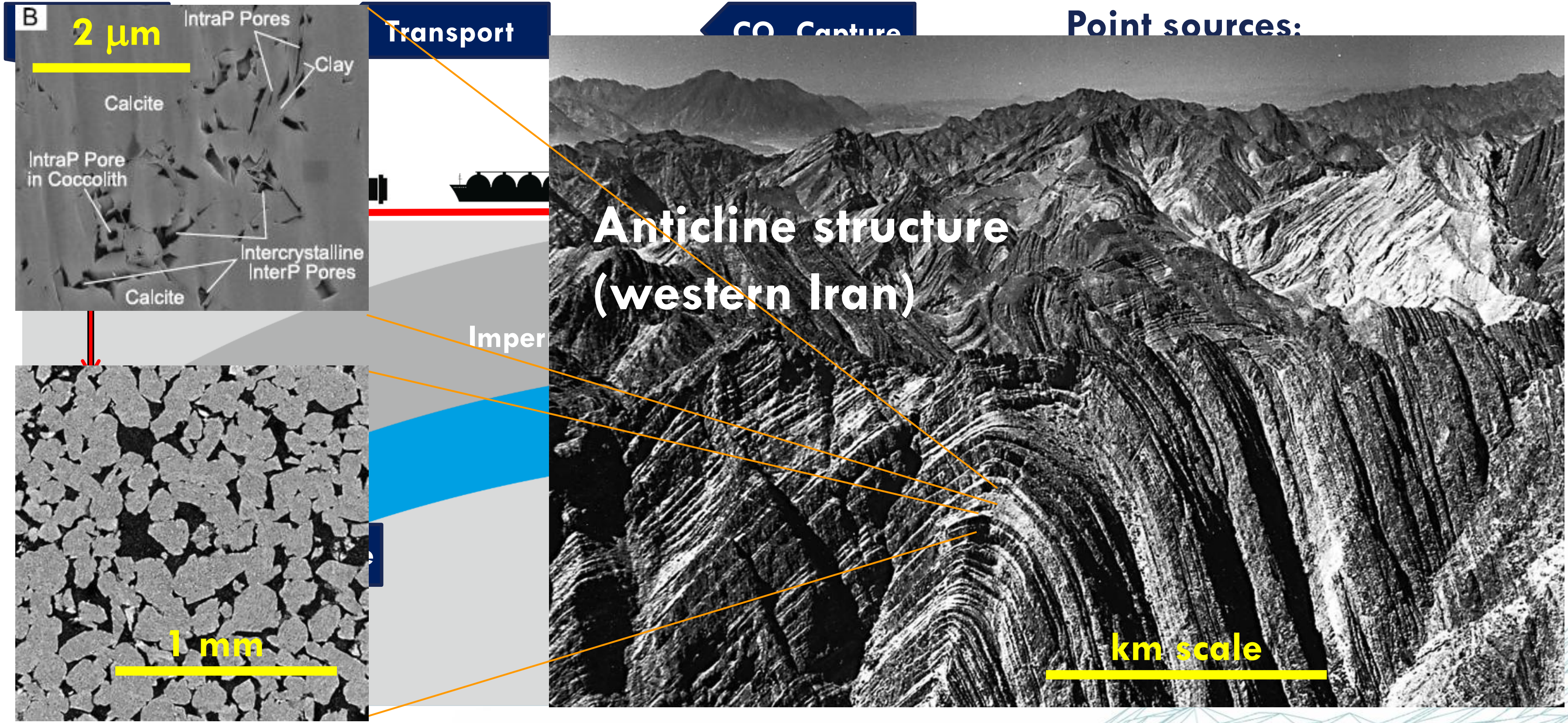
- ❑ Deep aquifers
- ❑ Depleted HC fields
- ❑ CO_2 EOR operations
- ❑ …

Carbon Capture and Storage





Carbon Capture and Storage



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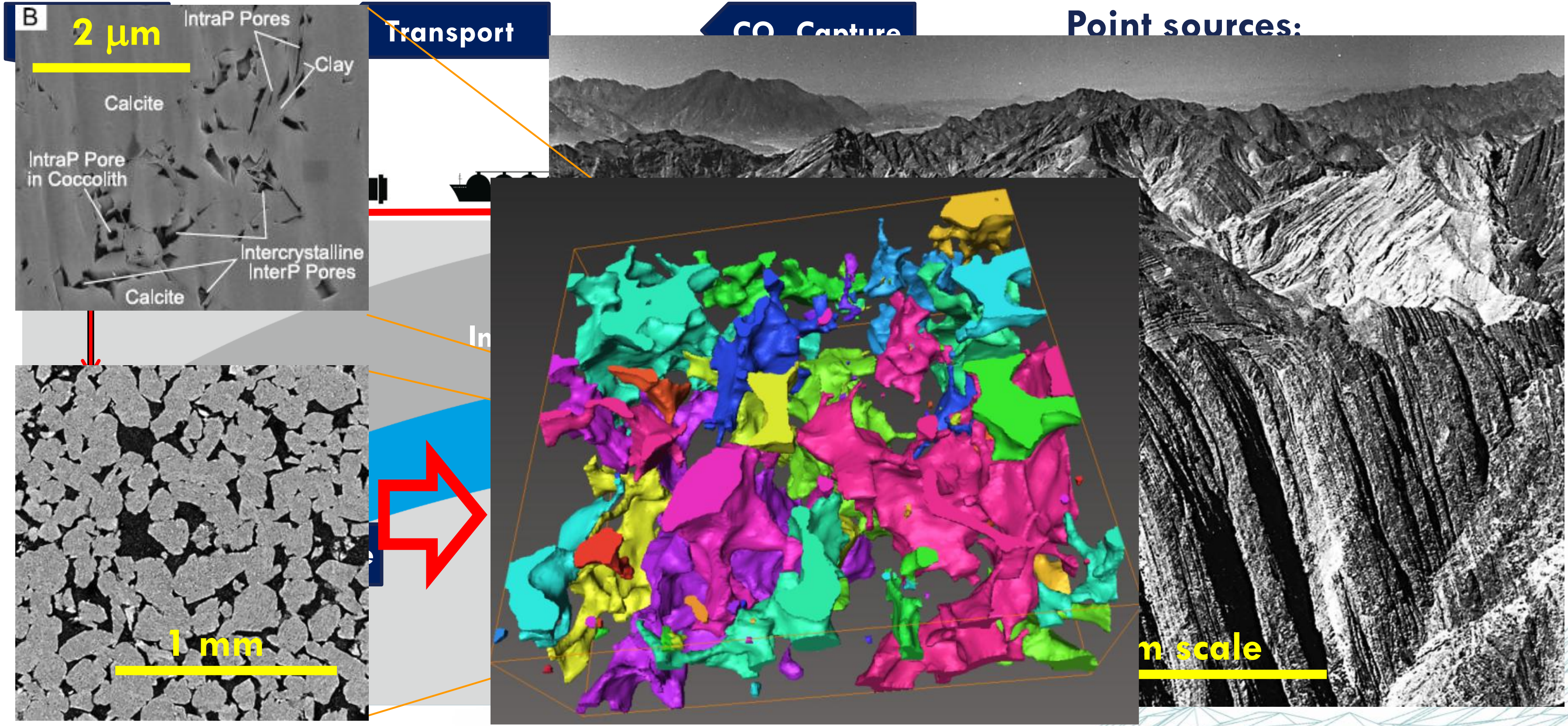
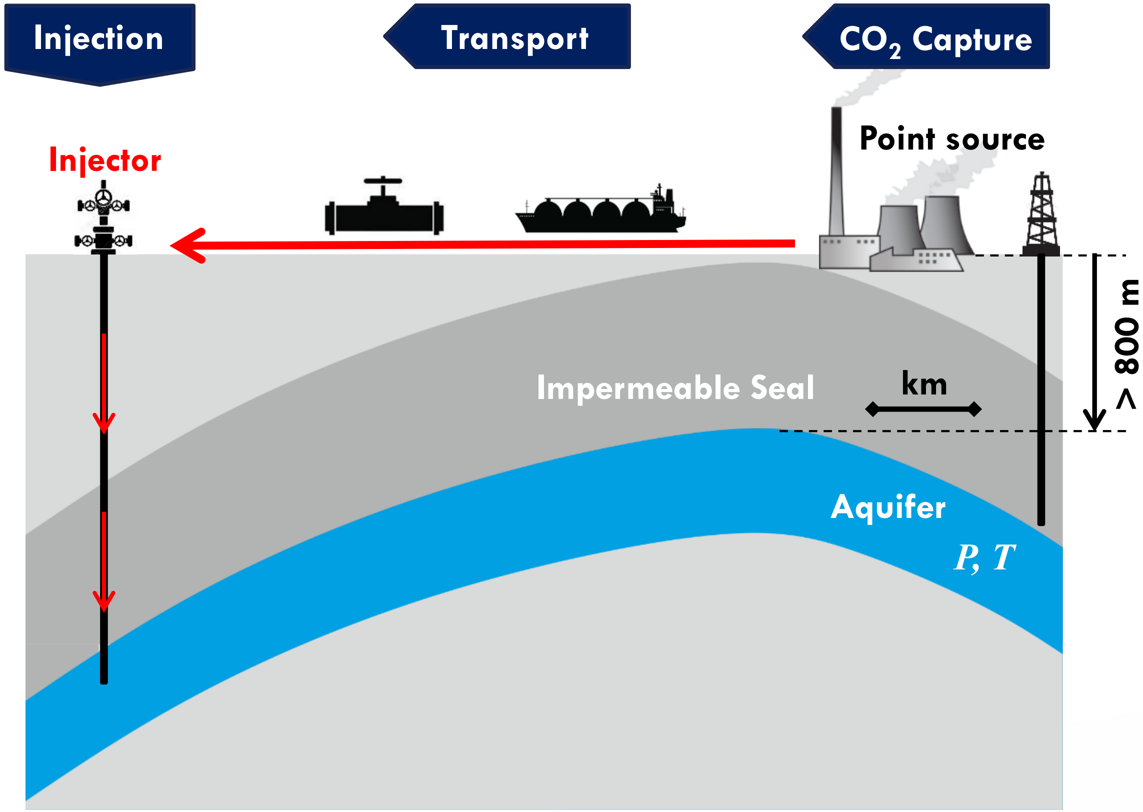
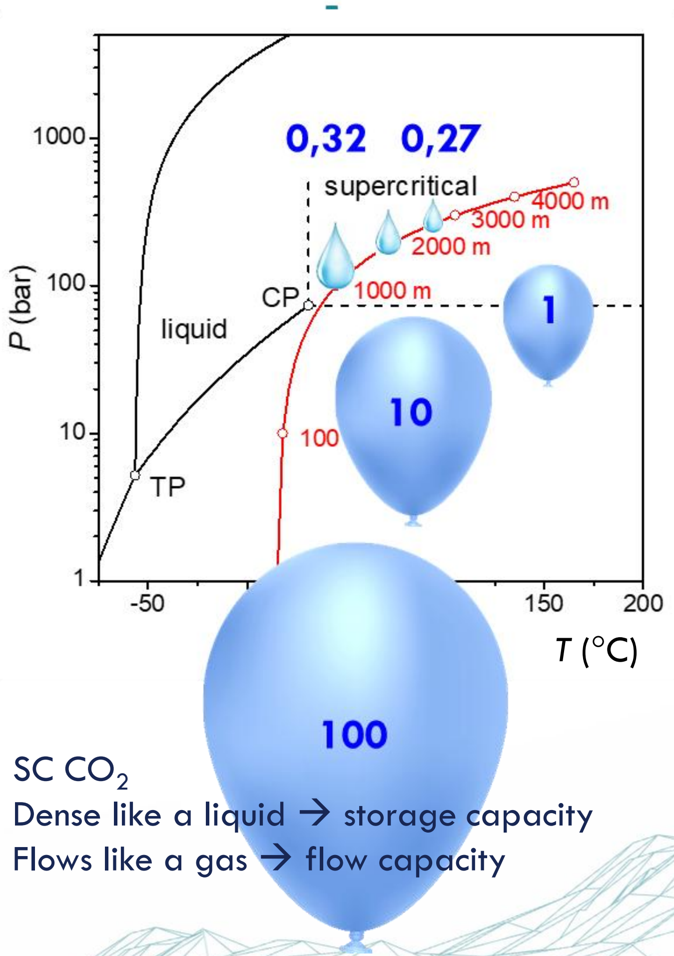


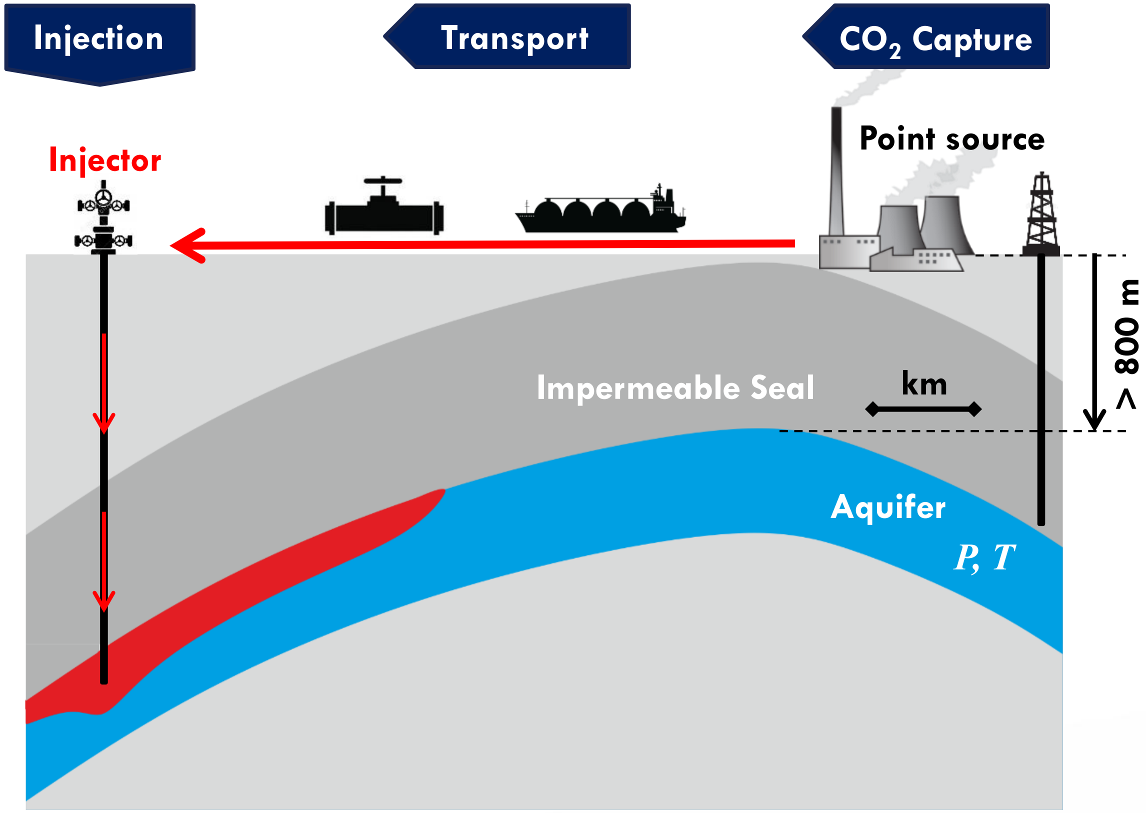
Carbon Capture and Storage

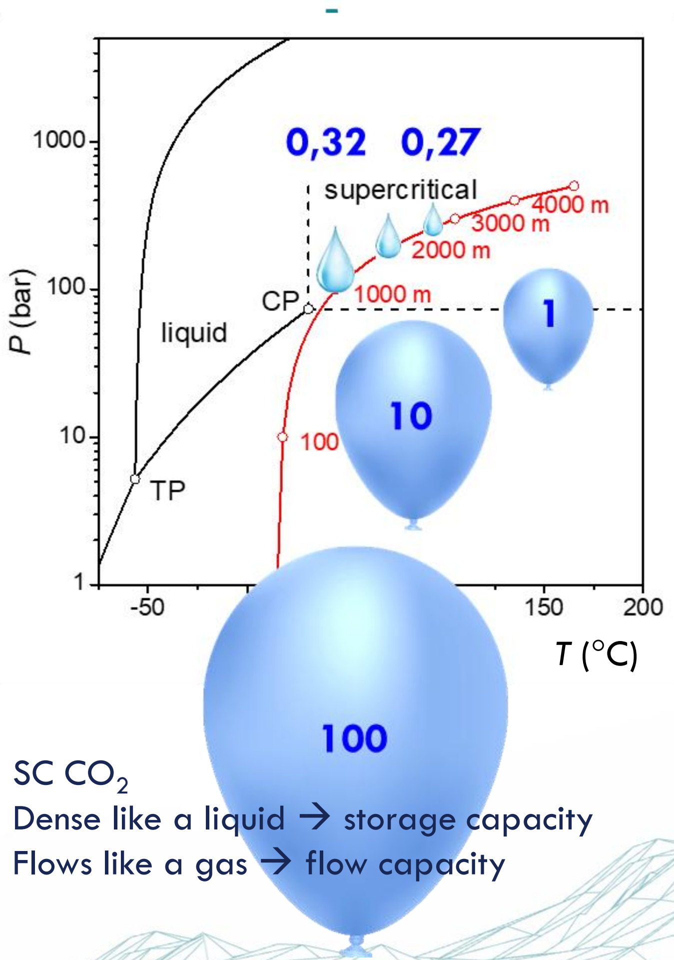




SC CO_2
Dense like a liquid → storage capacity
Flows like a gas → flow capacity

Carbon Capture and Storage

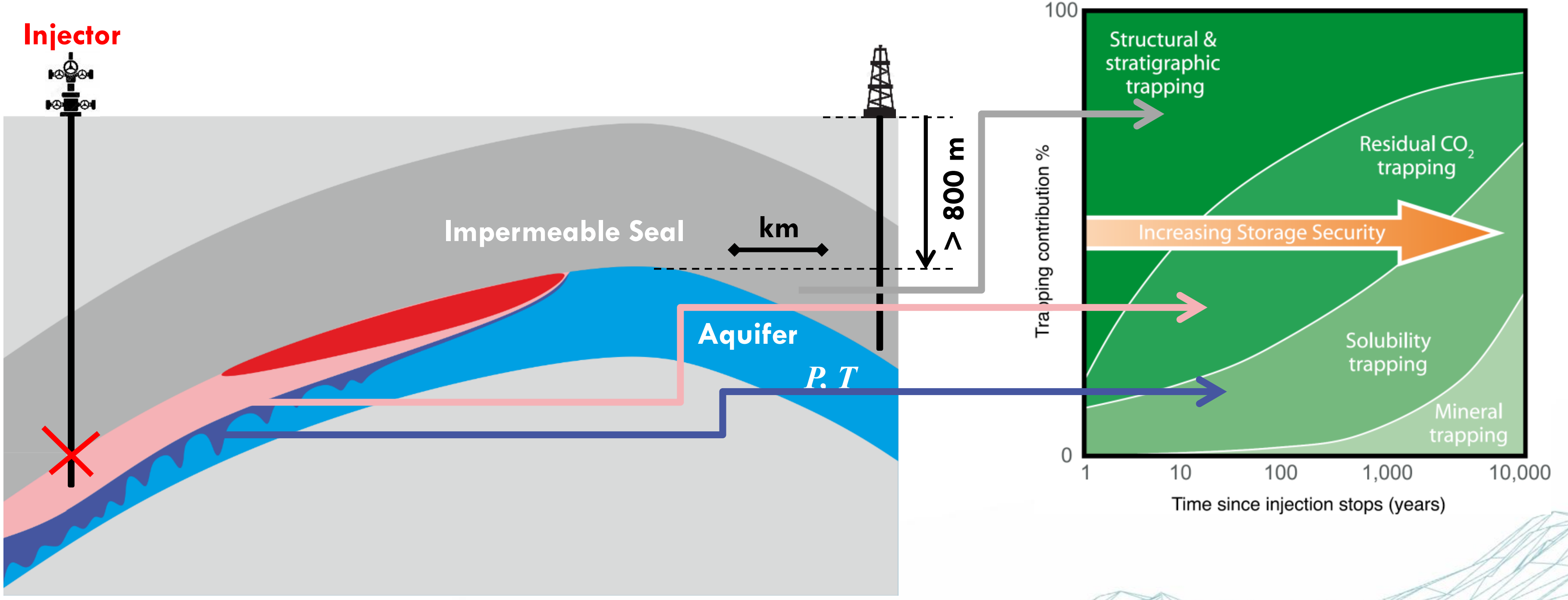




$SC\ CO_2$
Dense like a liquid → storage capacity
Flows like a gas → flow capacity

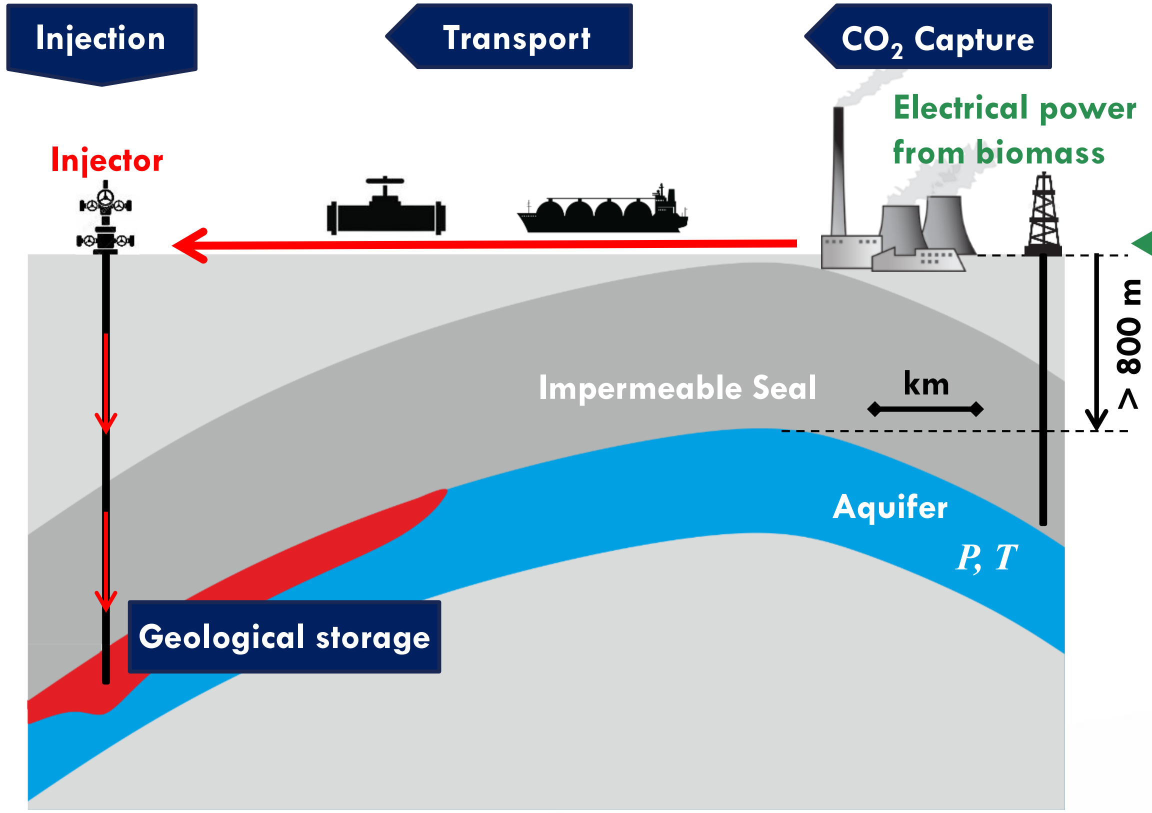
Storage Safety

Depends on rock formation and injection design/strategy



Carbon Dioxide Removal (CDR)

DEPARTMENT
GEO
ENERGY



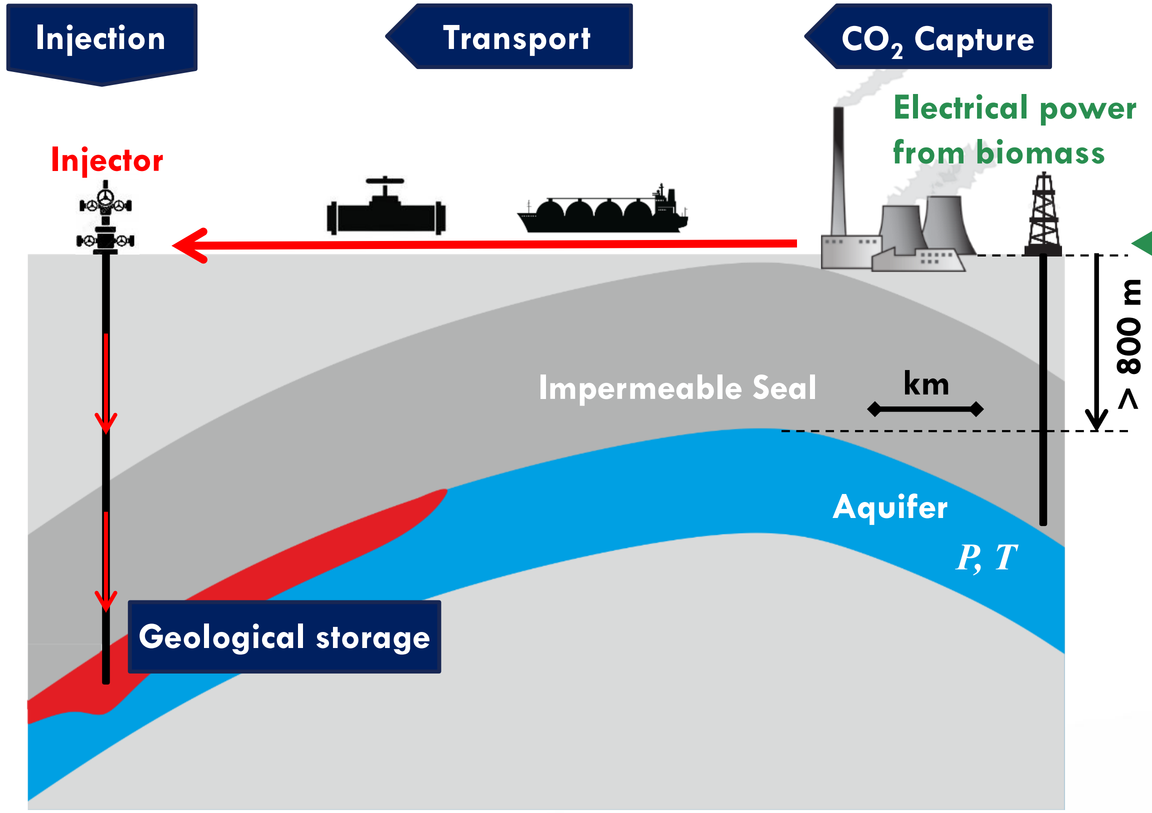
CO_2 from the atmosphere

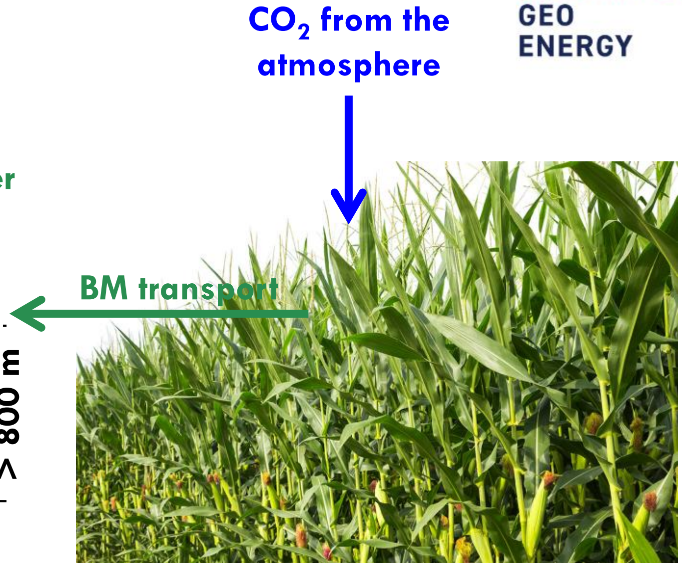
BECCS combines bioenergy and CCS
→ negative CO_2 footprint possible

Possible conflicts with:

- ❑ Existing woodland
- ❑ Agriculture and food production

Carbon Dioxide Removal (CDR)





BECCS combines bioenergy and CCS
→ negative CO_2 footprint possible

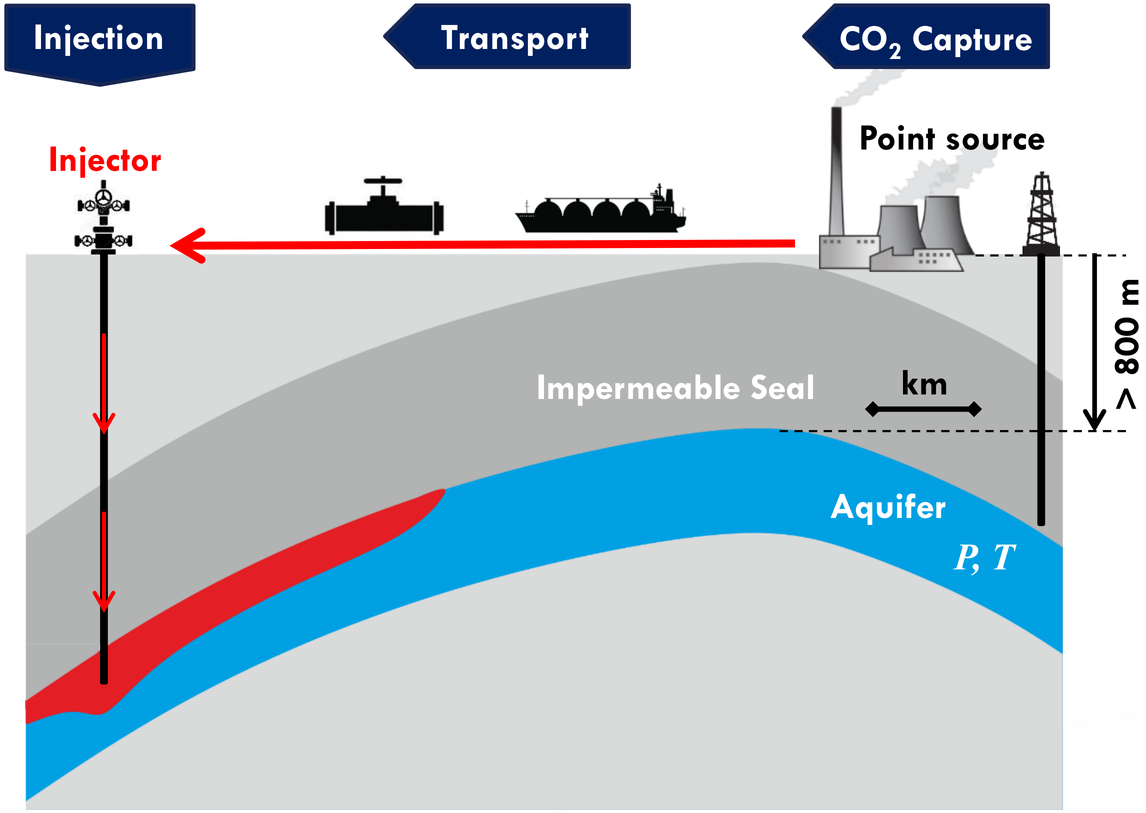
Possible conflicts with:

- ❑ Existing woodland
- ❑ Agriculture and food production

Why not, e.g., afforestation alone?

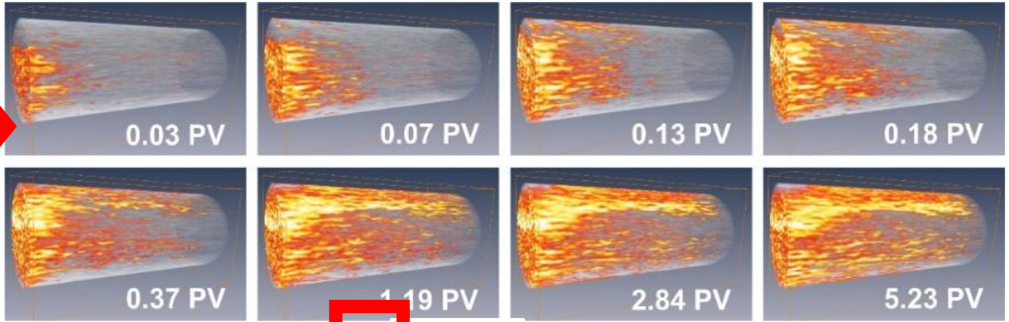
Aspects of Storage Safety

How does a CO_2 Plume Migrate?

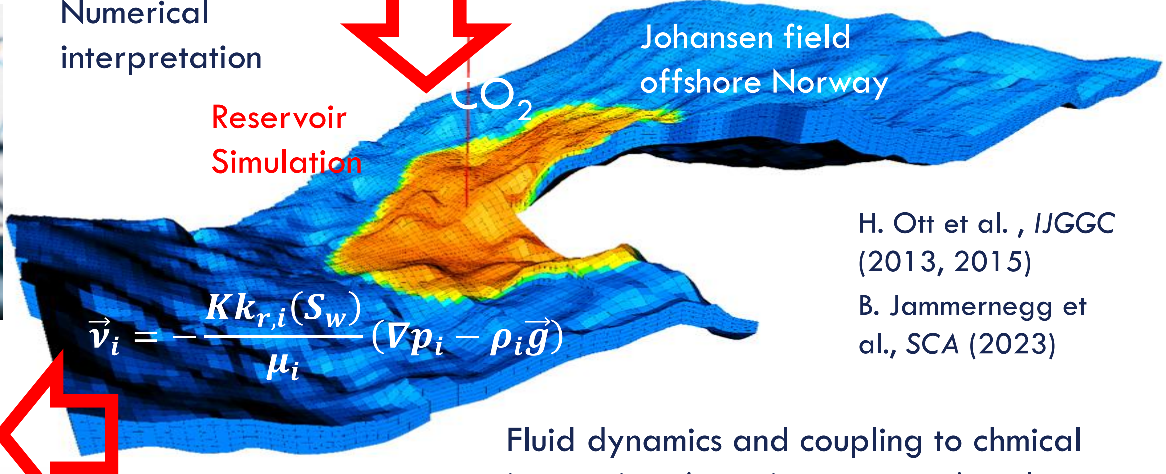


How does a Plume Migrate?

CO_2 core flooding expeirments



Numerical interpretation



$$\vec{v}_i = -\frac{K k_{r,i}(S_w)}{\mu_i}(\nabla p_i - \rho_i \vec{g})$$

H. Ott et al. , *IJGGC* (2013, 2015)

B. Jammernegg et al., *SCA* (2023)

Goal = Predictive models for

Plume migration and CO_2 trapping potential

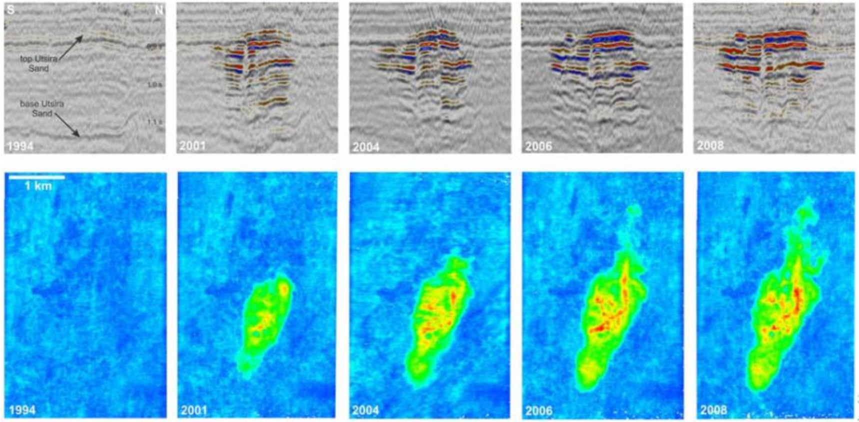
- Field development – injection strategy
- Storage capacity and safety

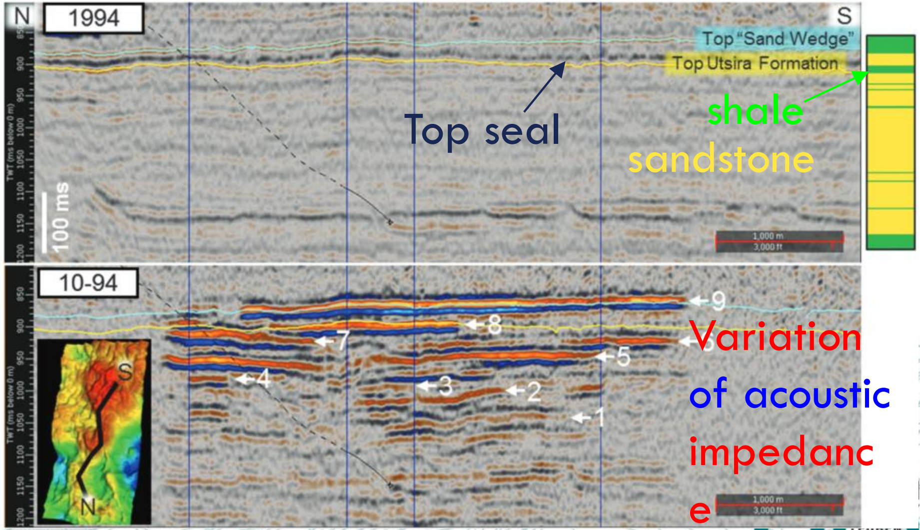
Fluid dynamics and coupling to chmical interactions (reactive transport) and mechanical rock properties


Sleipner

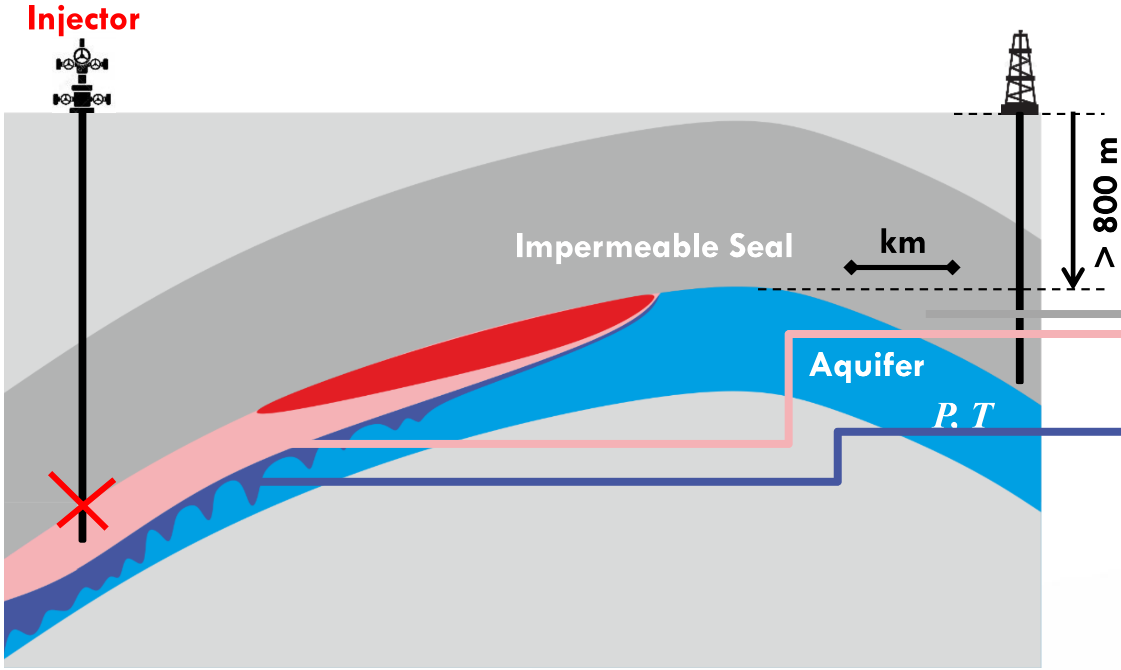
Sleipner – offshore Norway

- The extracted natural gas has a CO_2 content of 9% (weakly acidic gas).
- CO_2 is separated on the Sleipner platform and injected into an aquifer 800 meters below the seabed.
- Since 1996, almost one million tons of CO_2 have been stored annually.
- Lighthouse project: 4D seismic monitoring, first real CCS project

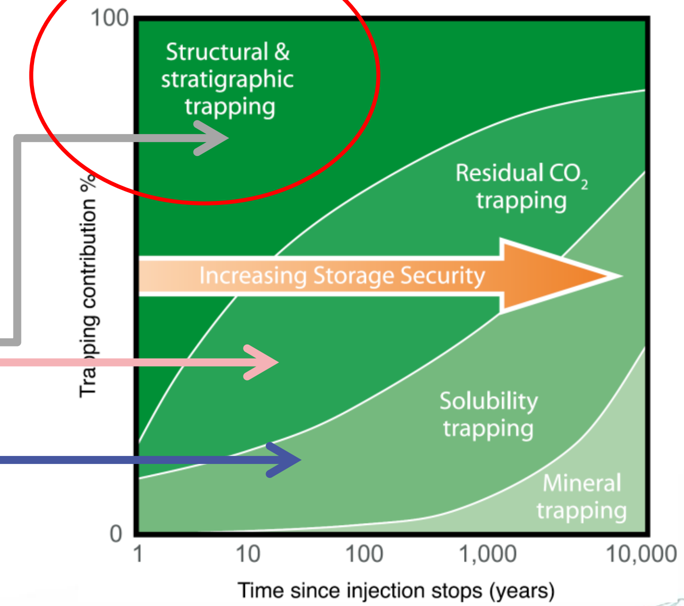




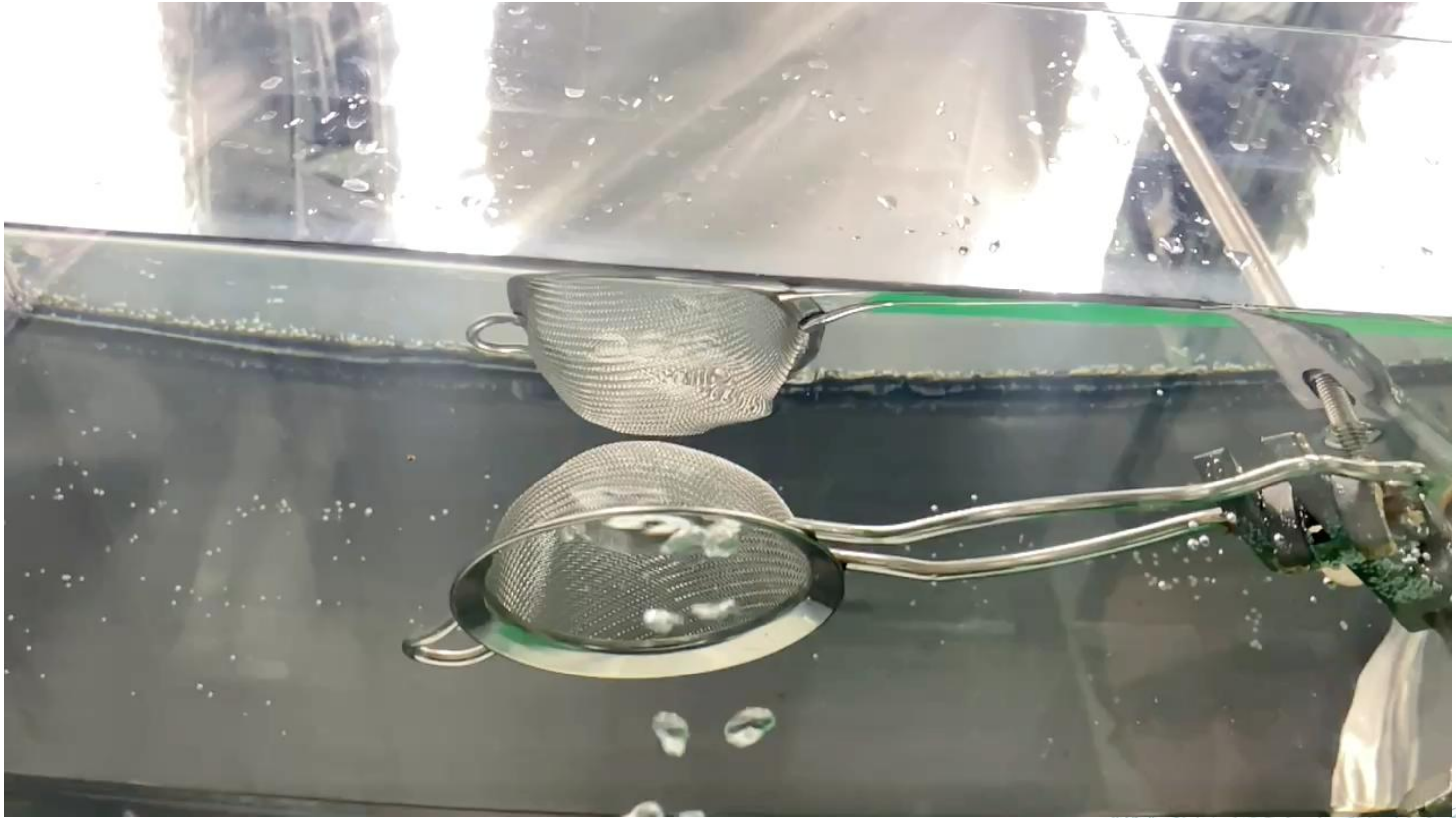
Storage Safety



Depends on rock formation and injection design/strategy

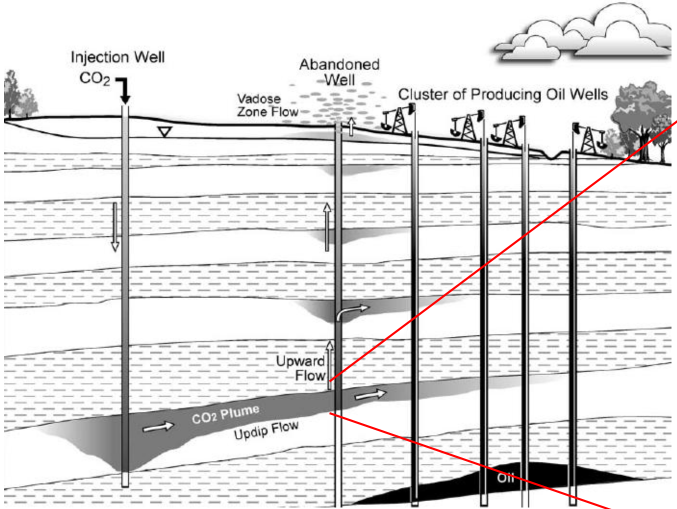


The Capillary Barrier (Video)

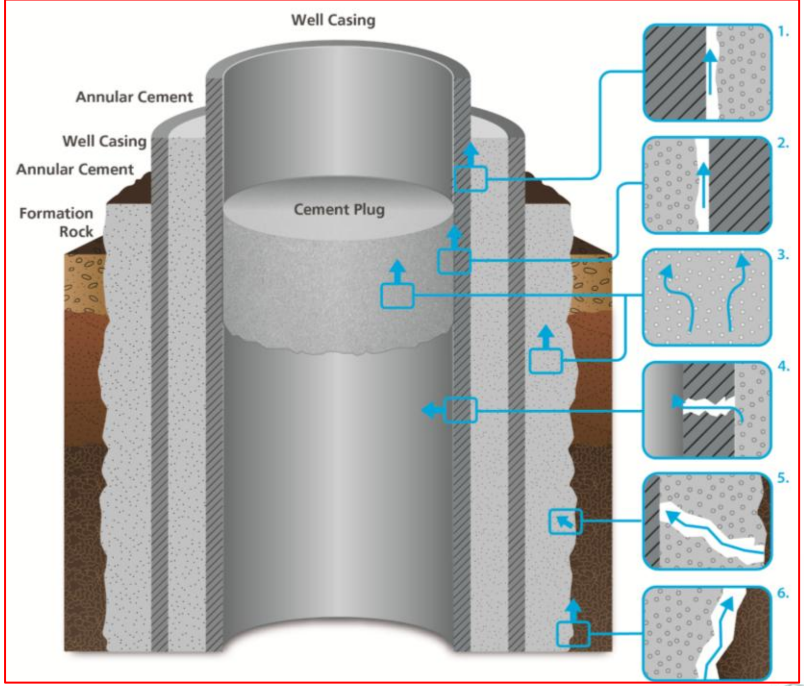


Video: https://youtu.be/h8tL_jkPTpY

Abandoned Wells as Potential Leakage Pathway

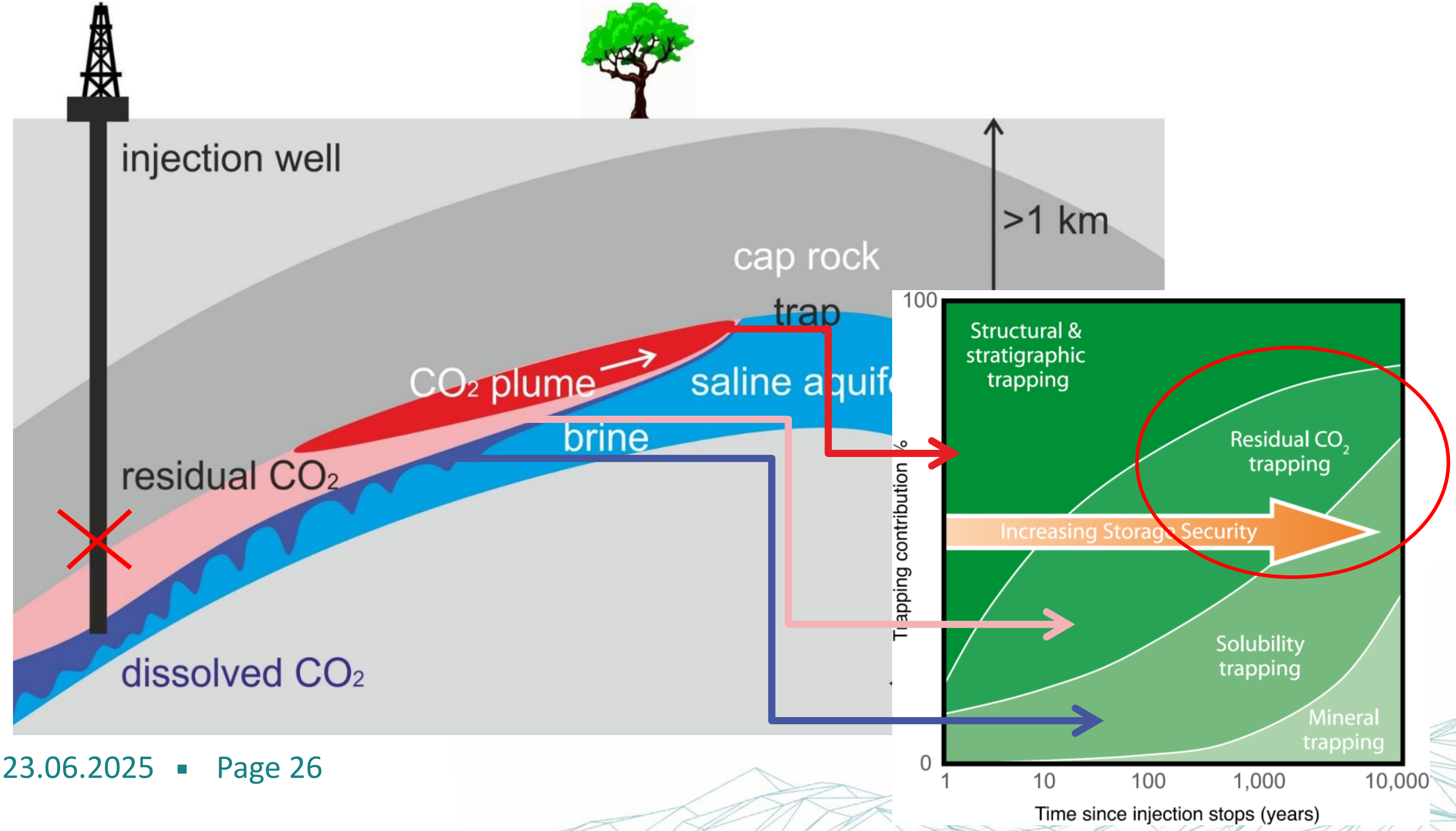


Many fields are highly perforated by wells
Oil and gas wells have often not the right grade of materials (steel and cement grade) for CO_2 storage projects – can they be worked over?

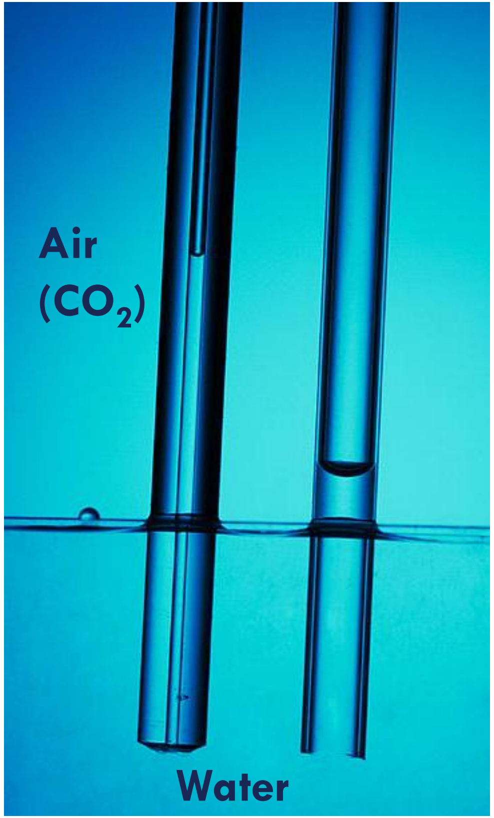


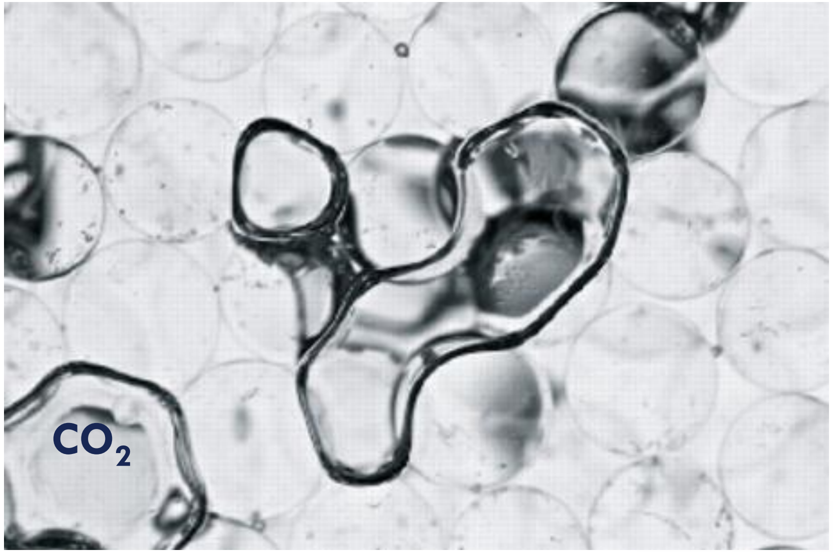
Potential leakage pathways in well environments

Capillary Trapping



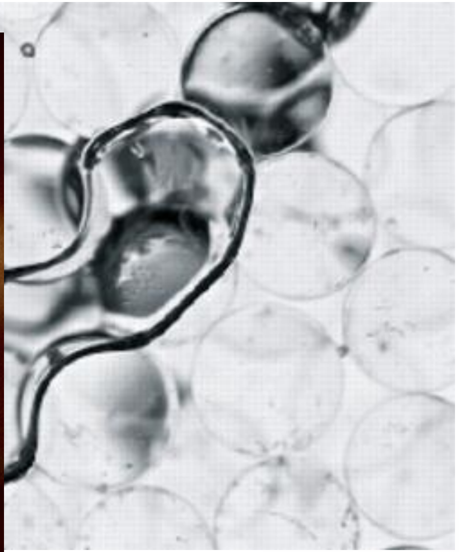
Capillary Trapping





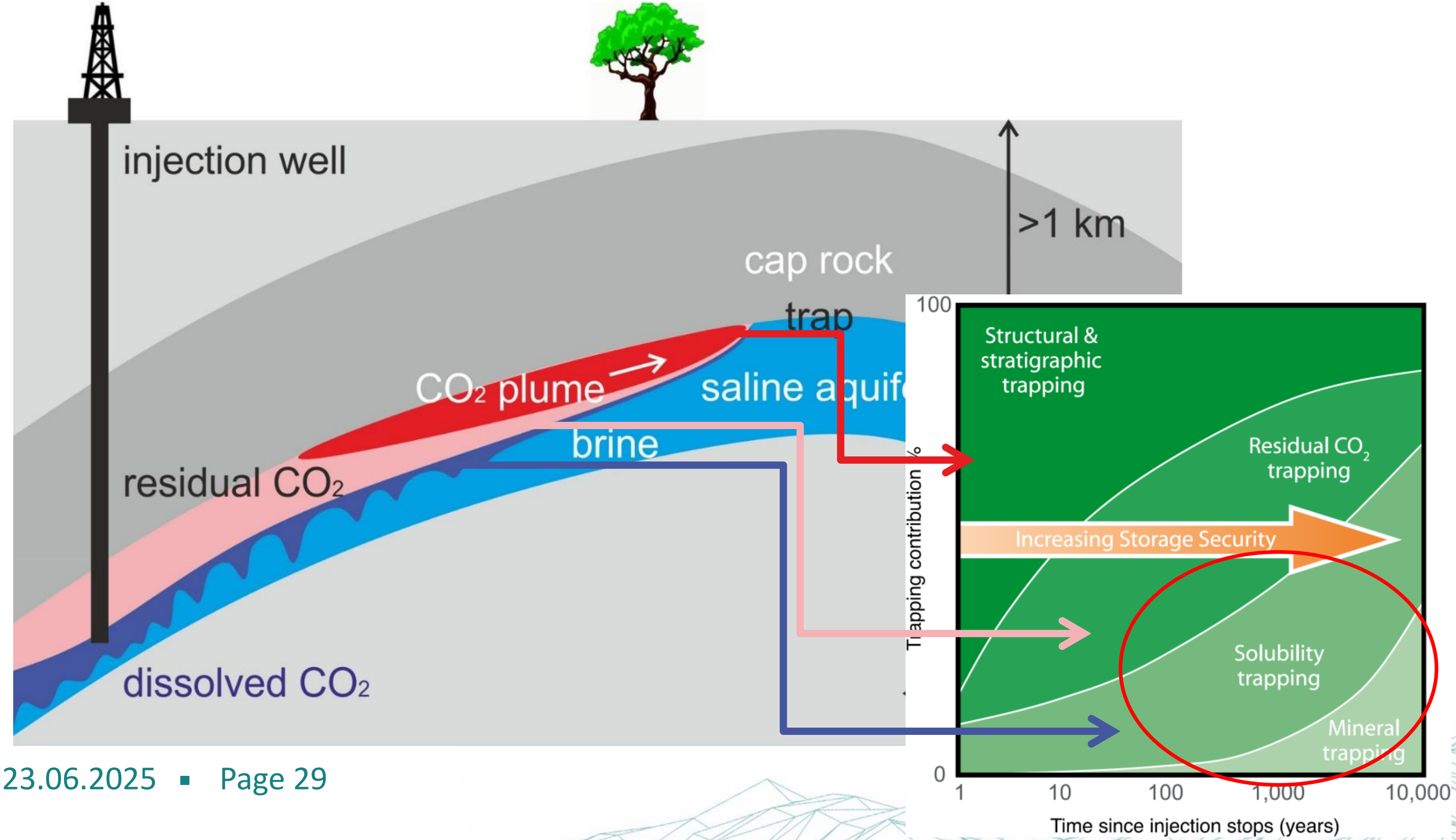
$$p_{F1} - p_{F2} = P_C = \frac{2\sigma_{F1F2}\cos\theta}{r}$$

Capillary Trapping

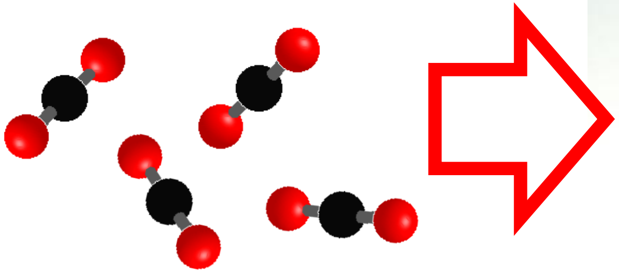


$$= \frac{2\sigma_{F1F2}\cos\theta}{r}$$

Solubility Trapping



Solubility Trapping



Properties:

$T \uparrow \rightarrow CO_2$ Solubility $\downarrow$

$P \uparrow \rightarrow CO_2$ Solubility $\uparrow$

$\rho_{CO2} < \rho_{wasser} < \rho_{CO2-sat.\,water}$

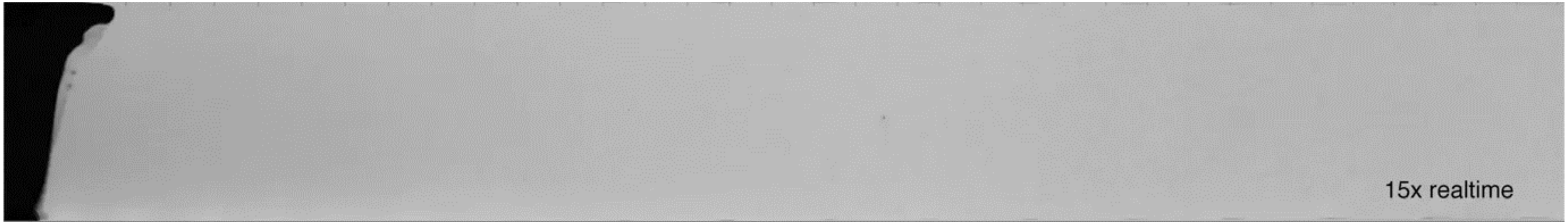
Water salinity $\uparrow \rightarrow CO_2$ Solubility $\downarrow$

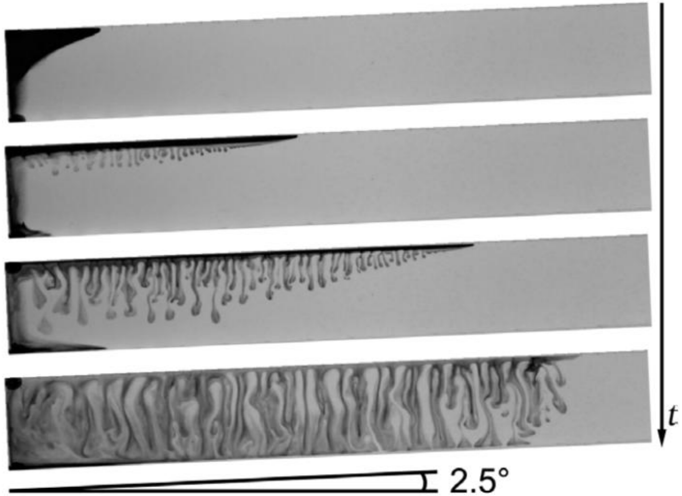
200 bar (CO_2) in water	~0.062 kg/kg
200 bar (CO_2) 4-molal NaCl	~0.024 kg/kg
1 bar (CO_2) in water	~0.00126 kg/kg
1 bar (air) in water	~ 8×10^{-6} kg/kg

@ $T = 30°C$

Hydrodynamic Trapping (Video) – What if we don't have a Trapp?

Video: https://youtu.be/kjZ25x2tF-Y

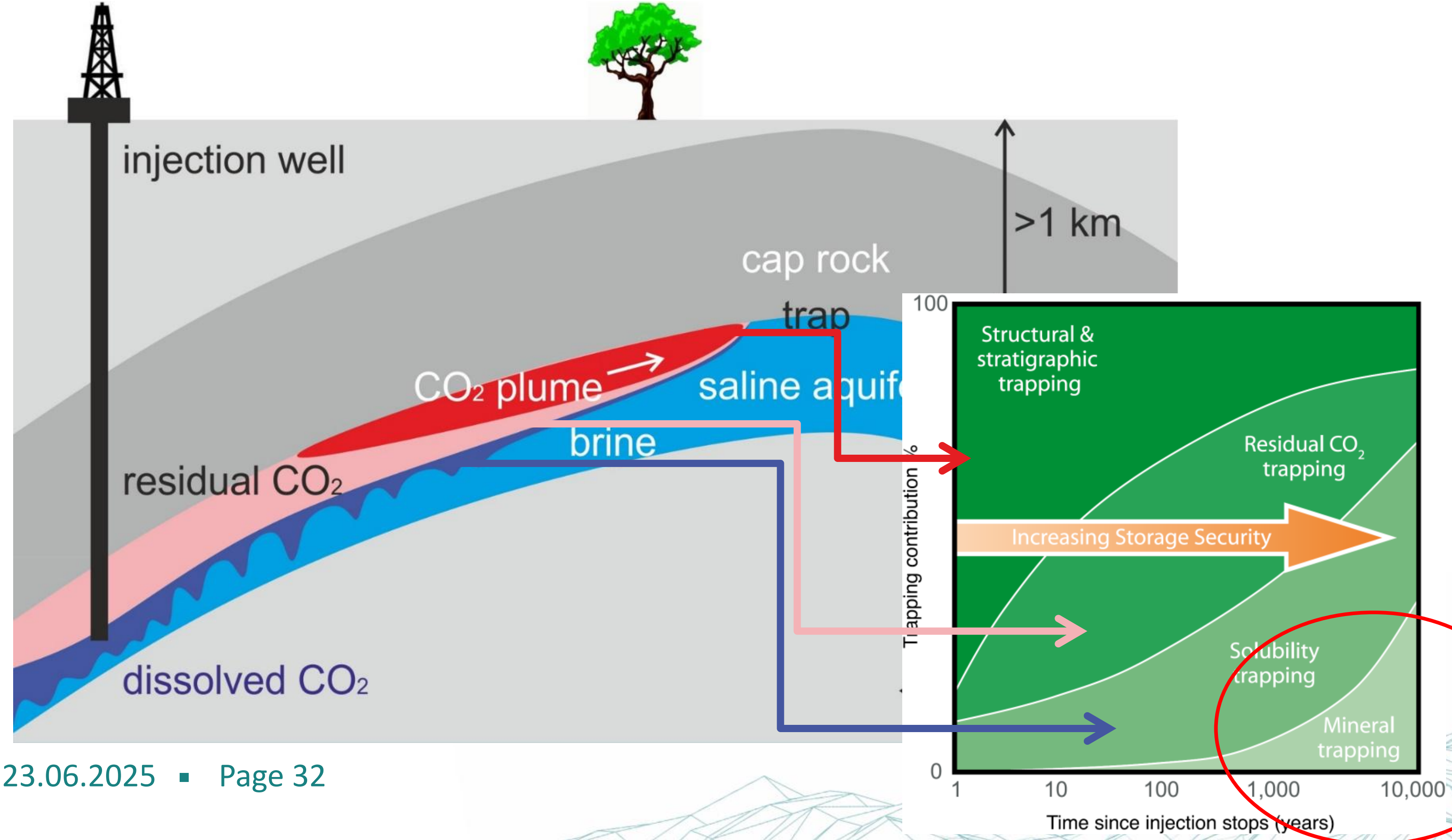




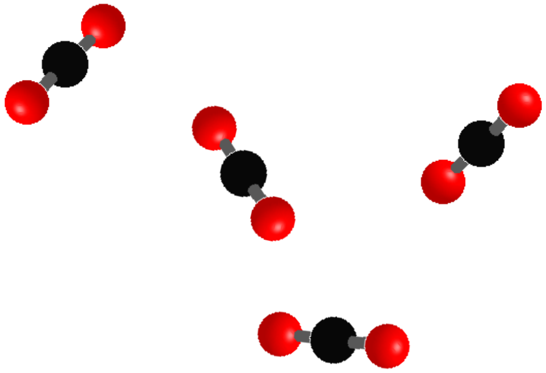
Required: long enough travel distance to dissolve CO_2 by extensive contact with the formation water

Convective dissolution arrests the up-slope migration of a buoyant current – a Hele-Shaw cell for illustration performed with model fluids. *Christopher W. MacMinn and Ruben Juanes, GRL, 40, 2017–2022, (2013)*

Mineral Trapping



Mineral Trapping

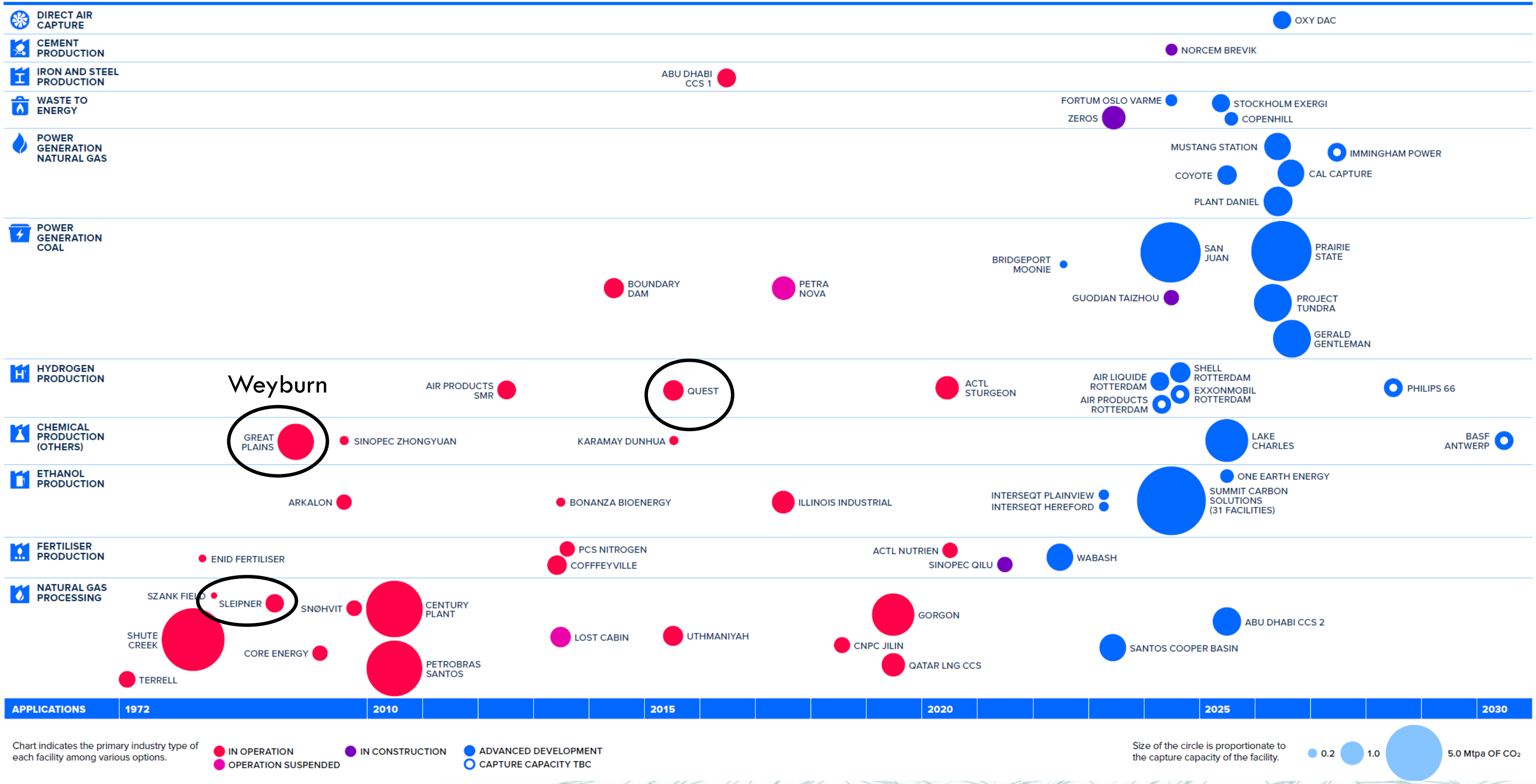


CCS Projects

Ongoing and Planned Projects

https://www.globalccsinstitute.com/

Ongoing and Planned Projects




CO2
Quest

Quest CCS Project

Upgrader: facility that upgrades bitumen (extra heavy oil) into synthetic crude oil – typically located close to oil sands production. Example: Athabasca oil sands or the Orinoco tar sands in Venezuela.
Fully integrated CCS project being developed for the Athabasca Oil Sands Project (Shell Canada Energy).

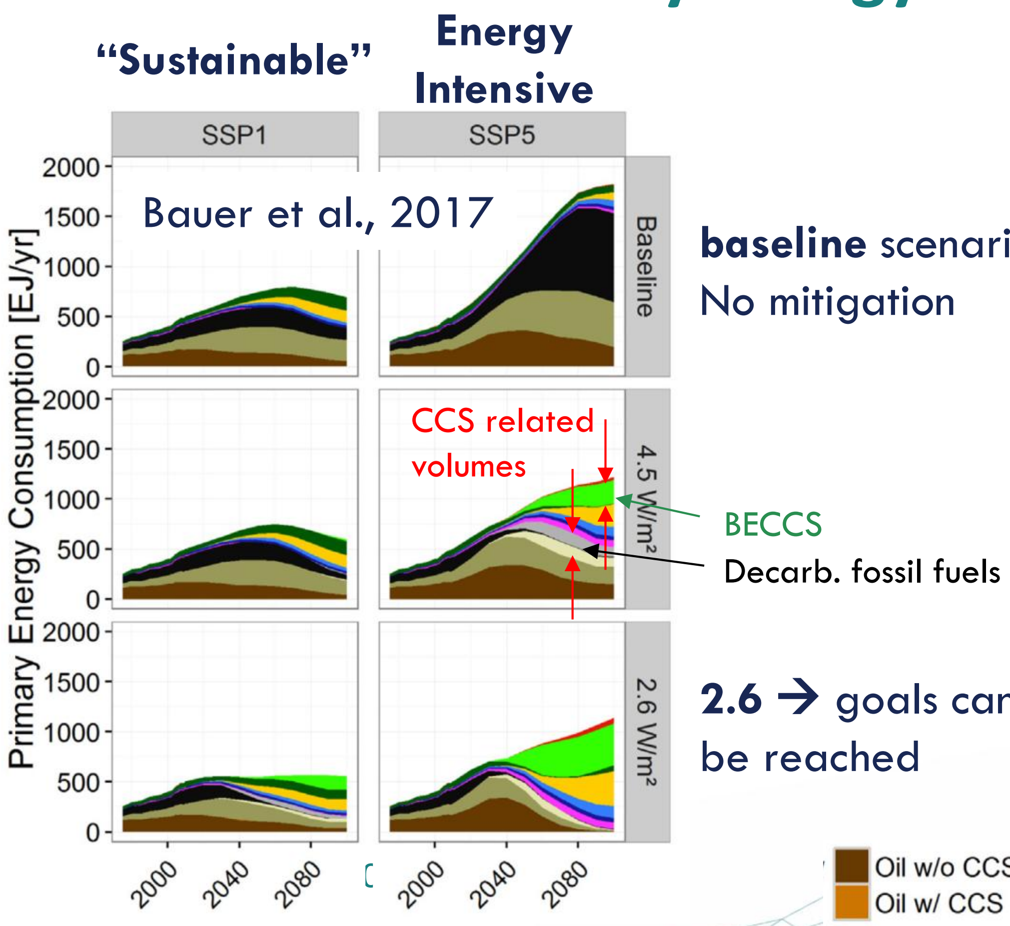
Unconventional heavy oils

Quest (Canada)
FEEDSTOCK: (blue) Hydrogen
by steam reforming (SR) for oil-sand upgrading
CO_2 CAPTURE CAPACITY: 1.08 Mtpa
CAPTURE METHOD: retrofit – Amine
STORAGE OPTION: onshore deep saline formations
FORMATION: Cambrian Basal Sands at a depth of around 2 km

CCS in Austria?

SSPs – Global Primary Energy Mix

IIASA – International Institute for Applied Systems Analysis
Database: https://tntcat.iiasa.ac.at/SspDb/



baseline scenarios
No mitigation

2.6 → goals can be reached

Oil extraction in **baselines** exceeds current estimates of conventional and unconventional reserves!

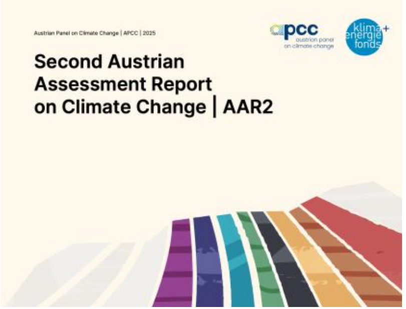
CCS plays a role in all mitigation scenarios

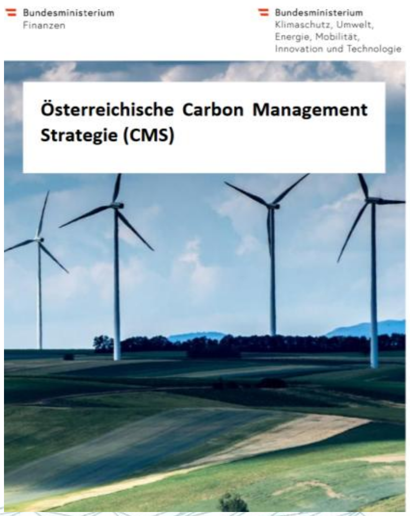
Major role if **BECCS** in all climate friendly and **2.6 scenarios**

Fossil fuels reduced to ~0 in **SSP5/2.6** – extremely high carbon price exceeding 300 US$/t CO_2

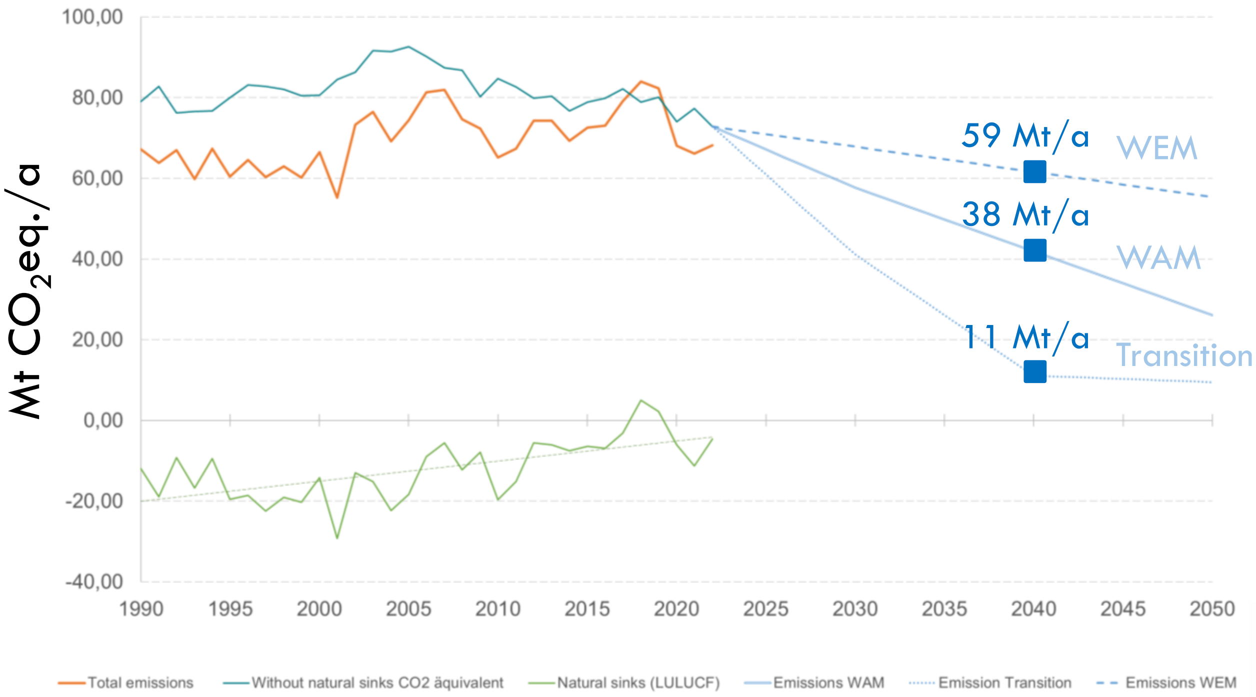
Literature on CCUS in Austria

- **Second Austrian Assessment Report on Climate Change** | AAR2, To be published in June 2025
- **Österreichische Carbon Management Strategie** (CMS) 2023 → bundeskanzleramt.gv.at
  https://aar2.ccca.ac.at/en
- Wolf-Zoellner, P., Böhm, H., Veseli, A., Hochmeister, S., Kulich, J., Fazeni-Fraisl, K., Lehner, M., Kienberger, T., Ott, H., Fleischhacker, J., Sachs, N. & Kapfer, M.; CaCTUS – Carbon Capture & Transformation, Utilization and Storage. **Berg Huettenmaenn Monatsh 170**, 230–237 (2025).
- Ott, H., Kulich, J. CCS: Chancen und Risiken einer umstrittenen Technologie. **Berg Huettenmaenn Monatsh 169**, 553–559 (2024).
- Hochmeister, S., Kühberger, L., Kulich, J., Ott, H., Kienberger, T.; Carbon Management für ein klimaneutrales Österreich. **Elektrotech. Inftech. 141**, 299–306 (2024).
- Kulich, J & Ott. H.; CCS Capacity in Austria and its Competitive Usage of the Subsurface, Proceedings of the 17th Greenhouse Gas Control Technologies Conference (GHGT-17) 20-24 October 2024
- Hochmeister, S., Kühberger, L., Kulich, J., Ott, H., & Kienberger, T. (2024). A Methodology for the Determination of Future Carbon Management Strategies: A case study of Austria. **International Journal of Sustainable Energy Planning & Management, 41**.
- CCUS in Österreich–Potenziale, Technologien und Folgenabschätzung, Hans Böhm, Susanne Hochmeister, Philipp Wolf-Zöllner, Jakob Kulich, Karin Fazeni-Fraisl, Markus Lehner, Holger Ott, **CCCA Policy Brief** #3 | 2025.
- H. Ott, Carbon Capture and Storage (CCS),
  CCCA Fact Sheet #43 | 2023, Klimawandel, Vermeidung und Anpassung.
- M. Lehner, Carbon Capture and Utilization (CCU),
  CCCA Fact Sheet #32 | 2021, Klimawandel, Vermeidung und Anpassung.





Austria: CO_2 Emission Scenarios



- Residual Emissions in 2040 between 10 and 60 Mt/a depending on scenario
- The *Carbon Management Strategy* 2024 considers 4-12 Mt/a

Is CCS in Austria needed? What are residual emissions?

Data: Umweltbundesamt 2023

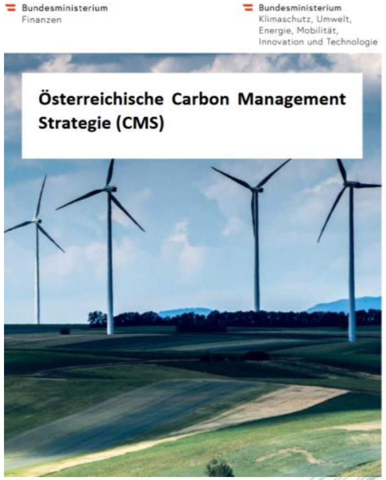
CCS in Austria?

CCS = mature technology and world wide applied, but - like any technology - not without residual risks

- **CCS is banned in Austria** with the original argument that there is still a considerable need for research

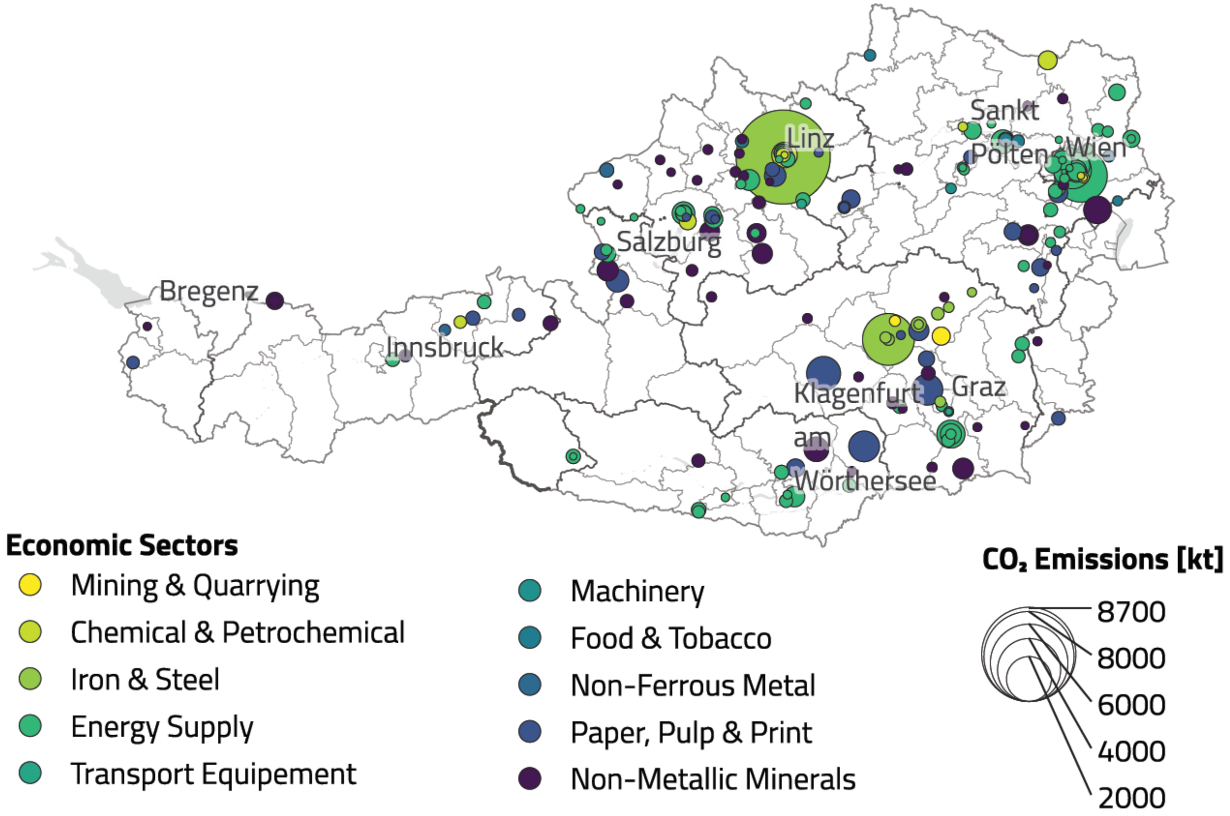
New Carbon Management Strategy of Austria (2024)

- Mitigation and efficiency first principle
- Emissions that are unavoidable or difficult to avoid (hard-to-abate)
- Risks of "fossil lock-in" and "stranded assets" should be avoided
- Conditional definition of hard-to-abate (considering time-dependent availability of substitutes/alternatives)



What is the size of the problem and what are **the potential** and **options** for CCS in and for Austria?

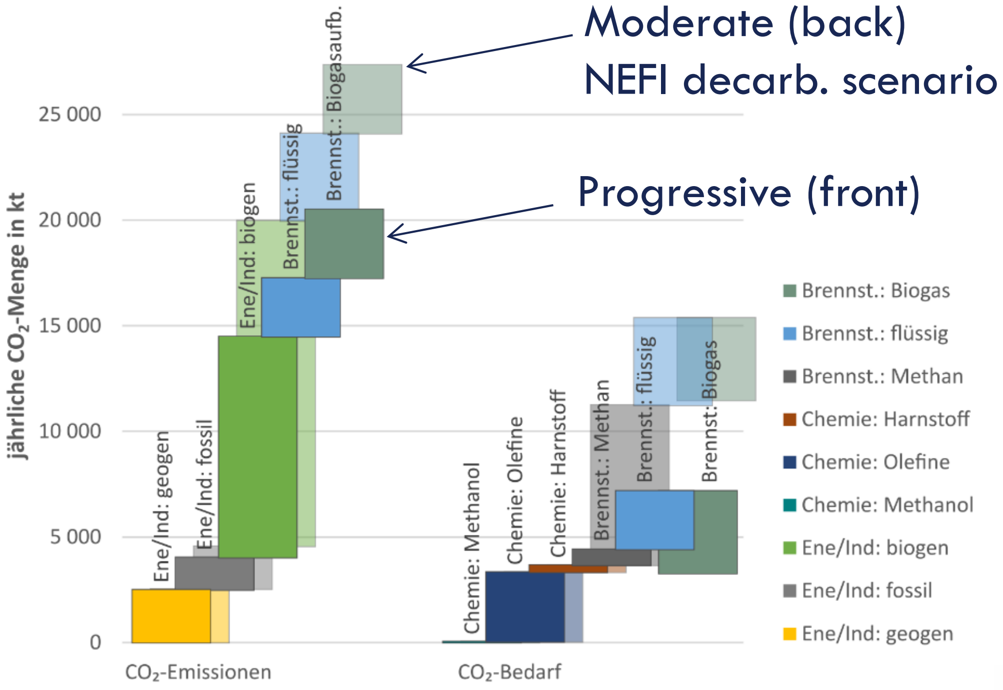
Current CO_2 Point Sources



Spatial and sectoral distribution of CO_2 point sources (data basis 2019)

Hochmeister et al. (2024)

CO_2 Sources and Sinks in 2050



Industry and Energy

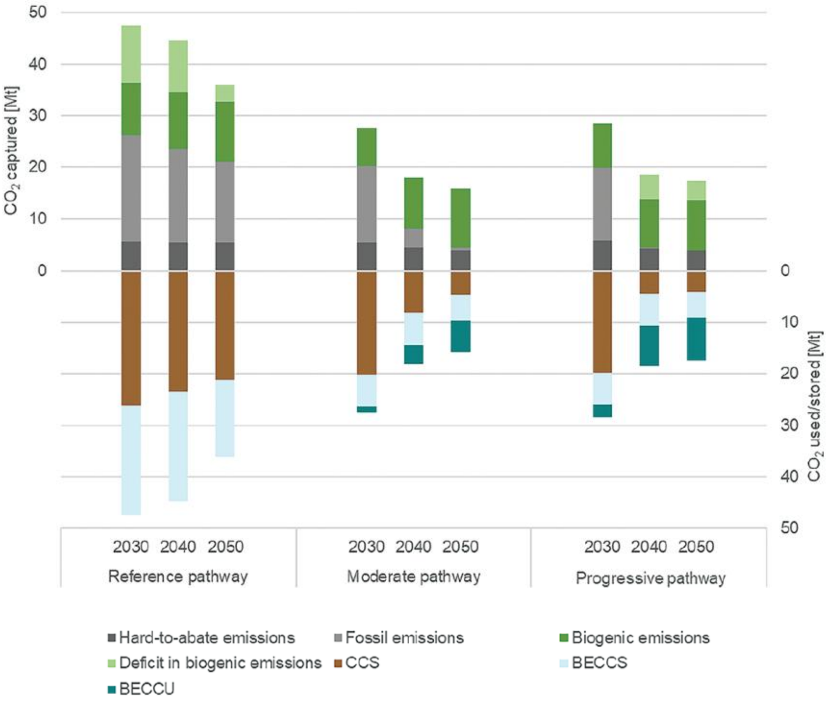
Potential demand for chemical raw materials and synthetic fuels ~15Mt CO_2/a

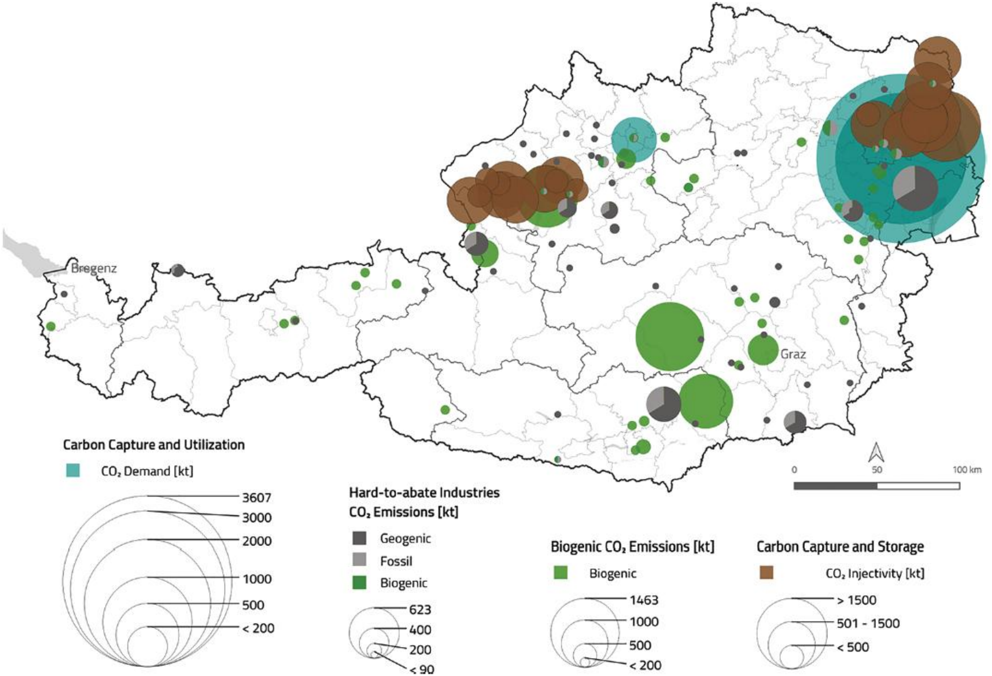
May not be covered by biogenic resources

→ CCU

Hochmeister et al. (2024)

CO_2 Sources and Sinks





Hochmeister et al. (2024)

Domestic and European Storage Options

Domestic hydrocarbon fields

- Fastest to implement – limited volume (200-350 Mt CO_2)
- Decades of residual emissions

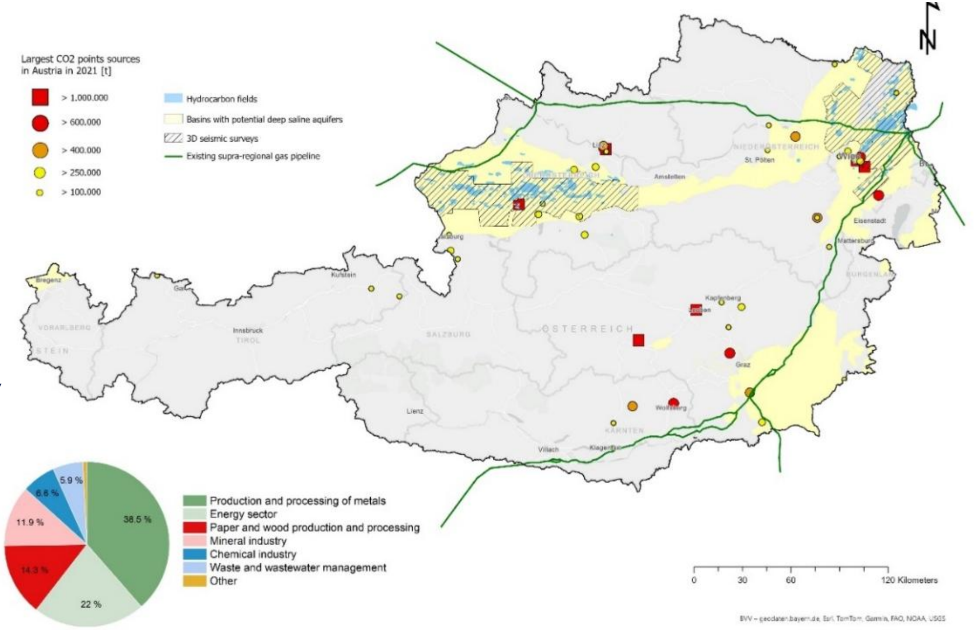
Domestic deep aquifers

- Potentially in the Gt range – insufficiently known/characterized to date

→ Exploration required

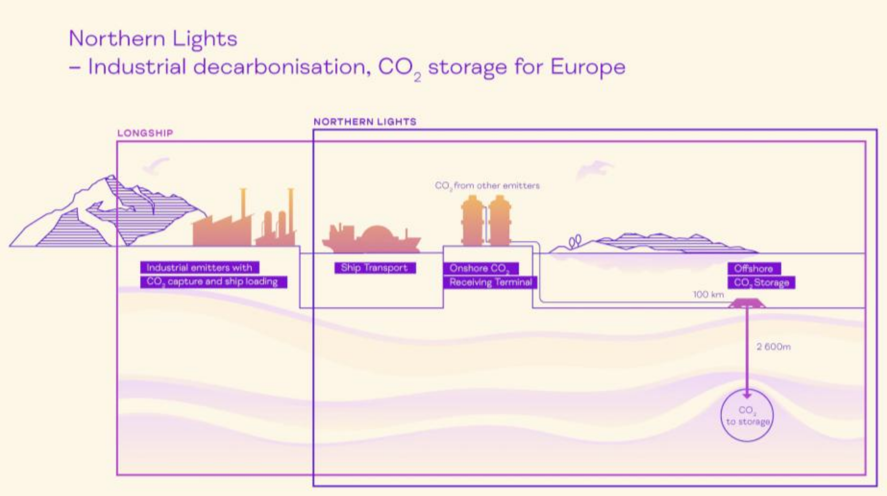
CO_2 export for offshore storage

- Enormous potential (North Sea 100 Gt range) likely limited by development time and access (transport network, contracts, etc.)



Kulich & Ott (2024, 2025)

Northern Lights and Longship



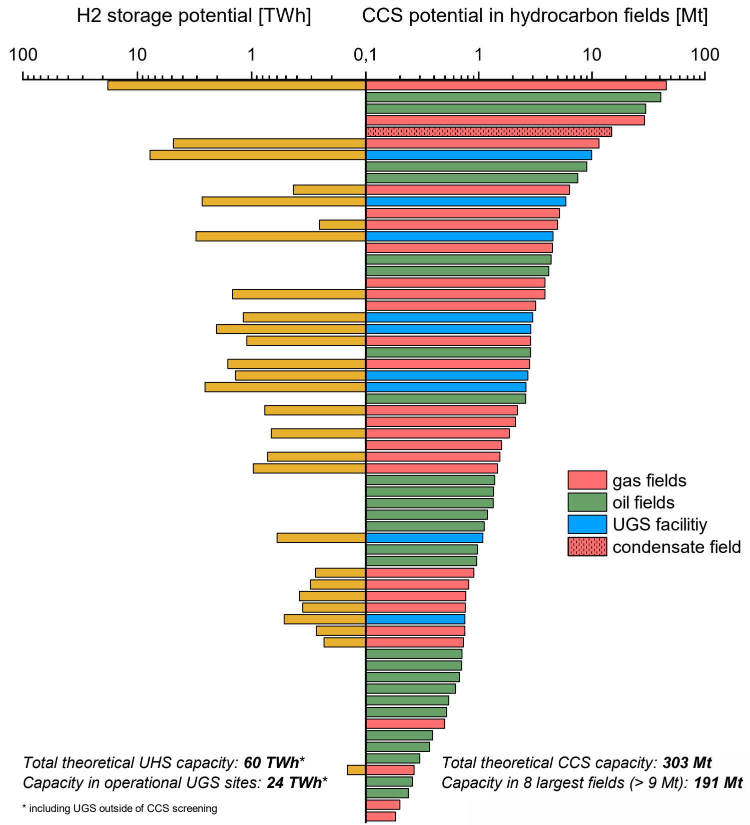
Key metrics

Location: North Sea and west coast of Norway (Offshore)
Operation date: 2024
Storage capacity (Mtpa): Phase one: 1.5, phase two: 5
Feedstock: Various
Transport length (km): 110 (from onshore receiving terminal)
Transportation type: Pipeline and ship

https://norlights.com/about-the-longship-project/
Northern Lights – CCUS around the world – Analysis – IEA

- **Northern Lights:** the first cross-border, open-access CO_2 transport and storage infrastructure
- NL will provide companies across Europe with the option of storing CO_2 deep below the seabed in Norway
- **Phase one** mid-2024 with a capacity of up to **1.5 Mt/a**. **Phase two:** expansion to a total of **5 Mt/a**, depending on demand
- Partnership between Equinor, Shell and Total
- Key component of Longship, the Norwegian government's large-scale CCS project

Alternative Use – Hydrogen



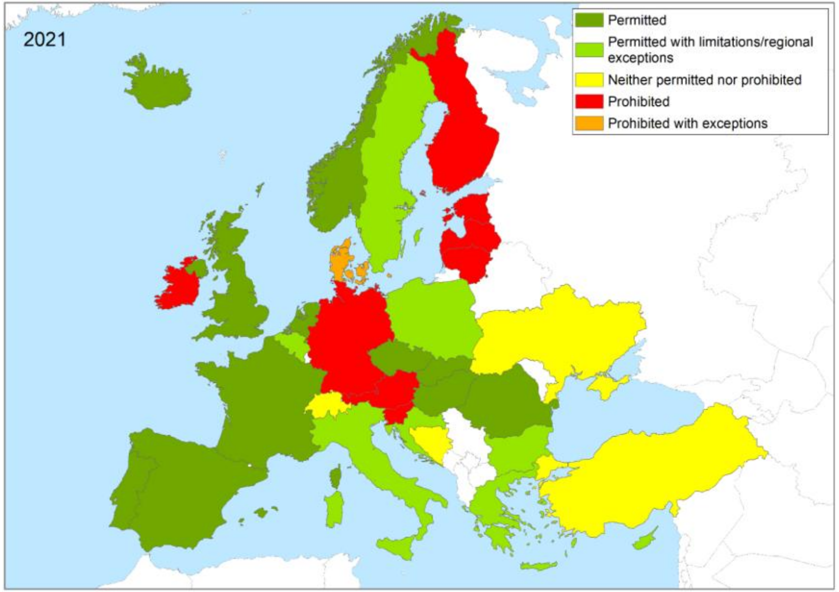
CCS screening:
Total CO_2 capacity: ~300 Mt (200-350Mt)
In bigger fields (>7Mt): 187 Mt (128-226Mt)
Kulich and Ott (2024, 2025)
versus
'Hard-to-abate' emission: ~4-12 Mt/a by 2040
Hochmeister et al. (2024), CSM (2024)

Underground hydrogen storage (UHS) capacity:
Potential UHS in gas fields: 73 TWh
In abandoned or existing UHS sites (UGS): 26 TWh
Kulich and Ott (2024, 2025)
versus
Storage demand expected to be between 32-56 TWh, see *Clemens et al. (2022)*

→ **CCS and hydrogen storage compete** with each other to some extent, **but do not exclude each other** in terms of the storage capacity required.

Kulich & Ott (2024, 2025)

The Situation in Austria



CO2GeoNet
(State of play report)

The Austrian Way to CCUS

“CCS EU” Directive 2009/31/EC

CCS ban (2011)

Reevaluation (2018)

Reevaluation (2023)

Austrian CMS (2024)

Lifting of the ban (2025)?

Implementation of EU regulations?

Implementation of CCUS?

Acknowledgement – Questions?

DEPARTMENT GEO ENERGY

The A team

CaCTUS
CARBON CAPTURE, TRANSFORMATION, UTILIZATION & STORAGE

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