What geological CO₂ storage quality is required?

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Motivation for study

• CO$_2$ capture and geological storage (CCS) may become one of a few major technologies to mitigate greenhouse gas emissions. (Transition phase to carbon-free technologies.)

• Not one but many measures and technologies required to meet stringent climate policy targets

• Background for developing rules for storage site selection and “good management”, and possibly to determine the “optimal” level of storage

• Quality important for public trust
Objective

• Explore quality requirements of large scale geological storage of CO₂
• Quality defined as retention time of stored CO₂ (average storage time)
• Must be consistent with defined climate policy targets – maximum warming by year 2100:
  * 2 °C (EU and Norway)
  * 2.5 °C
  * 3 °C

Research question: Is CCS a good global warming mitigation measure? – What storage quality is required?

- We make no assumptions about any specific regulatory frameworks for site selection and management in these calculations
Required quality of geological \( \text{CO}_2 \) storage:

Experimental set up

- Fossil fuel use scenarios
  - Drivers, policies, resources
- \( \text{CO}_2 \) storage scenarios
  - Climate goals, storage capacity
- \( \text{CO}_2 \) leakage scenarios
  - Reservoir simulations
- Climate consequences: \( \Delta T \)
  - Simple climate model
Potential leakage routes and remediation techniques for CO2 injected into saline formations

**Potential Escape Mechanisms**

A. CO₂ gas pressure exceeds capillary pressure & passes through siltstone
B. Free CO₂ leaks from A into upper aquifer up fault
C. CO₂ escapes through ‘gap’ in cap rock into higher aquifer
D. Injected CO₂ migrates up dip, increases reservoir pressure & permeability of fault
E. CO₂ escapes via poorly plugged old abandoned well
F. Natural flow dissolves CO₂ at CO₂ / water interface & transports it out of closure
G. Dissolved CO₂ escapes to atmosphere or ocean

**Remedial Measures**

A. Extract & purify groundwater
B. Extract & purify groundwater
C. Remove CO₂ & reinject elsewhere
D. Lower injection rates or pressures
E. Re-plug well with cement
F. Intercept & reinject CO₂
G. Intercept & reinject CO₂

SRCCS Figure TS-8
Leakage scenarios for saline formations (aquifers)

- Long-term reservoir simulations
- Injection into reservoirs of variable quality
- Leakage through fractures
- Percolation through a network of conducting sand bodies embedded in non-conducting shale
- A combination of the two above
- Several combinations of rock permeability, stored volume of CO$_2$, etc.
Leakage through a percolation network

Even if the conducting network of sand bodies eventually allows the CO$_2$ to escape to the surface (right) the retention allows a lot of the CO$_2$ to dissolve while some CO$_2$ is permanently trapped as free gas (escape curves right).
The graph illustrates CO₂ emissions (Pg carbon/year) for different storage scenarios in the A1 2.5K HFF scenario. The x-axis represents the year, ranging from 2000 to 4000, and the y-axis represents CO₂ emissions in Pg carbon/year. The graph shows four scenarios:

- **ES3**: Dashed blue line
- **ES2**: Dotted red line
- **No storage**: Solid black line
- **Perfect storage**: Solid green line

The peak emission occurs around the year 2000, with the no storage scenario showing the highest peak, followed by ES2, ES3, and perfect storage.
Preliminary findings

Large-scale geological storage of CO₂ can have a significant mitigating effect on man-made global warming, even when storage is not permanent.

A relative strict climate target, for example, is feasible with high fossil fuel use if balanced with a high storage rate.

In case of a high level of storage, long-term leakage from sites can be non-marginal and lead to a temperature increase over a couple of millennia.

- Into the future there can be efficient ways of handling long-term leakage, such as biomass in combination with CCS.
- Leakages can to some extent be controlled by good site selection and management, but the former may become more difficult with a very high level of storage.