ETH zürich

Schweizerischer Erdbebendienst
Service Sismologique Suisse
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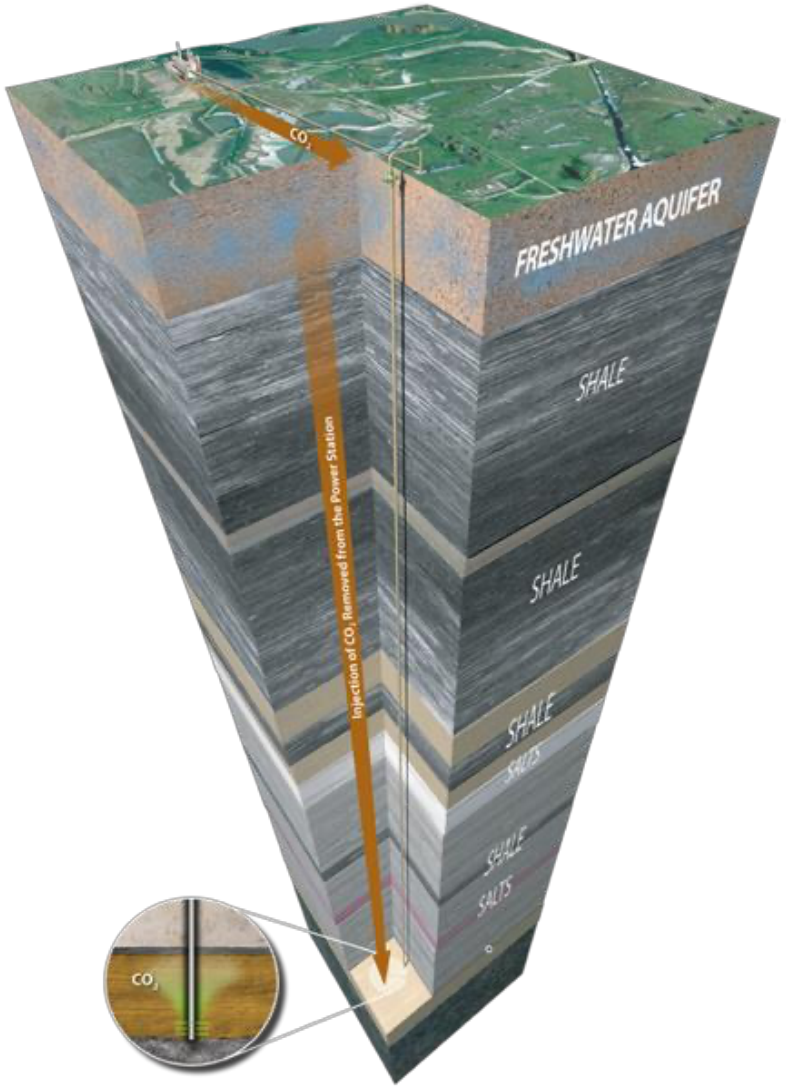
Swiss Seismological Service

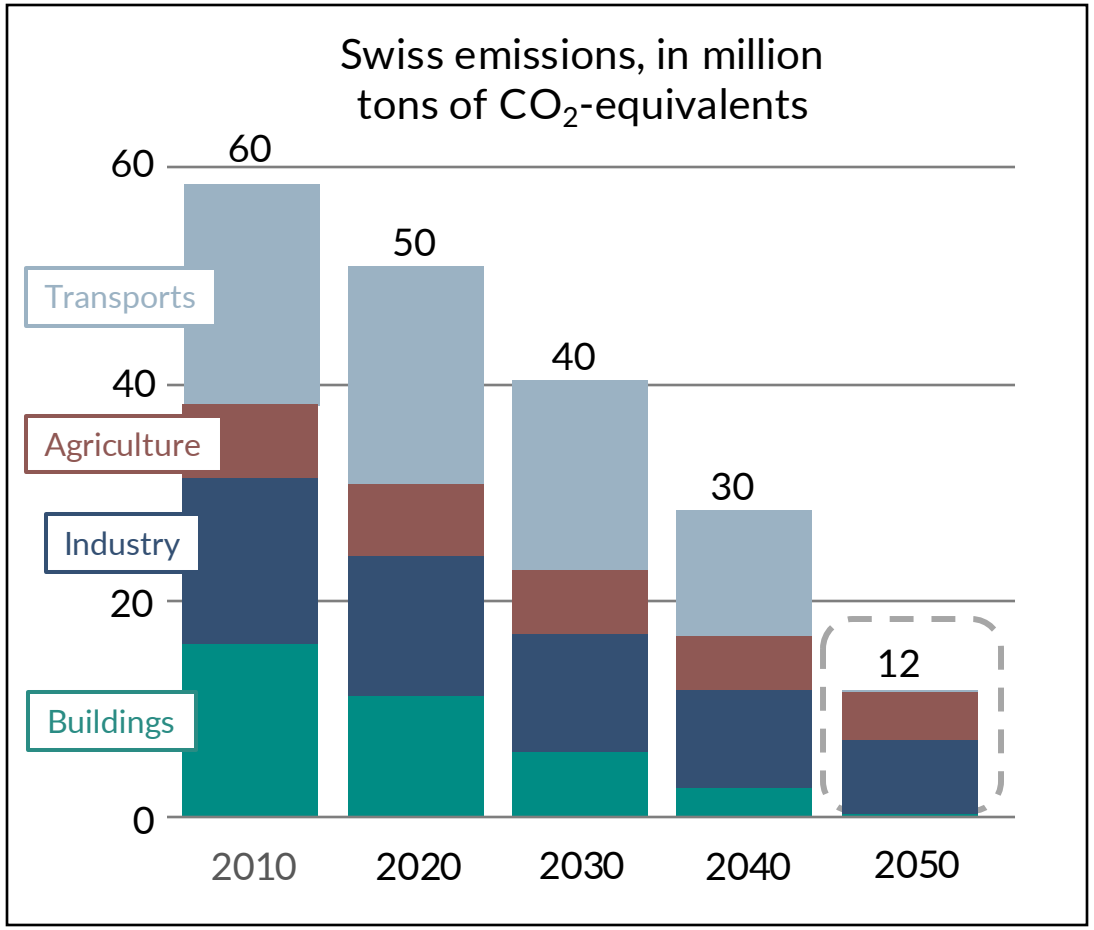
# Geological $CO_2$ Storage: Enabling Reduction, Removal, and Net Zero

**Tech for Net Zero – CEO4Climate-Briefing with ETH Zürich**
**September 8th, 2025**

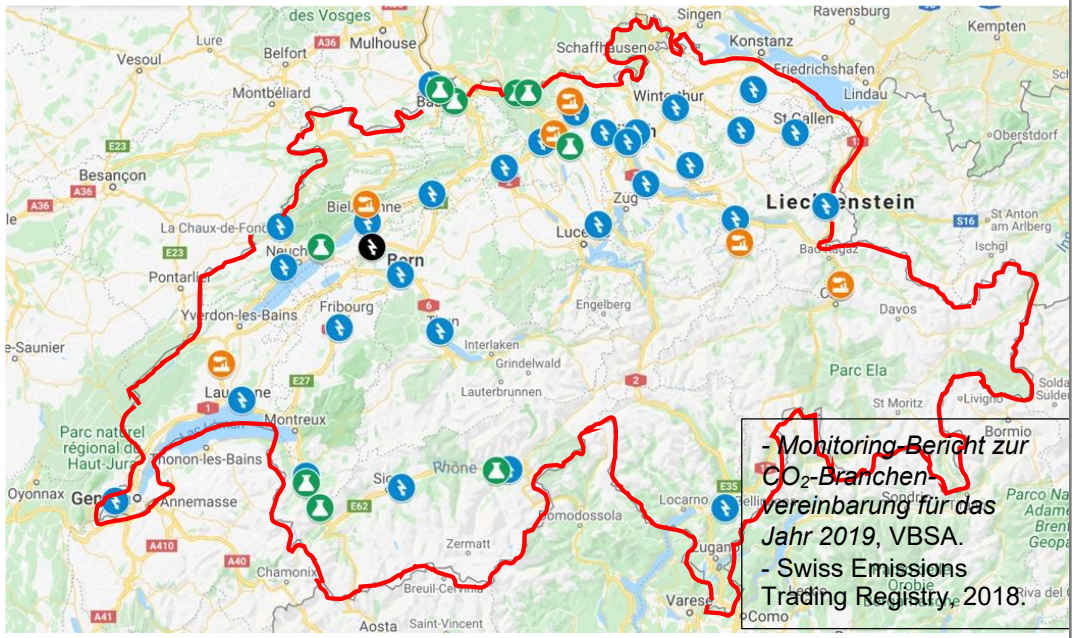
**Viola Becattini**
**Swiss Seismological Service, ETH Zurich**



# Swiss net-zero climate goal
## enshrined in law by the Climate and Innovation Act




## Swiss large $CO_2$ emitters (today and 2050)




- **Waste-to-Energy** (30 plants) 4.5 Mt $CO_2$/y
- **Mineral industry** (7 plants) 2.6 Mt $CO_2$/y
- **Chemical industry** (9 plants) 1.1 Mt $CO_2$/y


Switzerland's long-term climate strategy, The Federal Council, 2021.
Factsheet, $CO_2$ capture, removal and storage: overview of the legal framework, 2025, Federal Office for the Environment.

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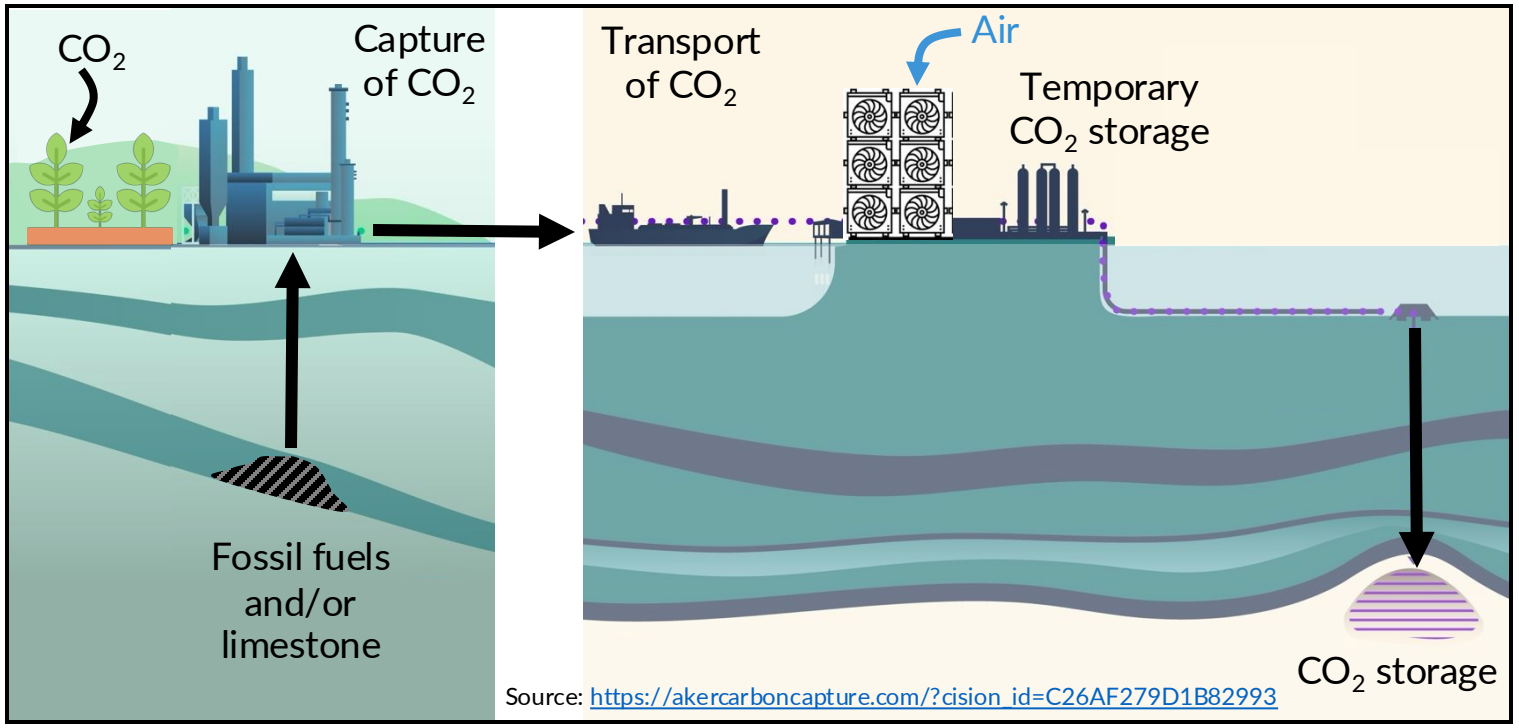
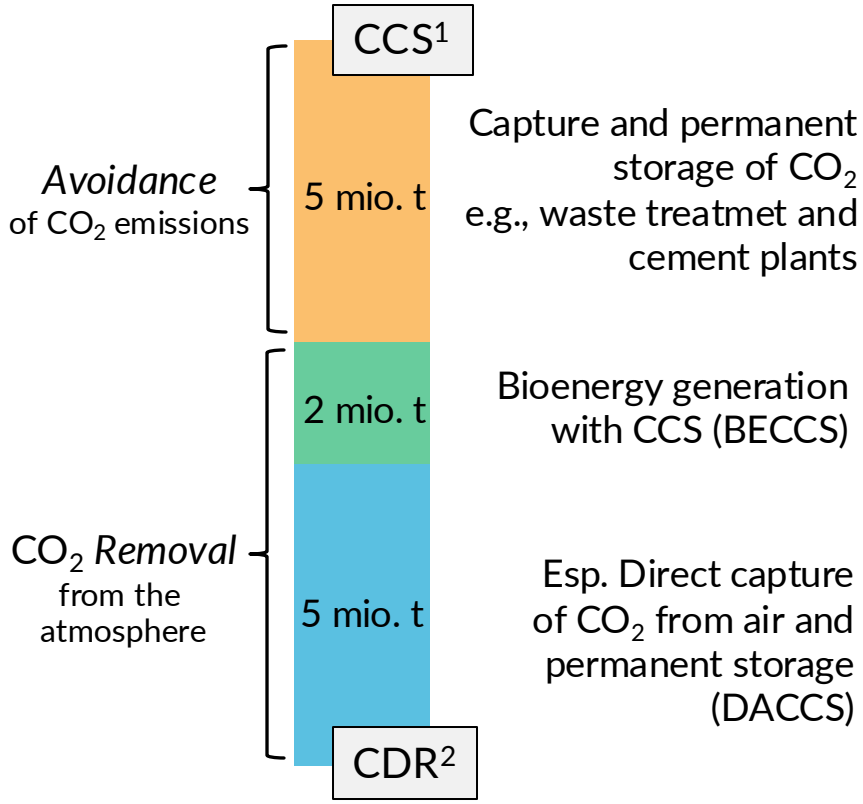



How to tackle *hard-to-abate* emissions (12 mio. t):




[1]CCS: $CO_2$ Capture and Storage
[2]CDR: Carbon Dioxide Removal

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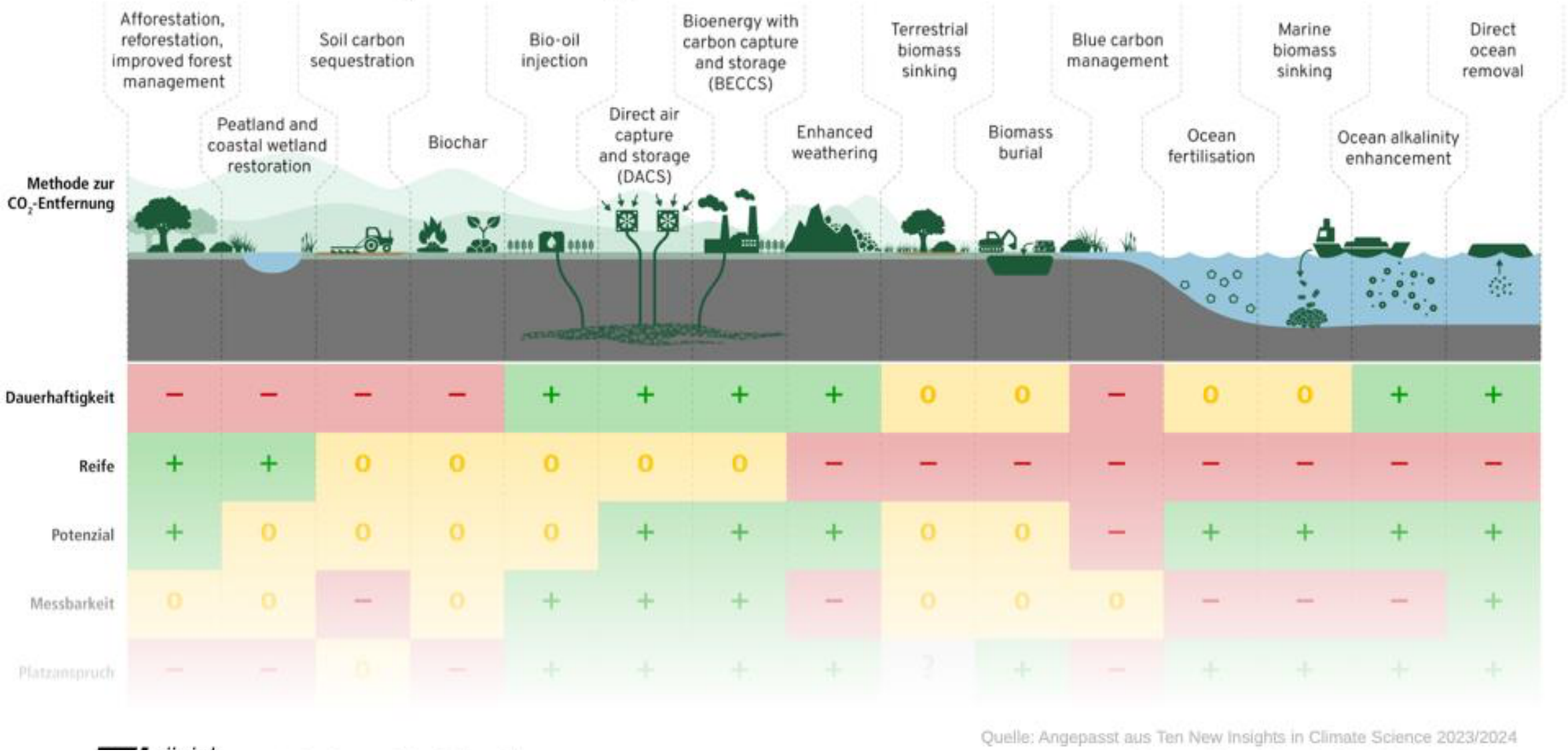
# Portfolio of CDR options




Source: Cyril Brunner

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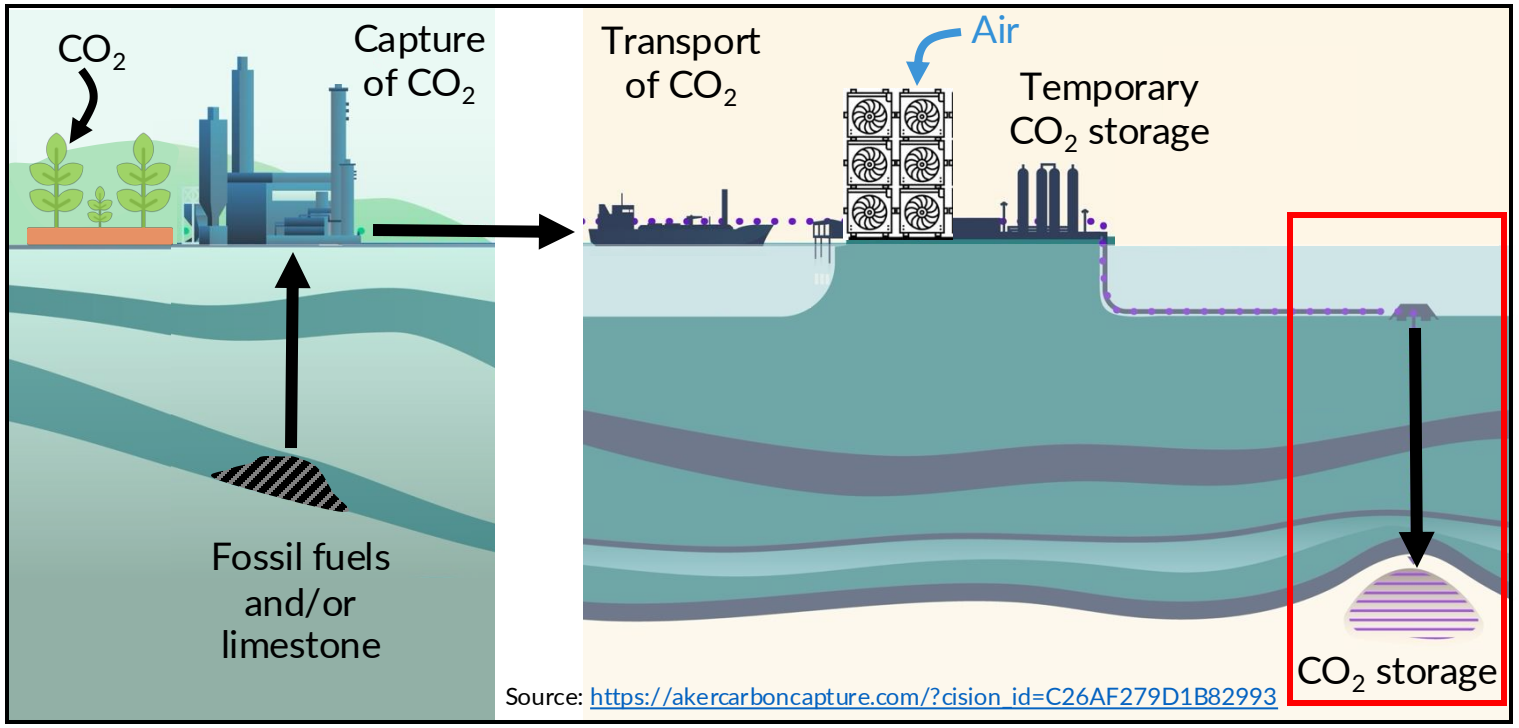


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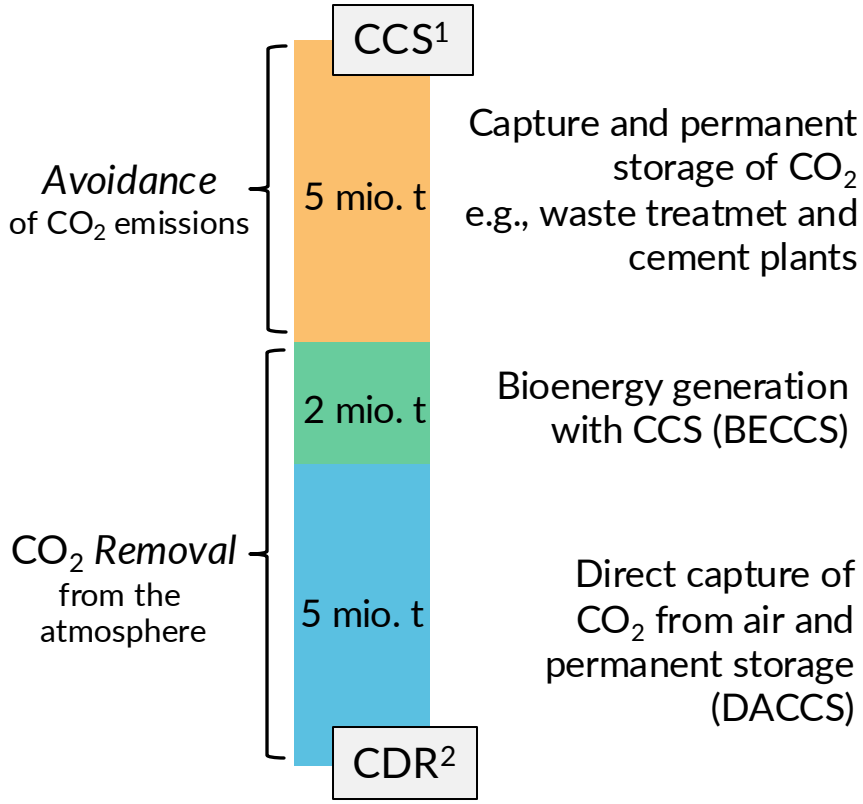


Switzerland's long-term climate strategy, The Federal Council, 2021.
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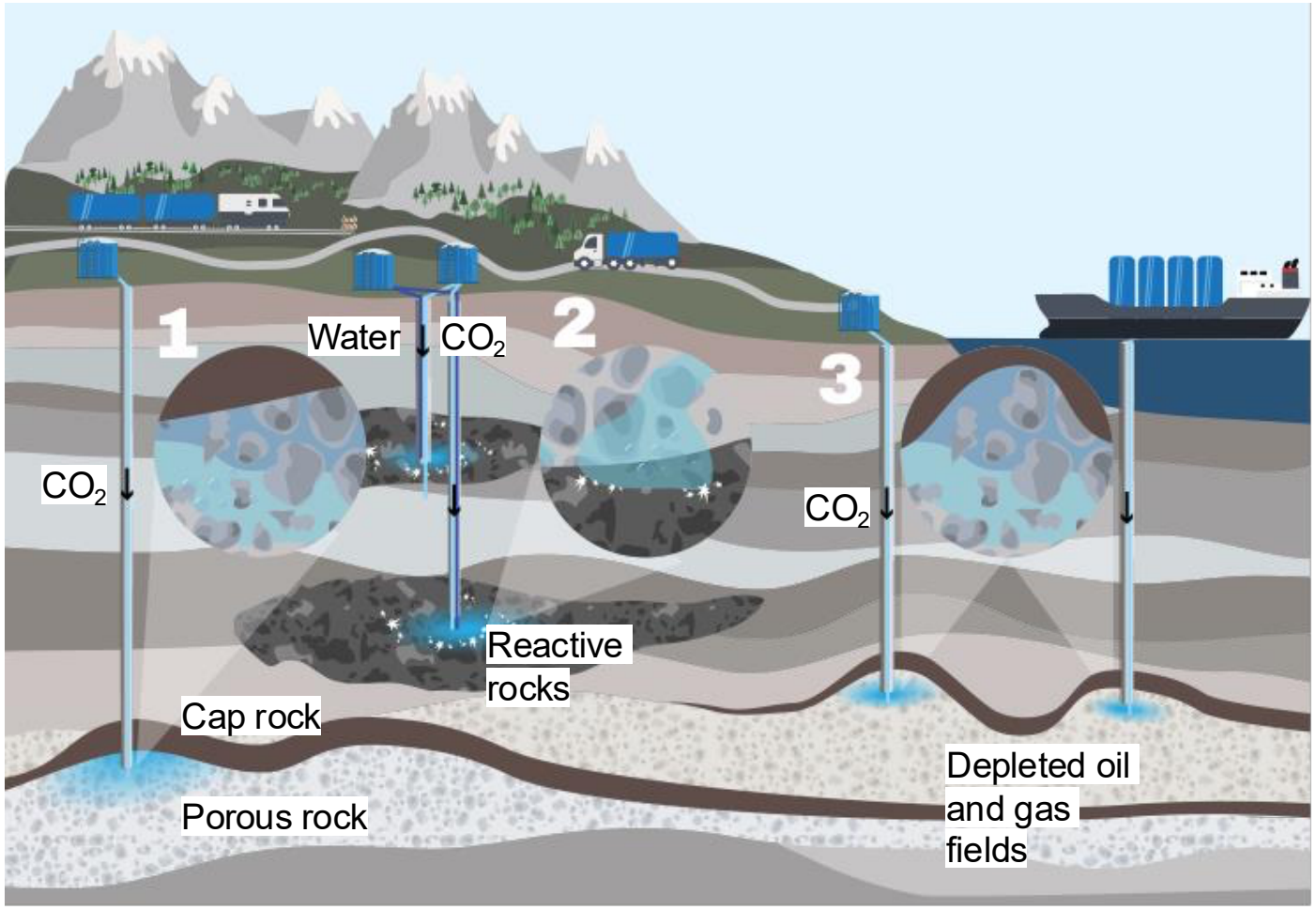
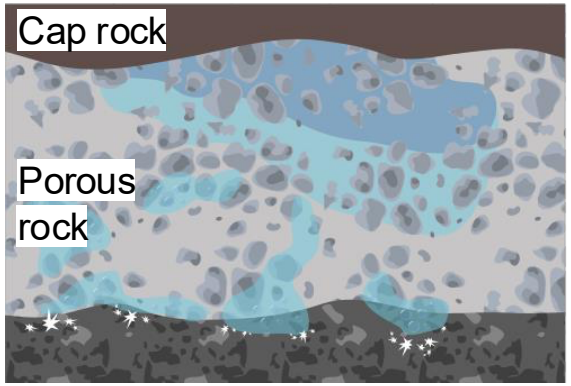
➢ Swiss demand for $CO_2$ storage in 2050 is estimated at ca. 12 M tons

# How is $CO_2$ stored in the underground?

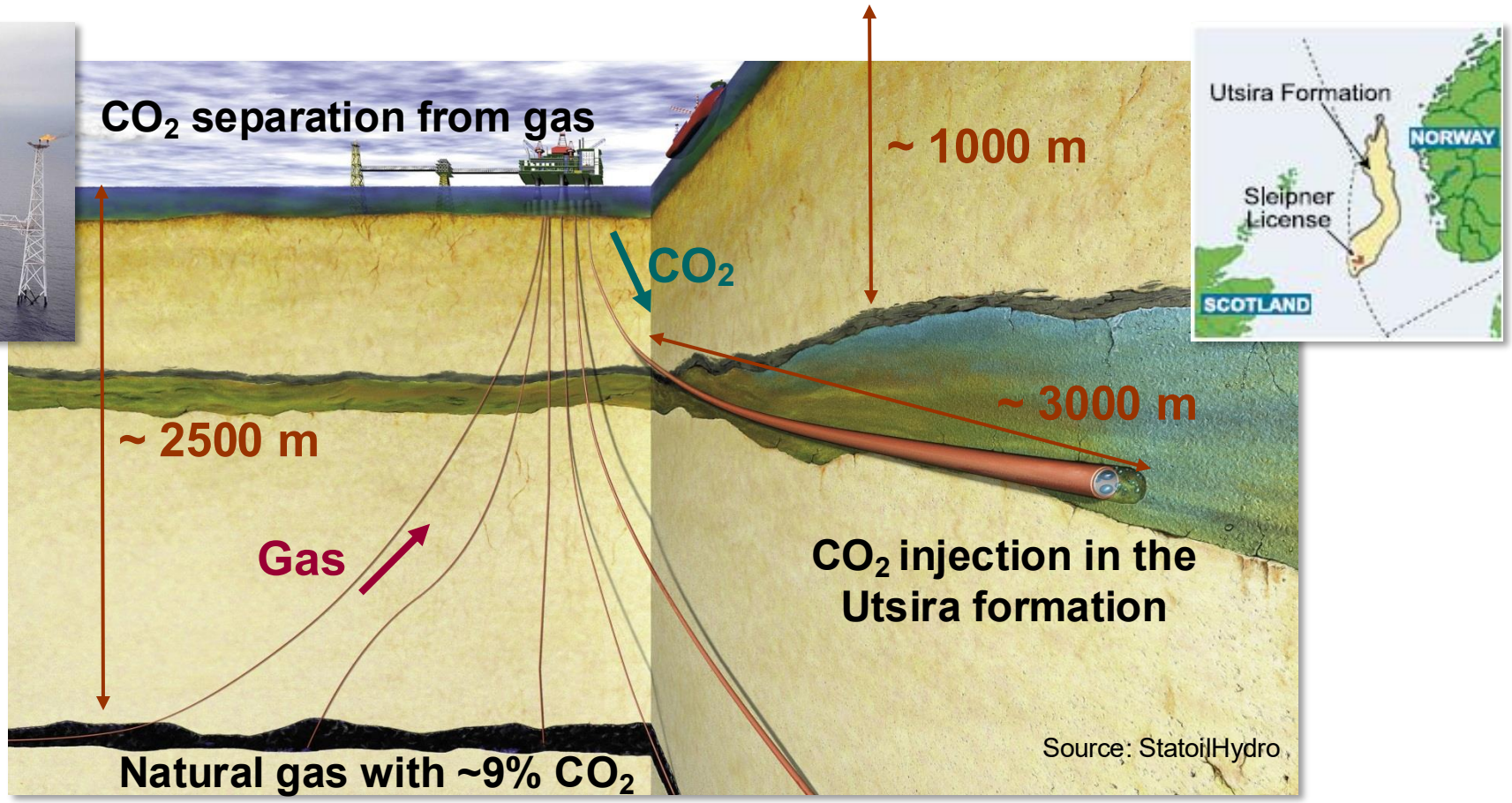



1. Storage in sedimentary basins (e.g., saline aquifers)
2. Storage via mineralization in reactive rock formations (e.g., basalts)
3. Storage in depleted oil and gas fields




- Structural trapping
- Residual trapping
- Solubility trapping
- Mineral trapping

# CCS at the Sleipner gas-field, Norway







- The world's first and longest lasting commercial storage project (since 1996, 20+ Mt $CO_2$ stored).

# $CO_2$ storage hubs across Europe

## Overview of existing and planned $CO_2$ storage projects in Europe

### BULGARIA
1. ANRAV (IF)

### CROATIA
1. Petrokemija Kutina*
2. Bio-Refinery Project*
3. CCGeo (IF)
4. **$CO_2$ EOR Project Croatia***
5. Geothermal CCS project (PCI)

### CZECH REPUBLIC
1. CO2-SPICER

### DENMARK
1. **Greensand***
2. Bifrost* (PCI)
3. Stenlille demo $CO_2$-storage
4. Norne (PCI)
5. Ruby

### FRANCE
1. Pycasso* (PCI)

### GREECE
1. Prinos CCS (PCI)

### HUNGARY
1. MOL-Hungary CCS Project*

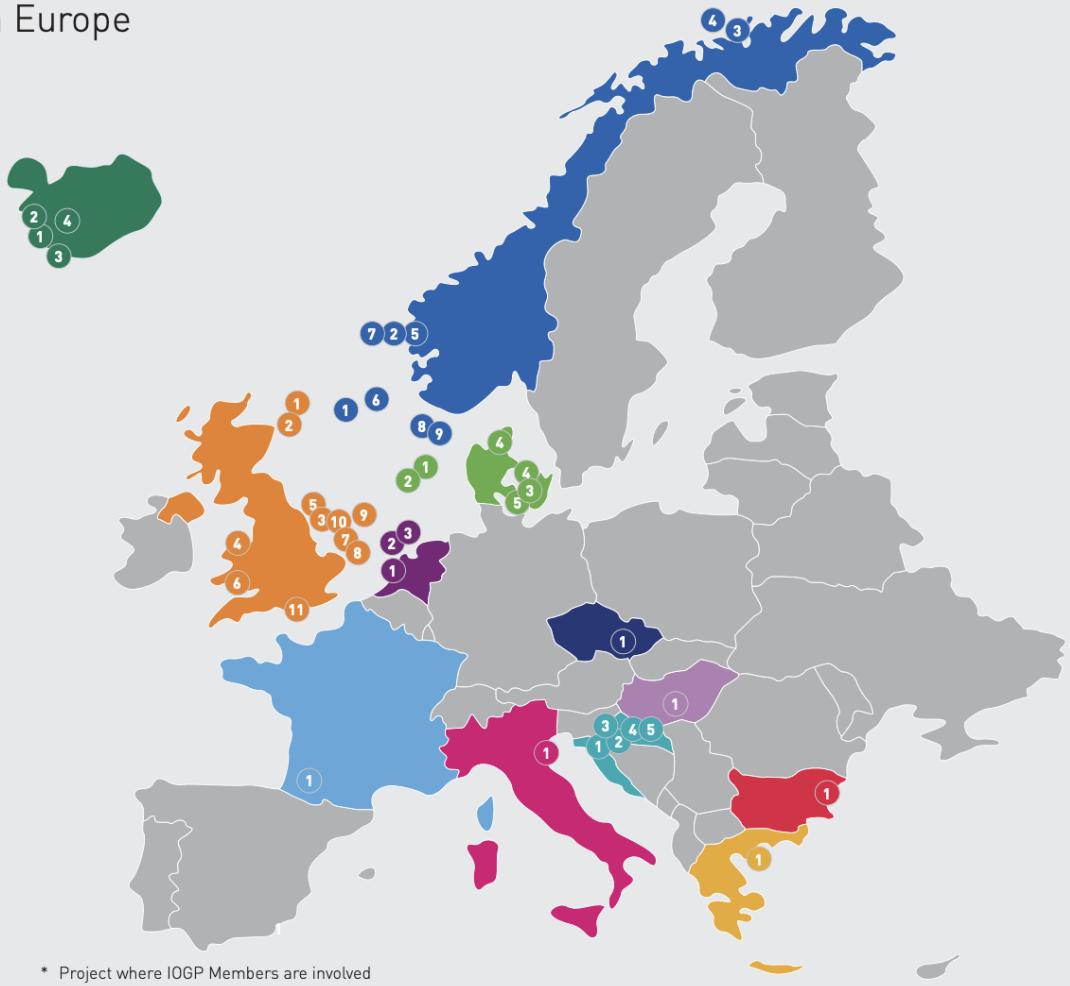
### ICELAND
1. **Orca**
2. **Silverstone** (IF)
3. Coda Terminal (IF)
4. Mammoth

### ITALY
1. **Ravenna CCS (includes Callisto)*** (PCI)

### THE NETHERLANDS
1. Porthos* (PCI)
2. Aramis* (PCI)
3. L10 CCS*

### NORWAY
1. **Sleipner***
2. **Longship (includes Northern Lights)*** (PMI)
3. Barents Blue (includes Polaris)
4. **Snøhvit***
5. Smeaheia*
6. Trudvang*
7. Luna*
8. Havstjerne*
9. Poseidon (NO)*

### UK
1. Acorn*
2. Caledonia Clean Energy
3. Zero Carbon Humber*
4. HyNet*
5. Net Zero Teesside*
6. South Wales Industrial Cluster
7. Bacton Thames Net Zero initiative*
8. Poseidon (UK)
9. Viking CCS*
10. Orion
11. Solent Cluster*



* Project where IOGP Members are involved
Projects listed in **bold** are in operation

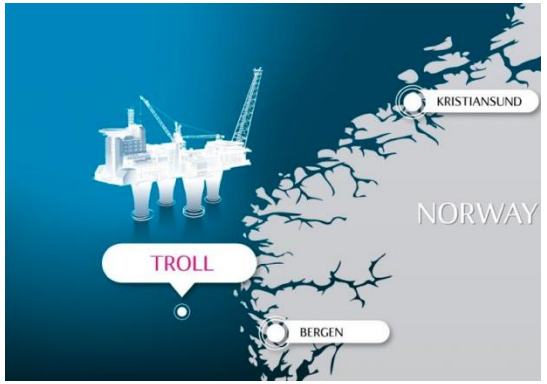
(PCI) – Project of Common Interest
(PMI) – Project of Mutual Interest
(IF) – Project supported by the EU Innovation Fund

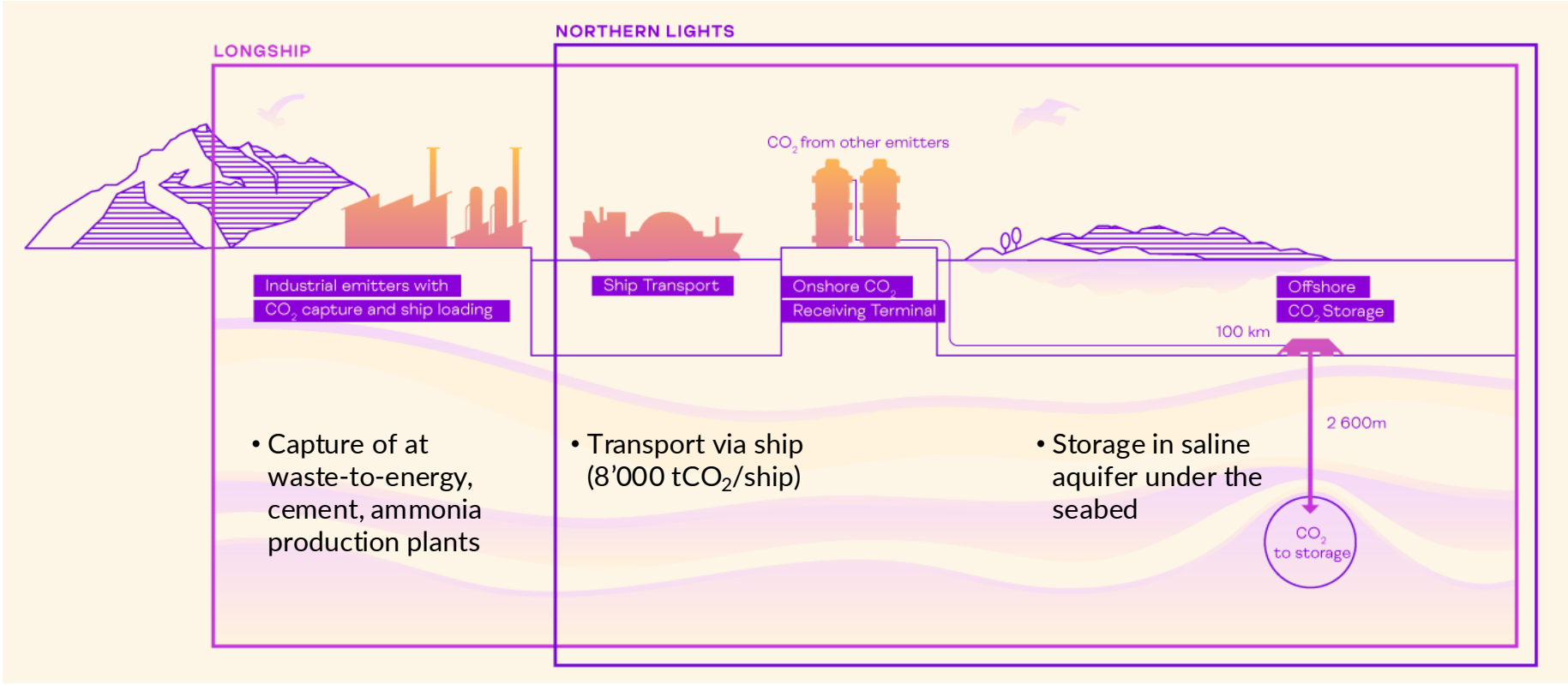
| | |
|---|---|
| EU | **19 projects** - 42 $MtCO_2$/yr by 2030 |
| Europe | **43 projects** - 141 $MtCO_2$/yr by 2030 |

https://iogpeurope.org/wp-content/uploads/2024/10/CO2-Storage-Projects-in-Europe-map.pdf

# CCS: Carbon dioxide capture, (transport) and storage

Example: The Longship project and the Northern Lights storage hub




https://norlights.com/news/northern-lights-is-expanding-capacity-through-commercial-agreement/

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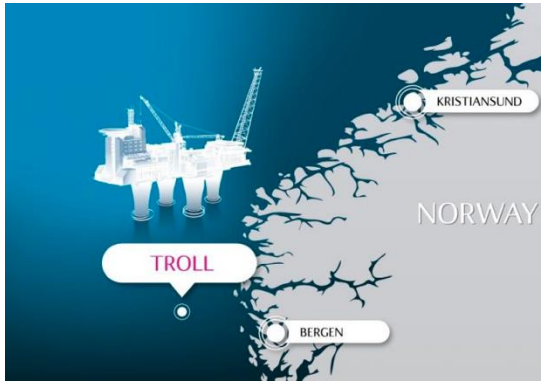


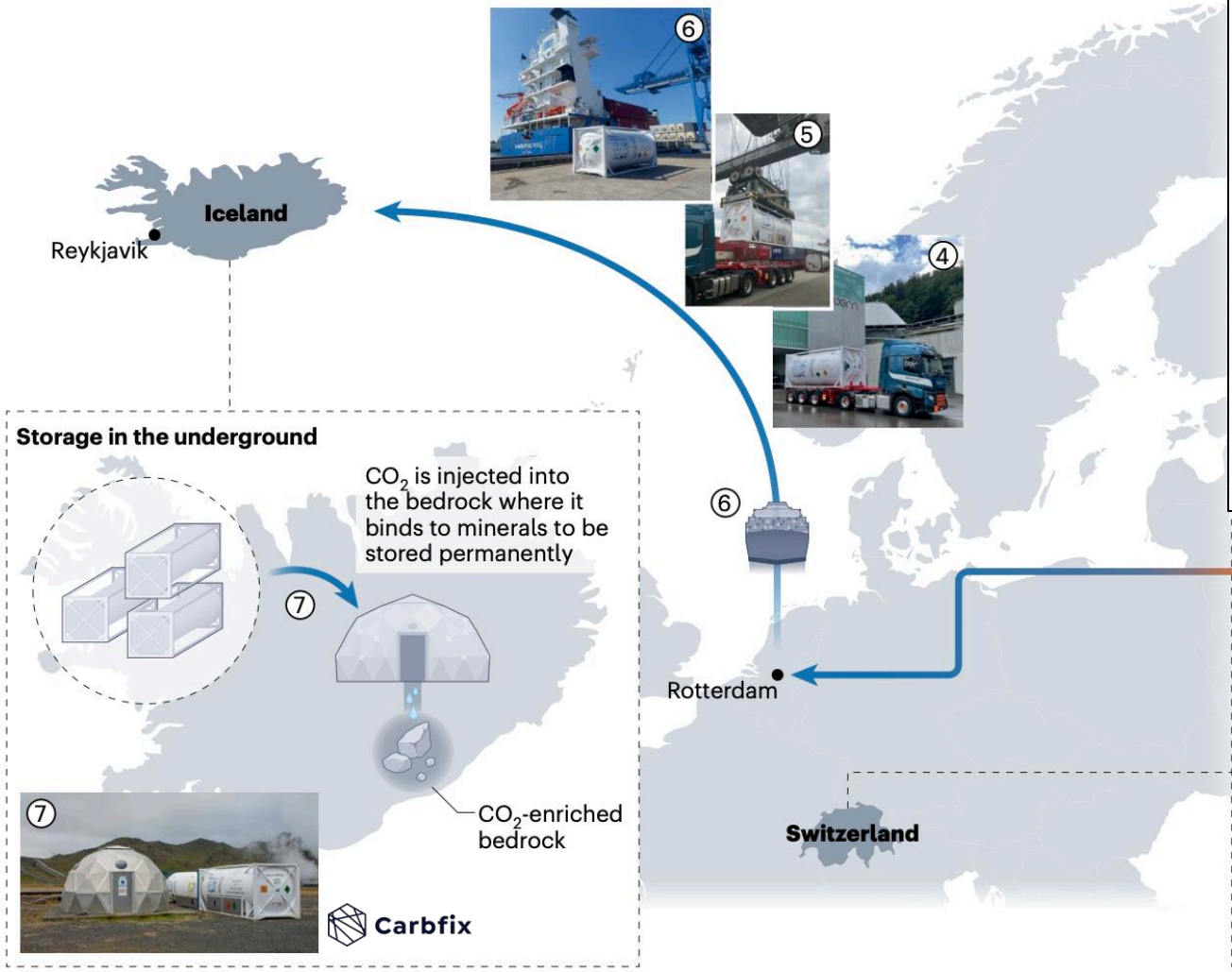

Northern Lights facility with illustration of the expansion infrastructure


- First $CO_2$ volumes injected on August 25th, 2025

https://norlights.com/news/northern-lights-is-expanding-capacity-through-commercial-agreement/

# Does it *work*? Yes!

Pilot project | DemoUpCARMA | 2021-2024

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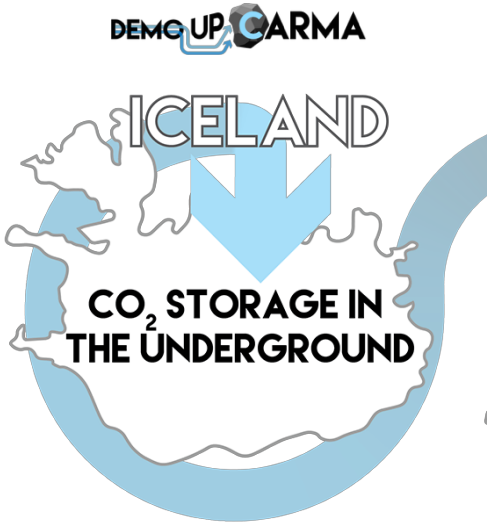
## Turning Swiss CO2 into Icelandic rock

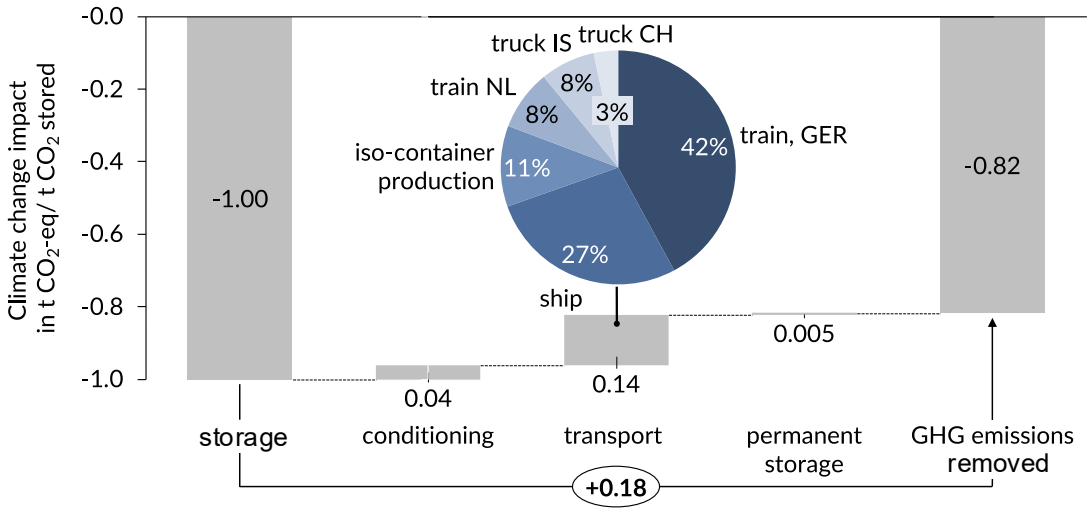
▲ As part of the DemoUpCarma pilot project, the Swiss CO2 is mixed with seawater in Iceland and then pumped underground, where it binds with the basalt and is expected to form limestone within a few years. © Keystone / Anthony Anex

Becattini, V., Wiemer, S., & Mazzotti, M. (2024). *Nature Chemical Engineering*, *1*(4), 267-269.

# Does it *make sense*? Yes!

- For each ton of $CO_2$ stored in the Icelandic underground, **820 kg$CO_2$** are removed from the atmosphere
- Largest contribution due to transport, especially ship and train, in Germany




Burger, J., Nöhl., ... & Bardow, A. (2024). *International Journal of Greenhouse Gas Control*, *132*, 104039.
Becattini, V., Riboldi., ... & Zotică, C. (2024). *Renewable and Sustainable Energy Reviews*, *205*, 114803.

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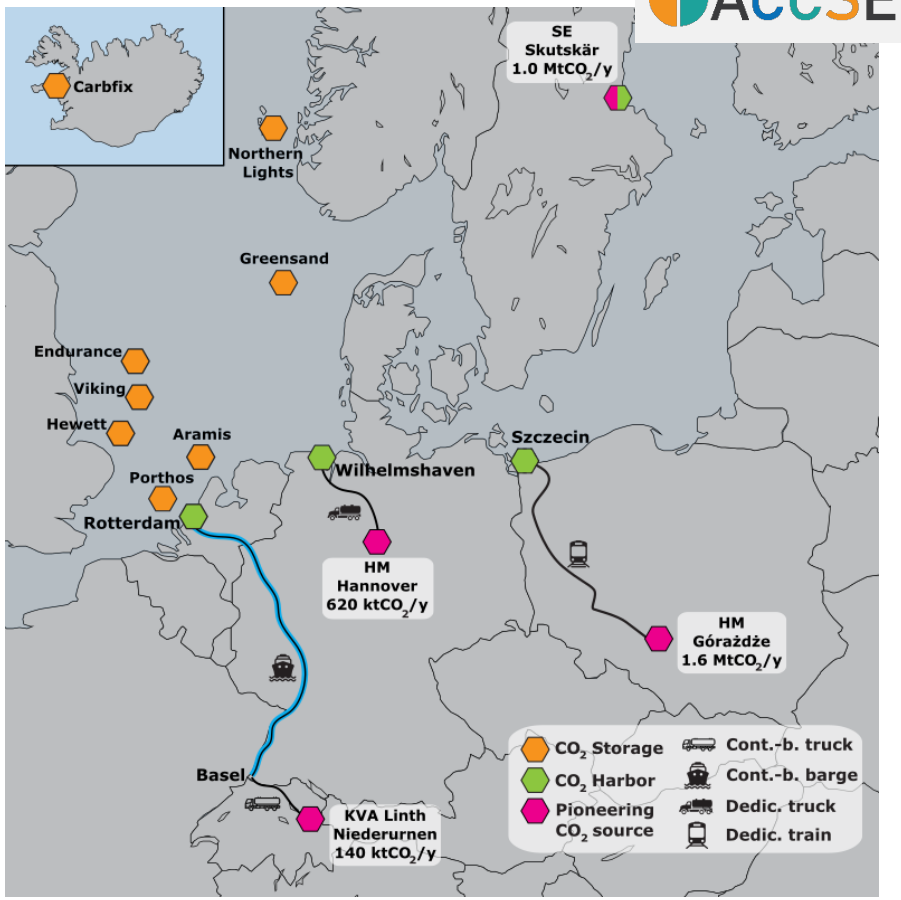


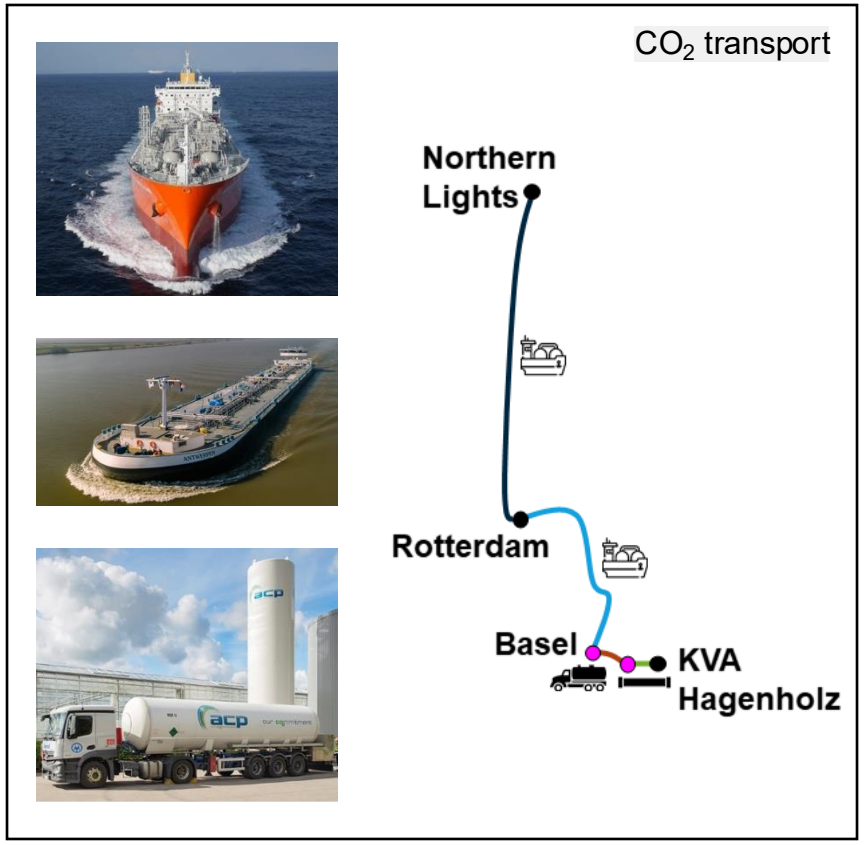

- Overall, including capture*, conditioning, transport and storage, $CO_2$ supply chains could **avoid in the short term ca. 65-80% of the industrial emissions caused**

➢ In the long-term higher environmental efficiency thanks to cleaner energy and pipelines

# Is it expensive? Yes, but..

- In the short term: **ca. few hundreds €/t$CO_2$ avoided** (ca. 400 €/t$CO_2$ in the example)
  - **First-of-a-kind** implementations
  - **Long transport distances** to currently available $CO_2$ storage sites, **moderate quantities of $CO_2$** being managed, point-to-point logistics

➢ Cost is **expected to decrease** thanks to **technology maturation, novel technologies, economies of scale,** and use of **pipelines**







Oeuvray, P., … & Becattini, V. (2024). *Journal of Cleaner Production*, *443*, 140781.
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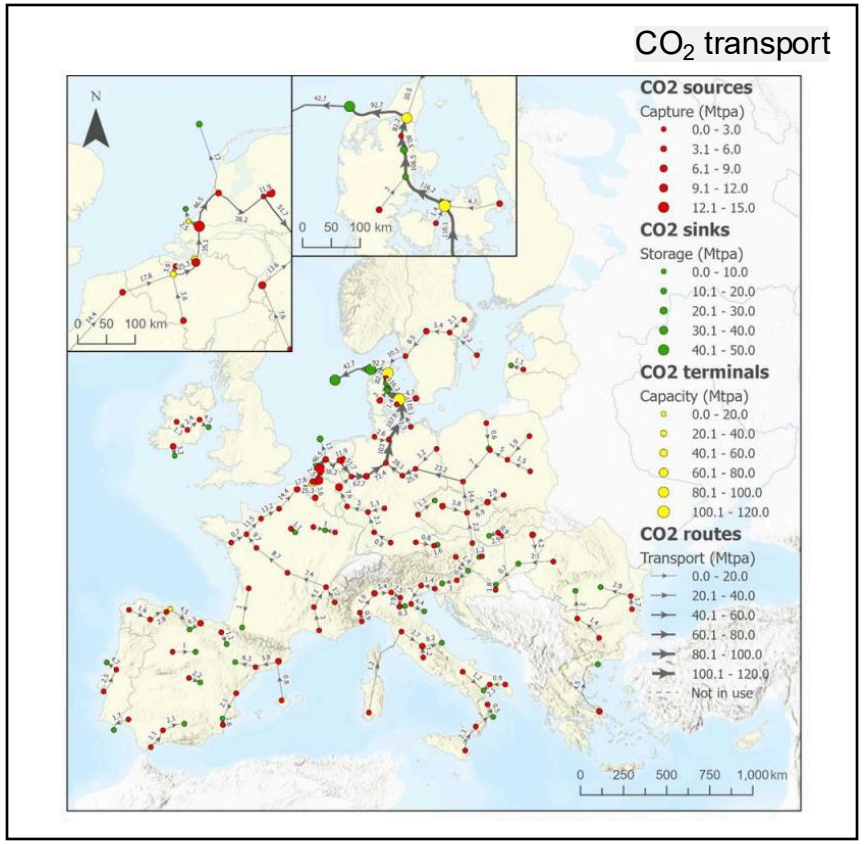



Tumara, D., Uihlein, A. and Hidalgo Gonzalez, I., Shaping the future $CO_2$ transport network for Europe, Publications Office of the European Union, Luxembourg, 2024




Oeuvray, P., … & Becattini, V. (2024). *Journal of Cleaner Production*, *443*, 140781.
Becattini, V., Riboldi., ... & Zotică, C. (2024). *Renewable and Sustainable Energy Reviews*, *205*, 114803.

# What about storing $CO_2$ in the Swiss underground? A promising solution from various perspectives

**Economical**

- $CO_2$ transport over long distance is expensive → 1-2 bn CHF savings per year
- $CO_2$ storage in Switzerland promotes domestic investment

**Environmental**

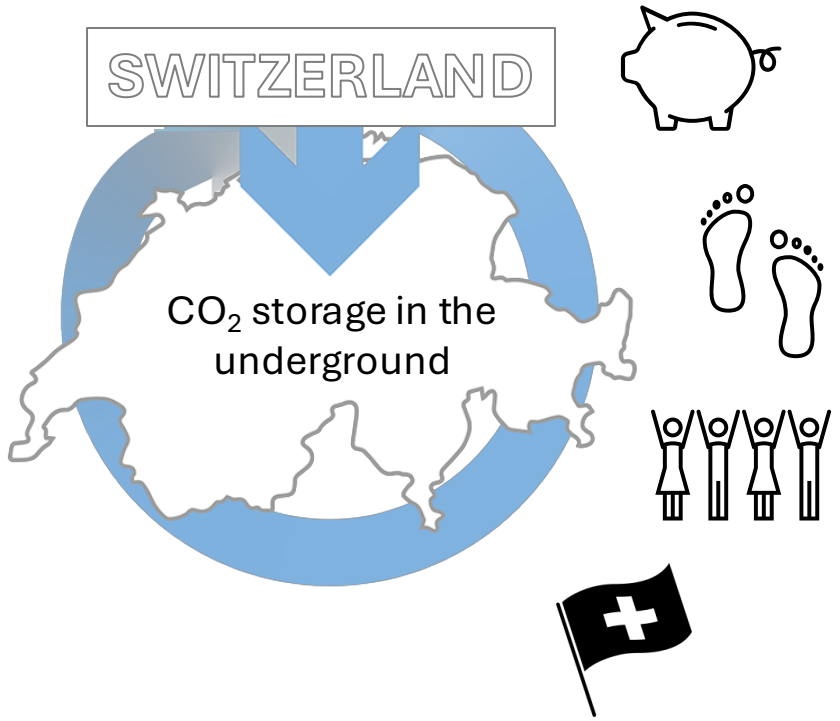
- $CO_2$ transport over long distance causes additional $CO_2$ emissions

**Societal**

- Swiss citizens prefer solutions that take care of our own "waste“

**Self-sufficiency**

- Independence from storage facilities abroad and international supply chains



# BUT: Is $CO_2$ storage in the Swiss underground geologically possible?

- Injection of supercritical $CO_2$ or $CO_2$ dissolved in water into saline aquifers beneath a suitable cap rock → Upper Muschelkalk most promising formation

- Most recent assessment[2]: 52 $MtCO_2$ storage potential

- Injectivity and storage parameters (e.g., porosity and permeability) are highly site dependent

**$CO_2$ storage potential[1]:**
700 $MtCO_2$?

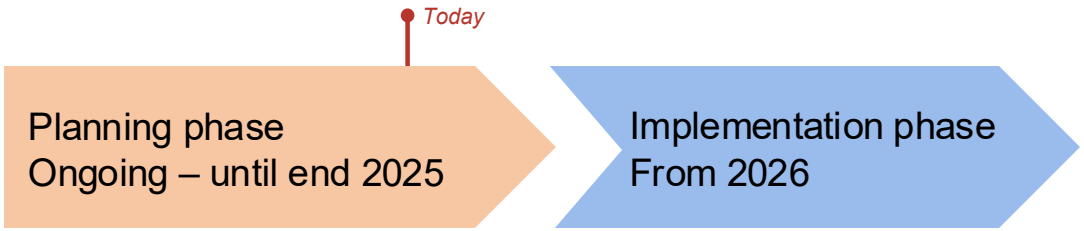

**Maybe, Maybe Not**

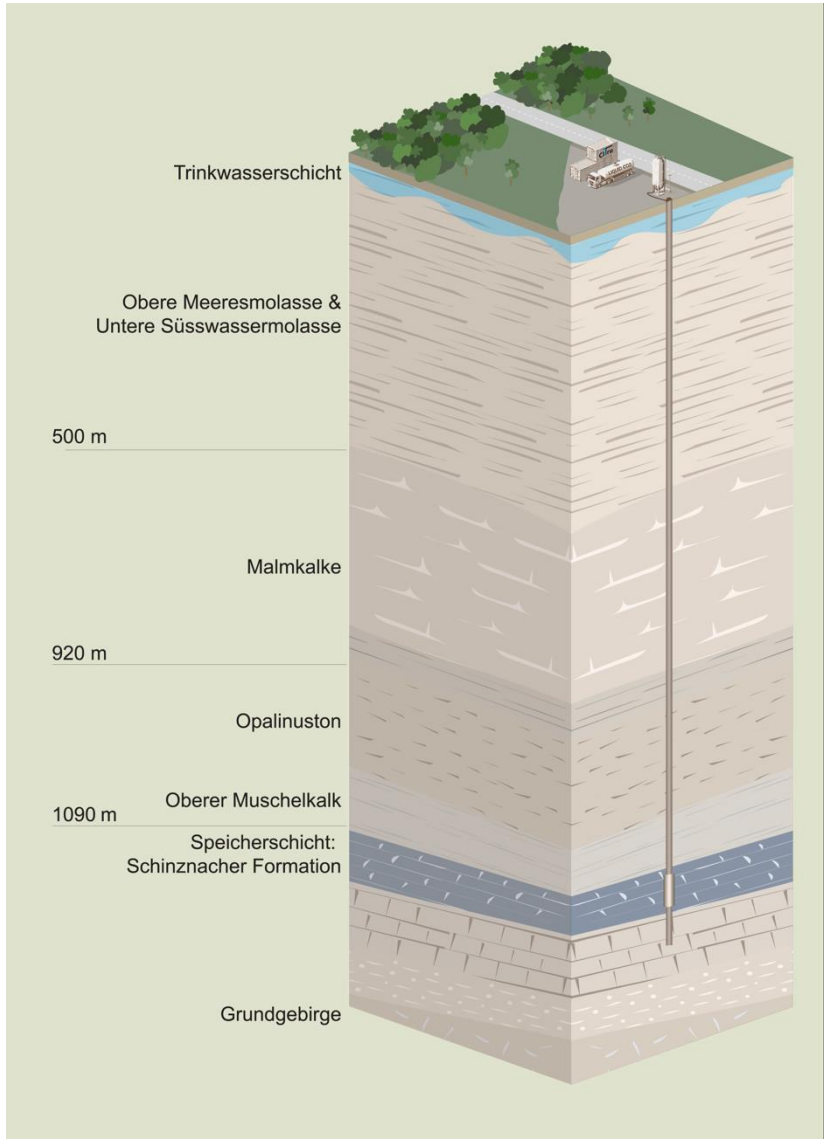
[1]Chevalier, G., Diamond, L. W., & Leu, W. (2010). *Swiss Journal of Geosciences*, *103*, 427-455.
[2]ELEGANCY – Final report (2021). Efficient generation of renewable $H_2$ from biomass, while harvesting geothermal heat and enabling negative $CO_2$ emissions.

# CITru pilot initiative

- **CITru pilot initiative**: Focused on the **planning and potential execution** of $CO_2$ injection into a decommissioned borehole in the commune of Trüllikon (ZH)

- Is the permeability at the borehole sufficient for $CO_2$ injection?
- How can the injected $CO_2$ be monitored underground?
- How can we transfer the results to other sites in Switzerland?
- What equipment and expertise are required?
- What costs arise for exploration and injection in Switzerland?
- How does the local population view it?
- What regulatory steps are necessary?

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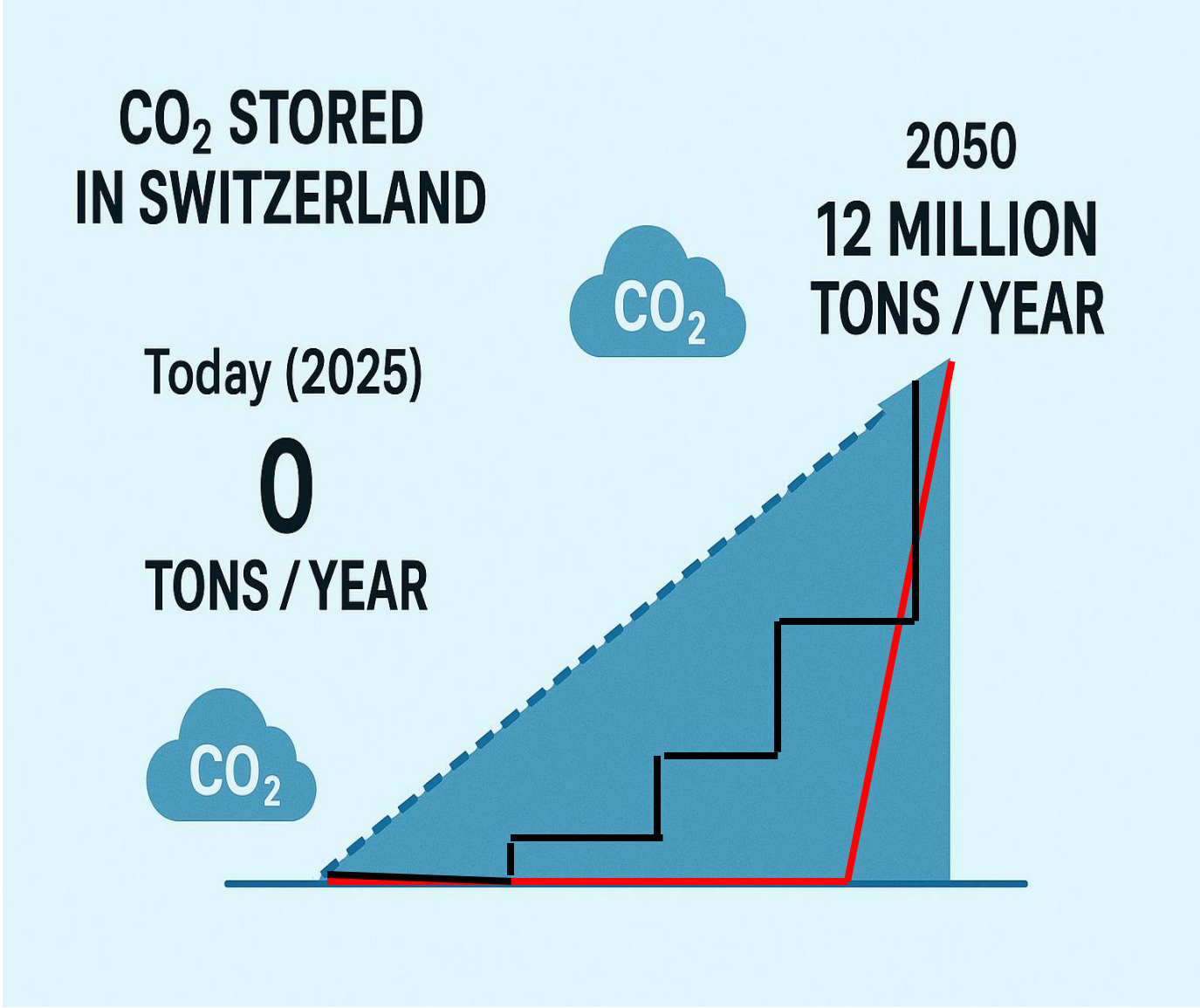
# 2050-Goal: Starting today!?

- At present, we store **0 $MtCO_2$** – by 2050 more than **7 Mt/year** must be achieved → 700 MCHF/year market?
- Project development for $CO_2$ storage takes time (5–10 years?) – the **Northern Lights / Longship** project began in 2016..
- To reach the interim target of storing **1.2 $MtCO_2$ by 2035** (at least partly in Switzerland), we must start today (better: yesterday) with resolving the open questions and then developing a site!



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