Geological CO_2 storage: how is CO_2 trapped?

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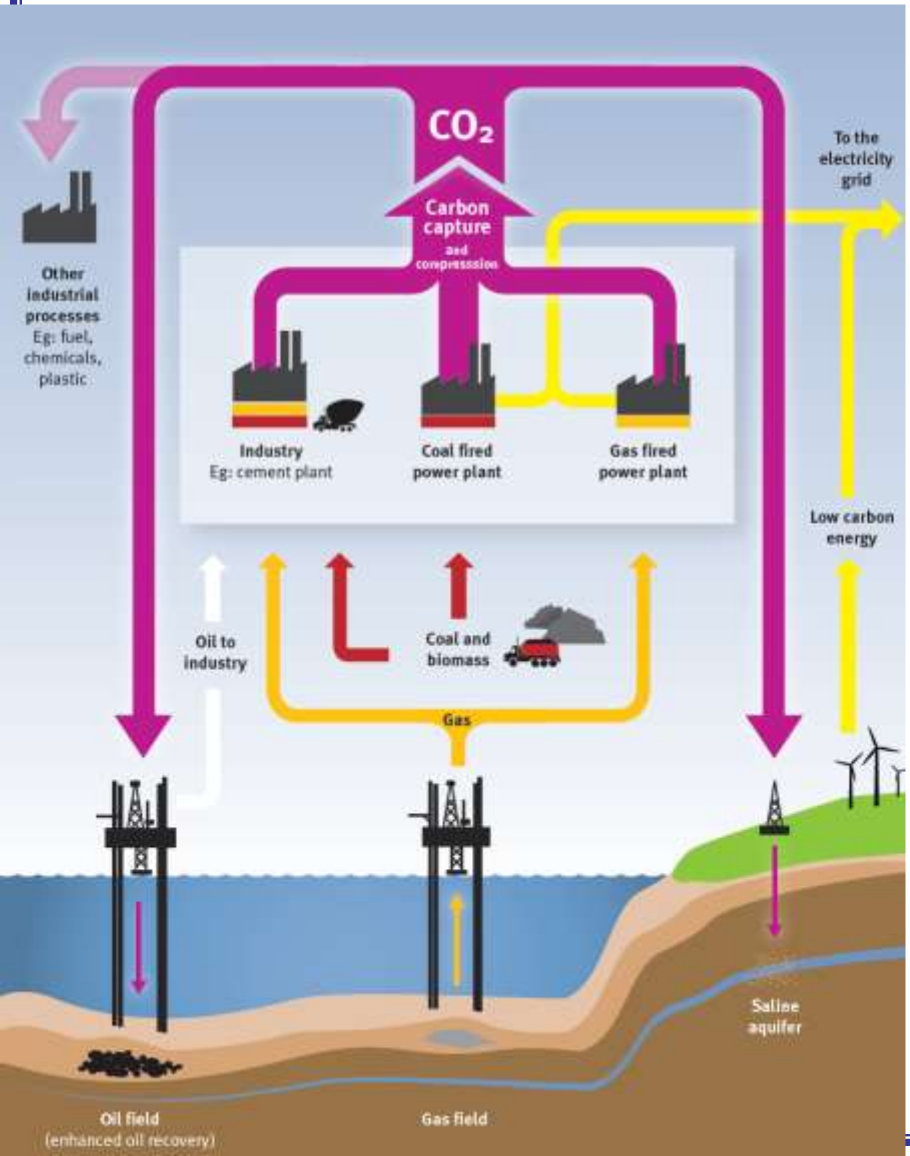
Carbon capture and storage



How much can be stored?

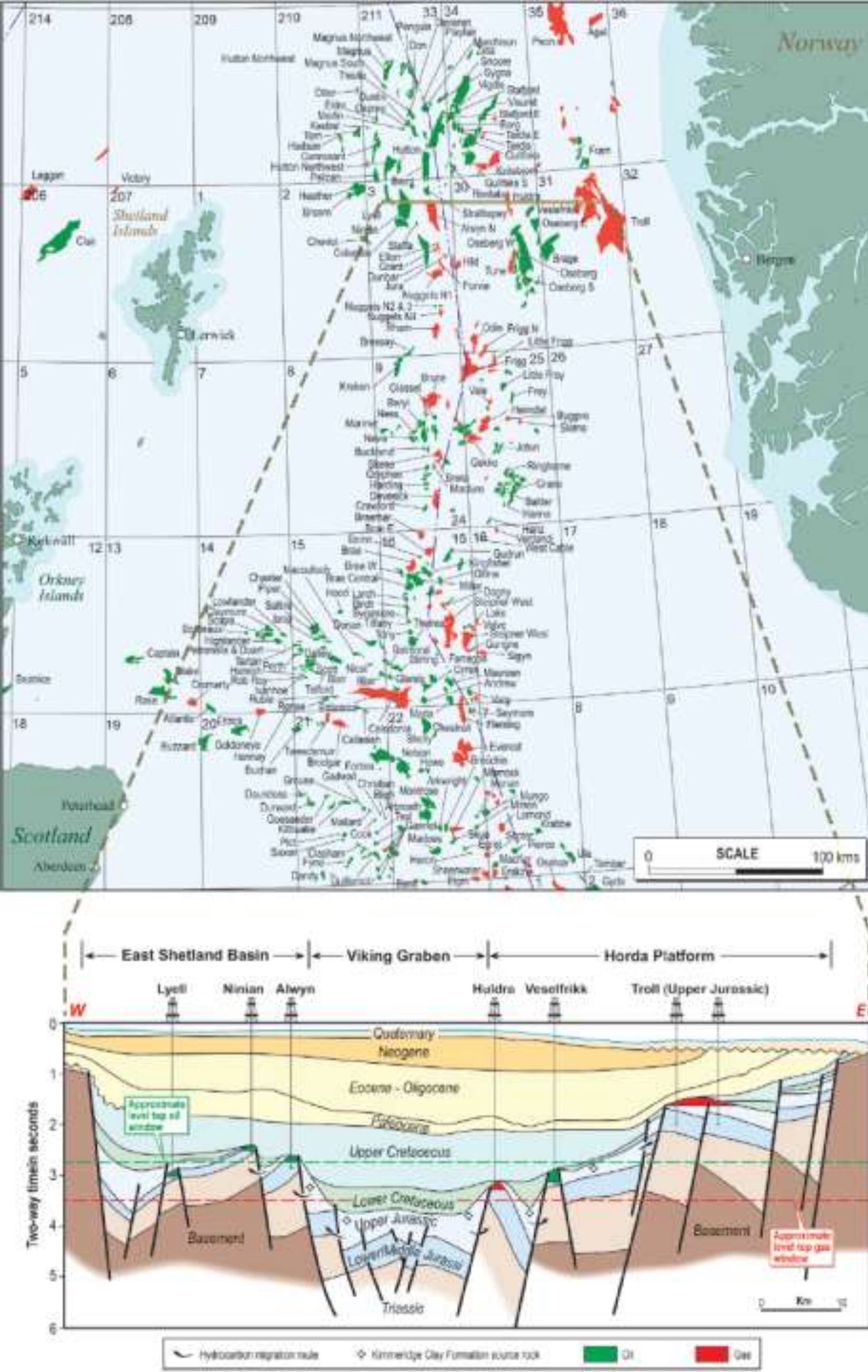
920 Gt – 45% of emissions to 2050 in oil and gas fields.

400-10,000 Gt in aquifers
20-500% of emissions to 2050

IEA estimates.

700 Gt in North Sea alone (DTI) ≈ CO_2 produced by all UK population for >50 years

ETI UKSAP database.



North Sea storage

Large capacity in mature oil and gas fields.

Oil and gas field relatively small traps in much larger aquifers.

Engineering challenge to construct the capture, transport and injection infrastructure.

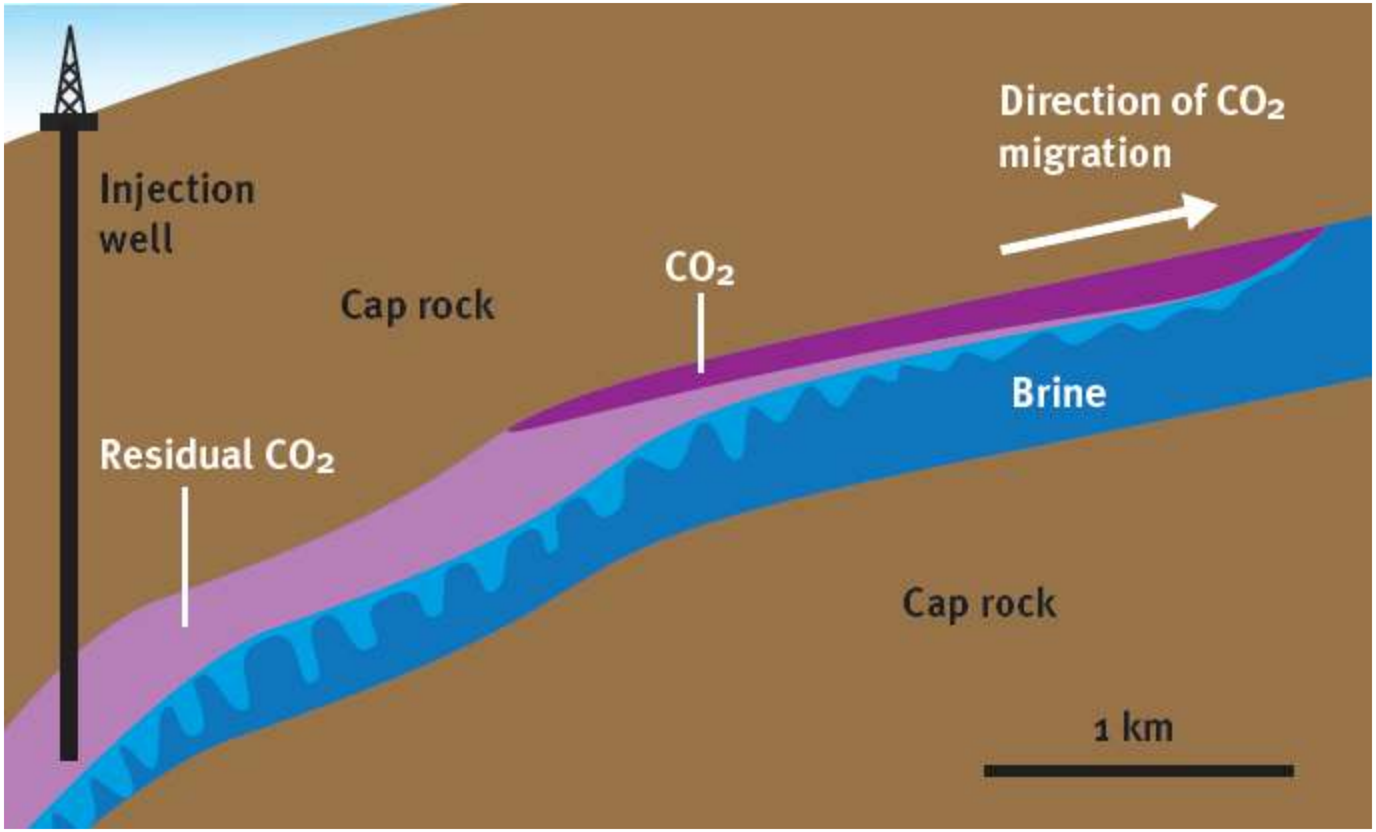
Most current infrastructure would need to be replaced.

Trapping background

How can you be sure that the CO_2 stays underground?

Dissolution, chemical reaction, cap-rock and capillary trapping.

Capillary trapping is rapid (decades): CO_2 as pore-scale bubbles surrounded by water.



Juanes et al., *Water Resources Research* 2006

Pore-to-core-to-field

- **Pore-scale**: exciting new imaging technology to study fluid distributions at the micron-scale. How is CO_2 trapped? Confirm the existence of a residual phase of super-critical CO_2.

- **Corefloods**: to determine amount of trapping (and dissolution constants and capillary pressure). See significant trapping, but less than for an analogous strongly water-wet system.

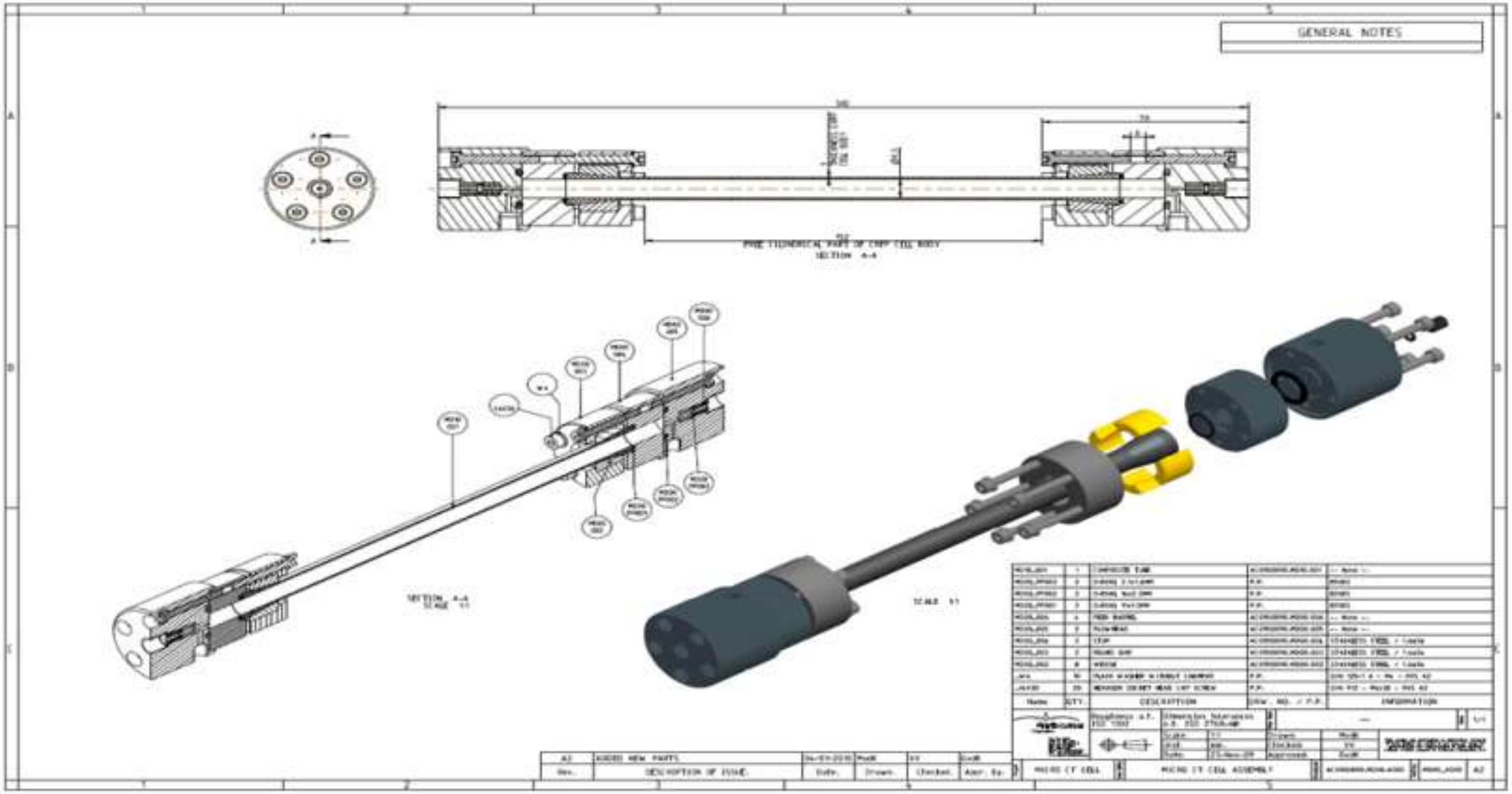
- **Field-scale** simulation: to design optimal storage strategies. Can ensure storage security through co-injection of brine.

Pore-scale experiments (5 mm core)

Novel micro-flow design in collaboration with Shell.

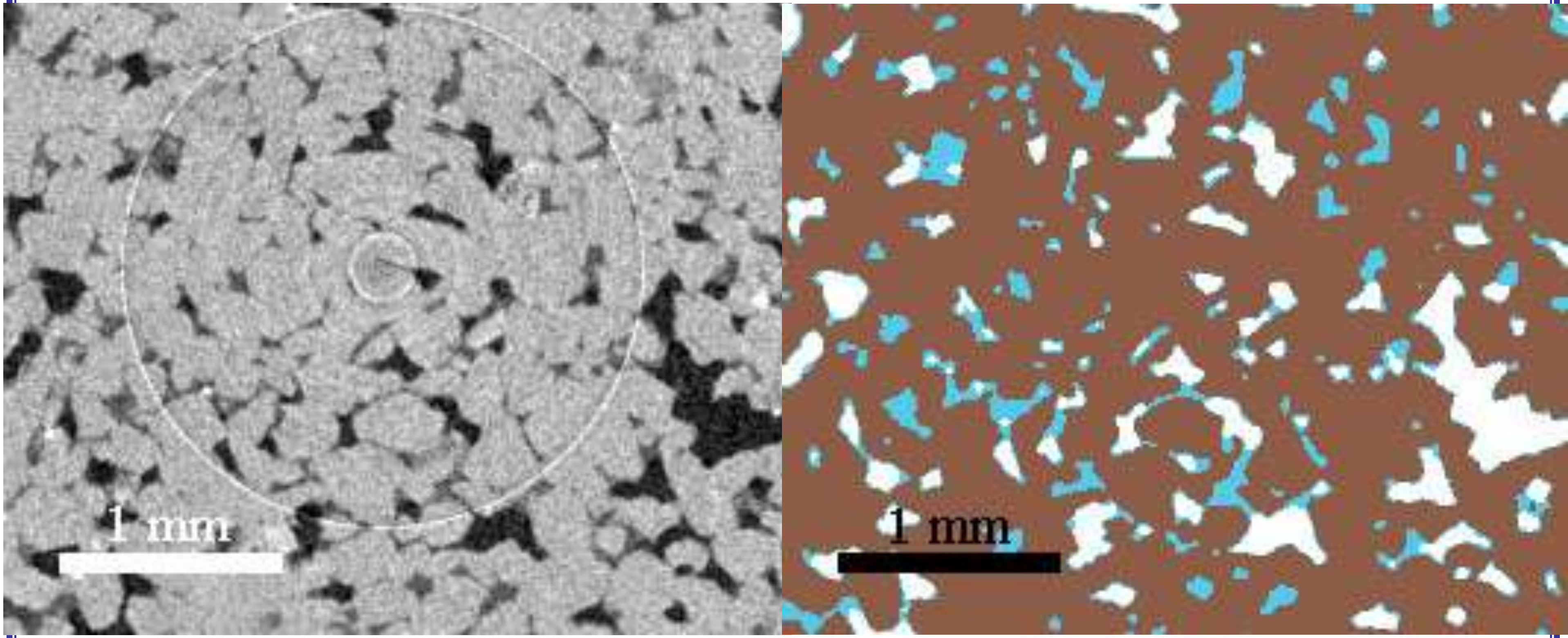
Miniature Hassler-type core holder.

Carbon fibre core holder. Experiments at 9 MPa, 50^oC.



Primary drainage (CO_2 displaces brine)
Brine is blue and CO_2 is white

Raw image – X-ray sorption | Processed image to segment phases



Doddington sandstone core; permeability 1.6 D; image resolution 13 μm.

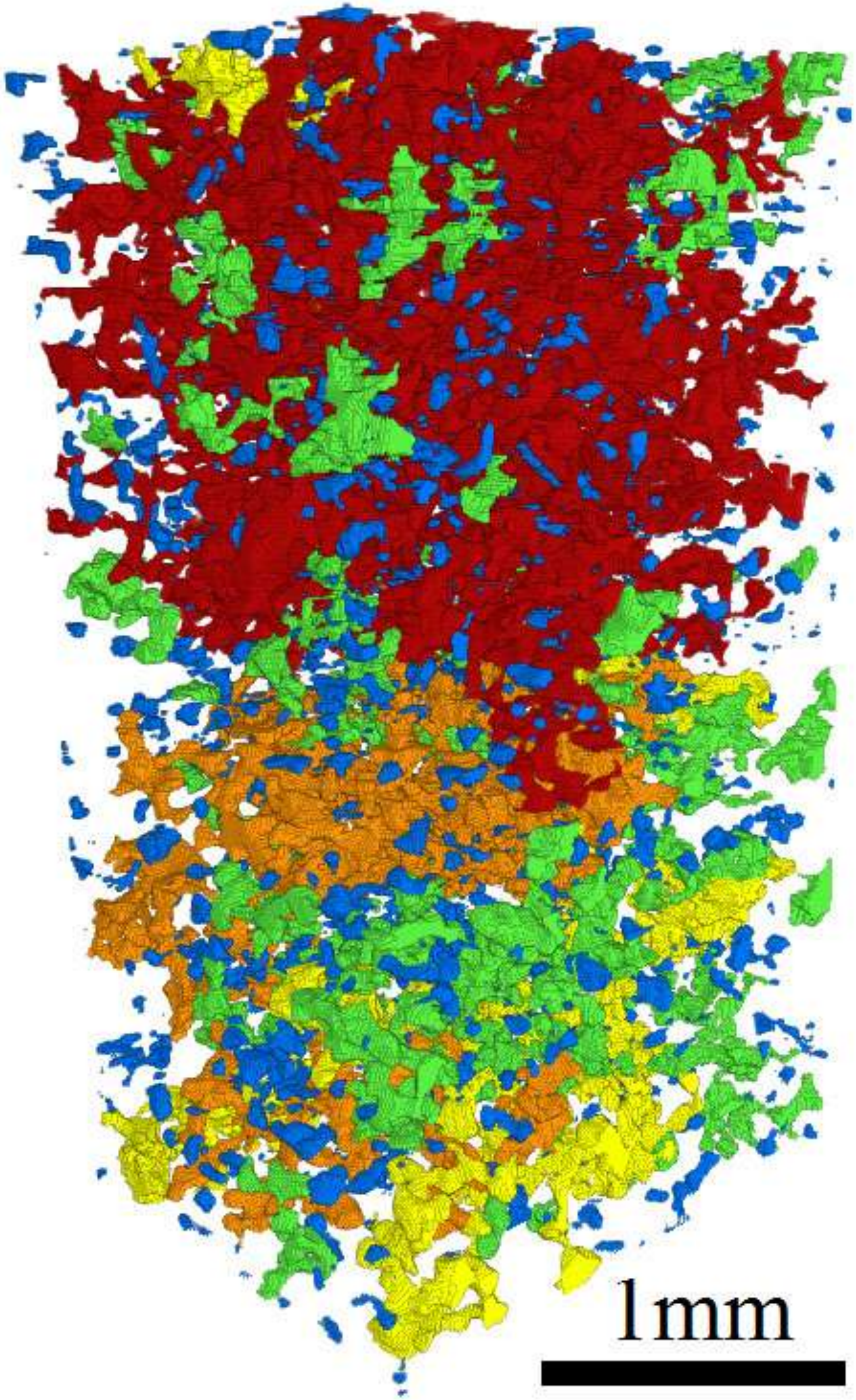
Iglauer et al., *Geophysical Research Letters* 2011

CO_2 clusters

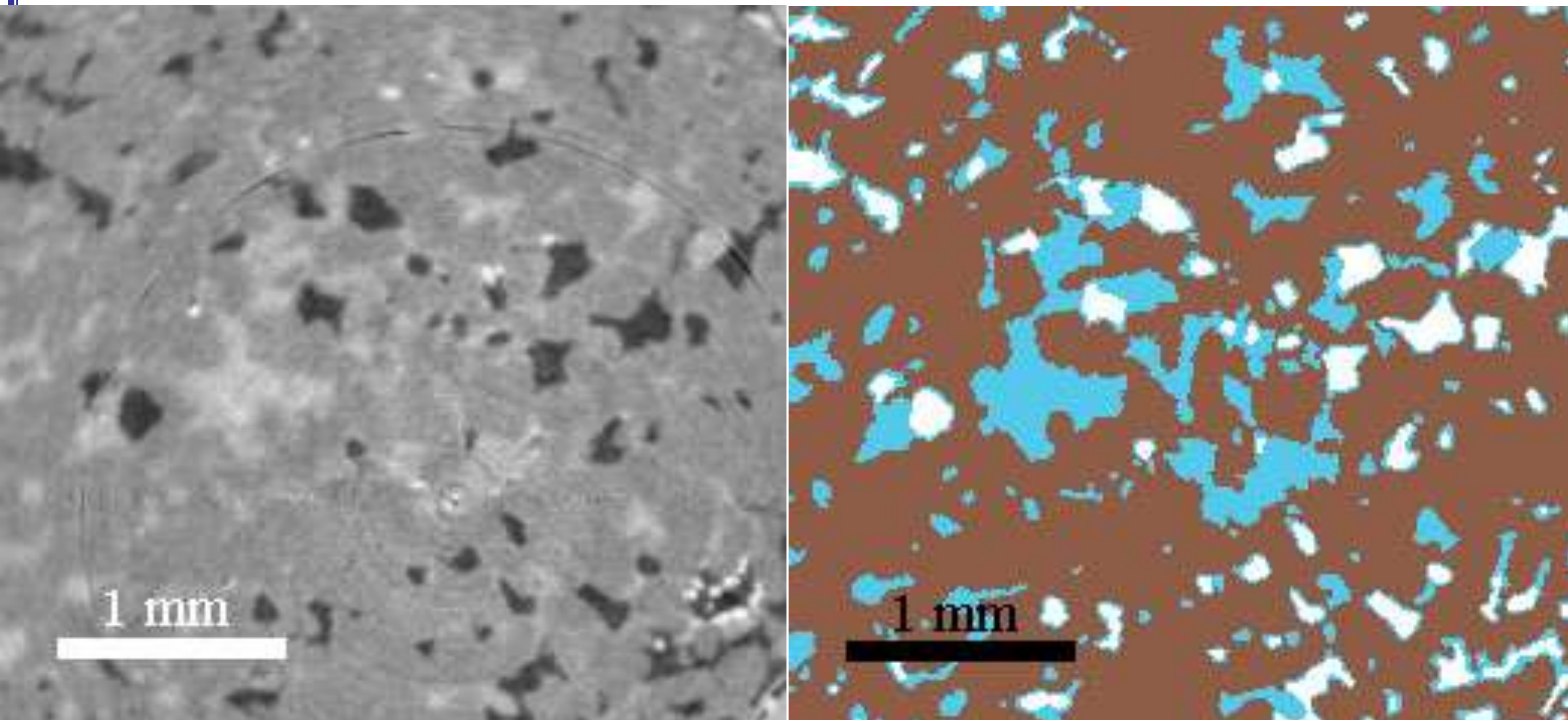
Large clusters – colour represents size.

Not all connected, as snap-off causes some disconnection after primary drainage.

CO_2 saturation is 44%.

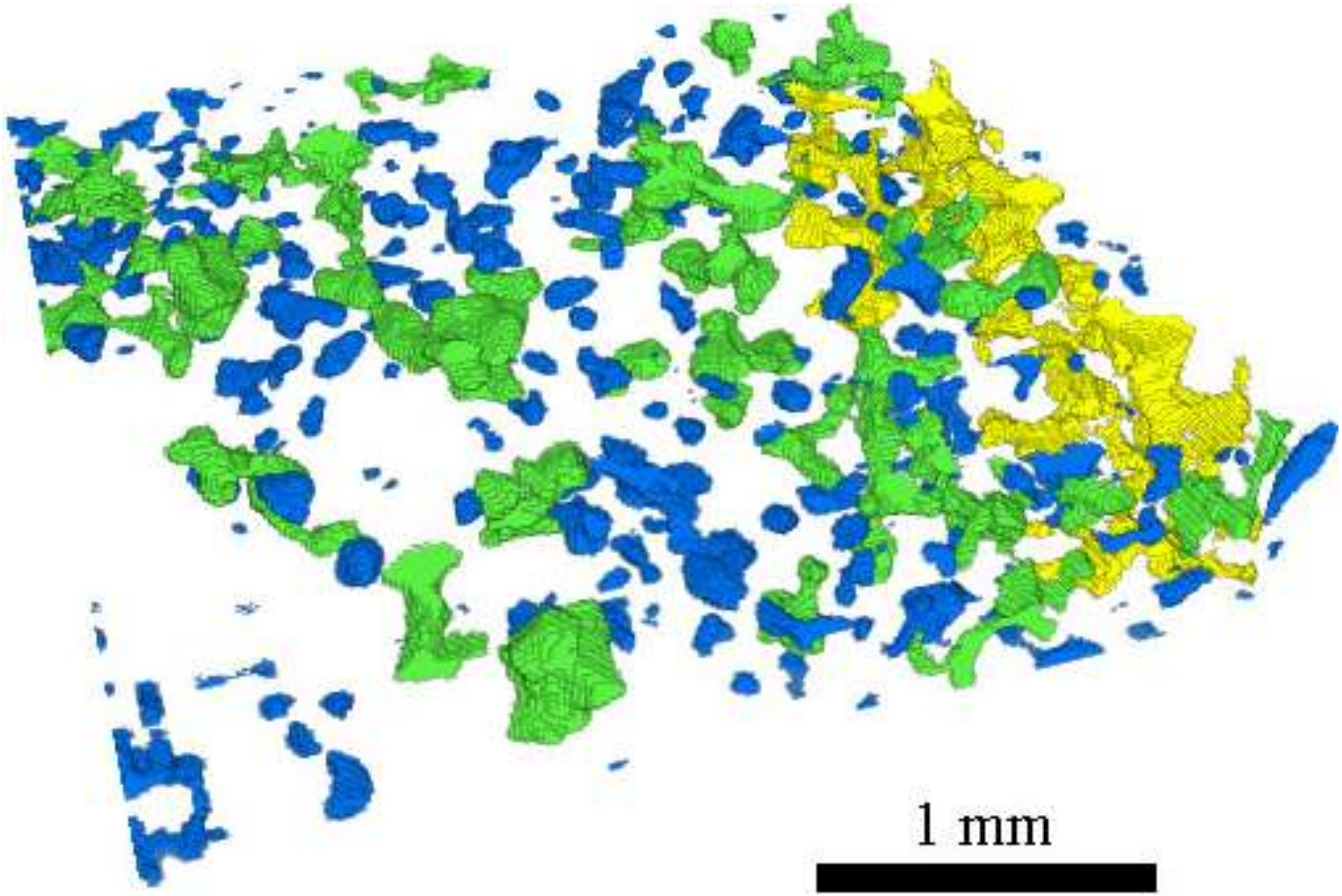


Residual CO_2; 50 PV brine injected



Iglauer et al., *Geophysical Research Letters* 2011

Trapped CO_2 clusters
Residual saturation of 25%



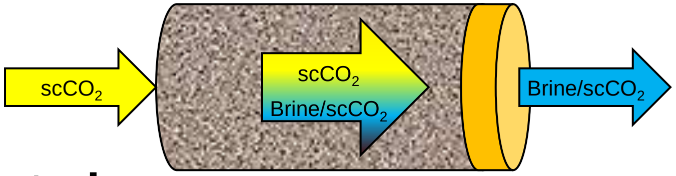
Iglauer et al., *Geophysical Research Letters* 2011

Coreflood experiments (7 cm core)

There are different methods that can be used to measure initial and residual non-wetting phase saturation for different rocks.

(1) Un-steady state method
(used for pore-level expts.)

(2) Porous plate method



- **Capillary end effect will be eliminated**
- **Larger initial and residual non wetting phase saturations can be achieved**

El-Maghraby et al., SPE147373

Apparatus

Brine and $scCO_2$ equilibration methodology

- ***First step***:

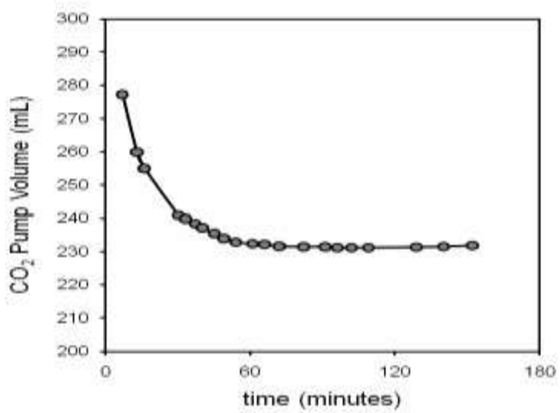
Preparation of supercritical CO_2

- ***Second step***:

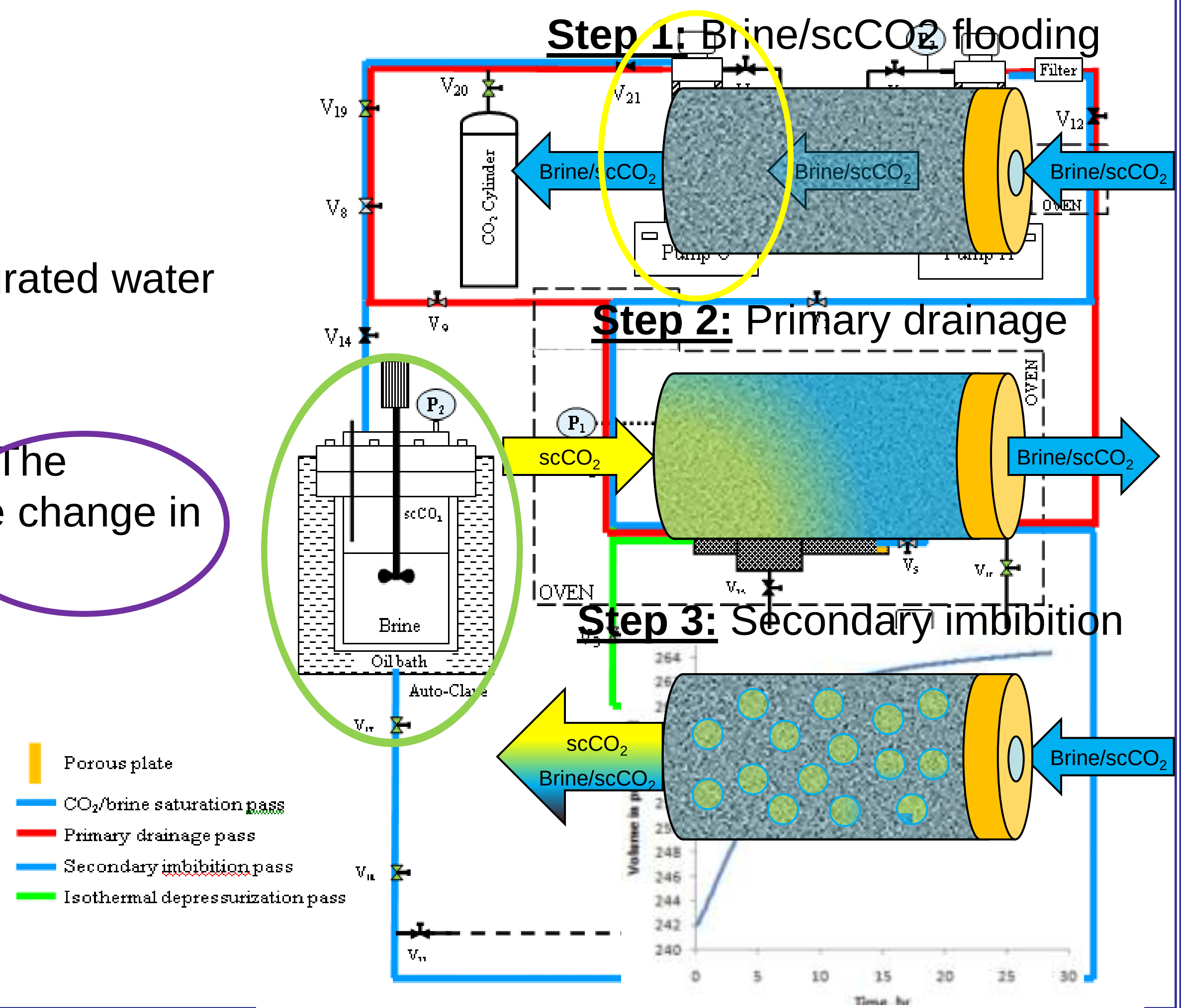
Preparation of supercritical CO_2 saturated water

- ***Third step***: (Mixing)

The mixing takes about 60 minutes. The equilibrium is reached when no more change in $scCO_2$ pump volume is detected.



Capillary Trapping methodology



Results

Berea sandstone properties

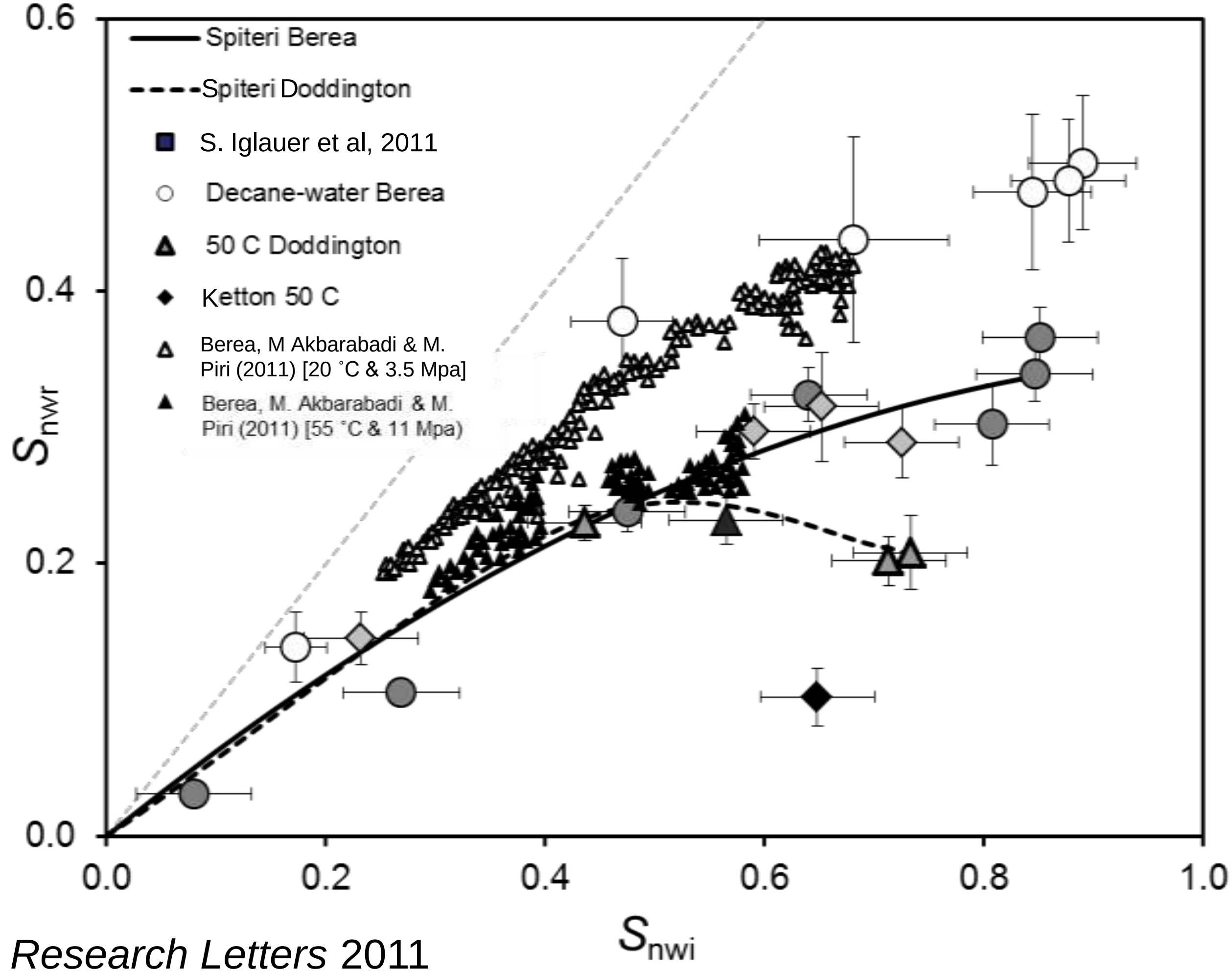
Length (mm)	Width (mm)	Φ (%)	K_{brine} (mD)
75.12	38.25	21.88	460

Doddington sandstone proper

Length (mm)	Width (mm)	Φ (%)	K_{brine} (mD)
76.44	38.24	21.00	1600

Ketton carbonate properties

Length (mm)	Width (mm)	Φ (%)	$K_{mercury}$ (mD)
76.5	37.78	23.38	450



Pentland et al., *Geophysical Research Letters* 2011

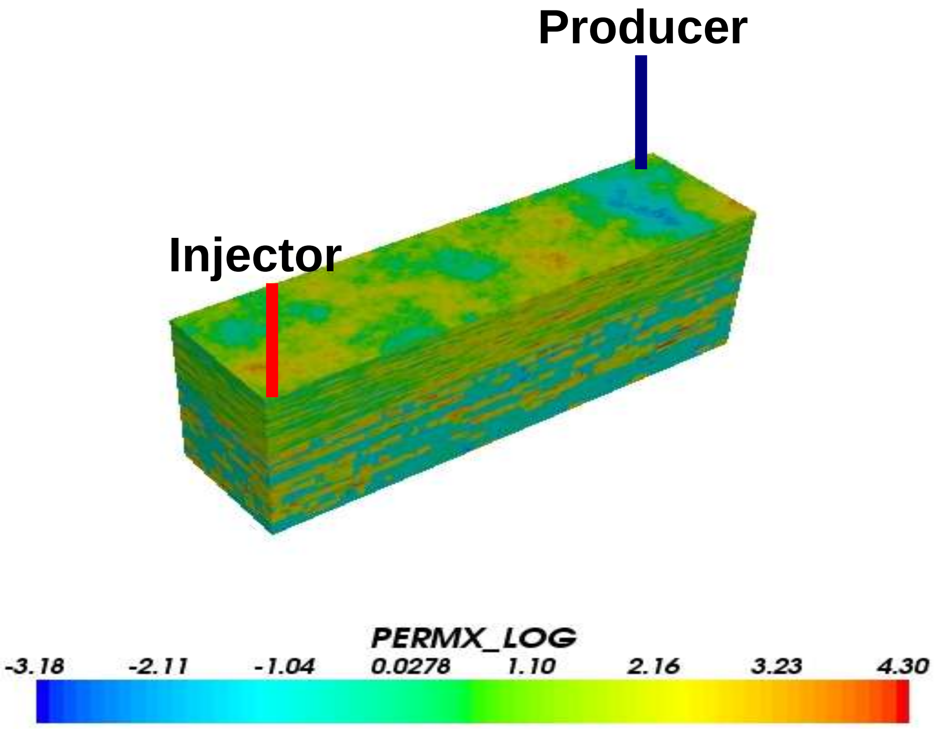
Design of CO_2 storage

A case study on a highly heterogeneous field representative of an aquifer below the North Sea.

Inject brine and CO_2 together and then use chase brine to trap CO_2

1D results are used to design a stable displacement

Simulations are used to optimize trapping

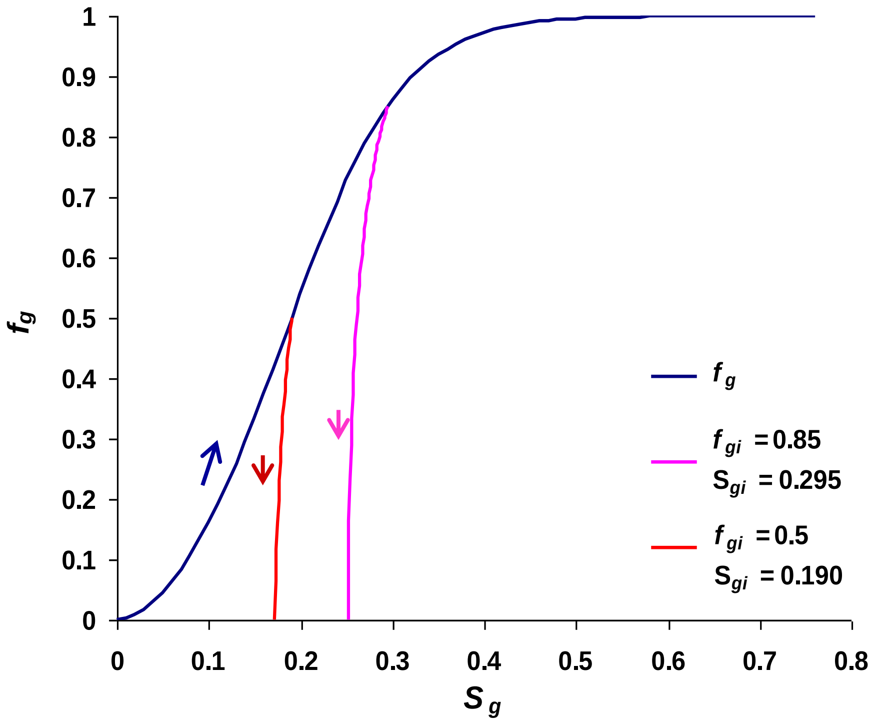


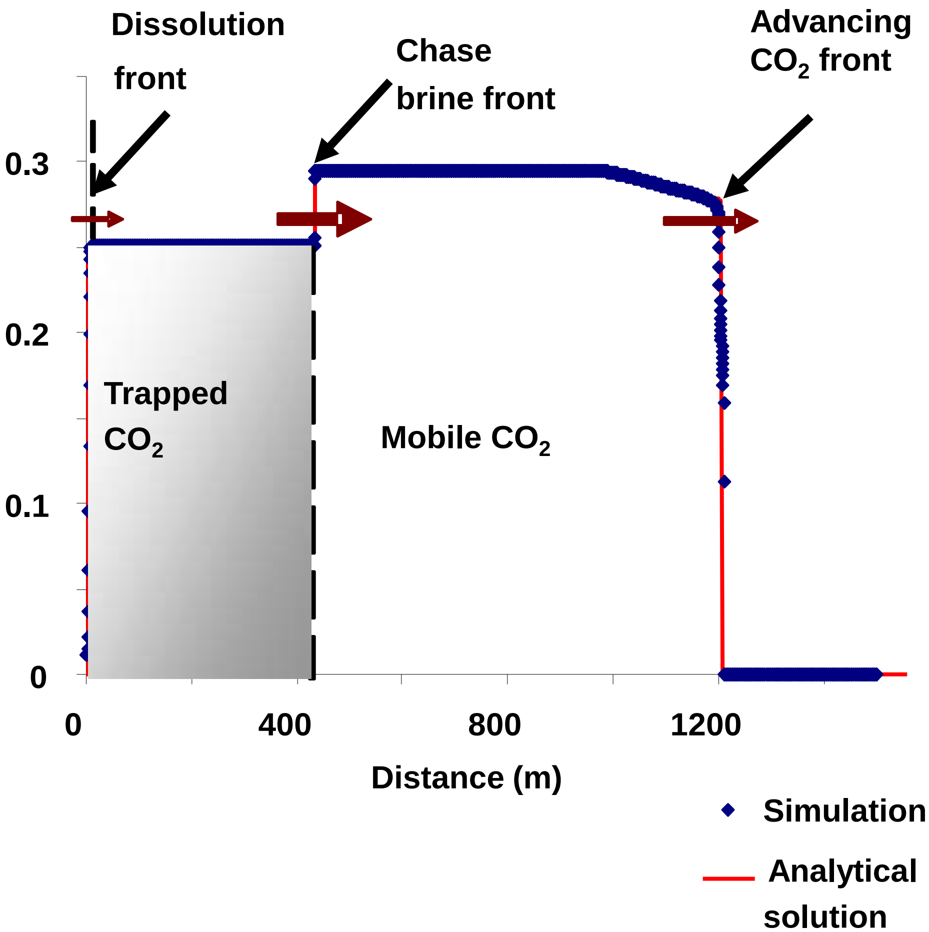
SPE 10 reservoir model, 1,200,000 grid cells (60X220X85), 7.8 Mt CO_2 injected.

Qi, LaForce and Blunt, SPE 109905; IJGGC 2009

ID results at the field scale with trapping

Design to have both injection fronts stable



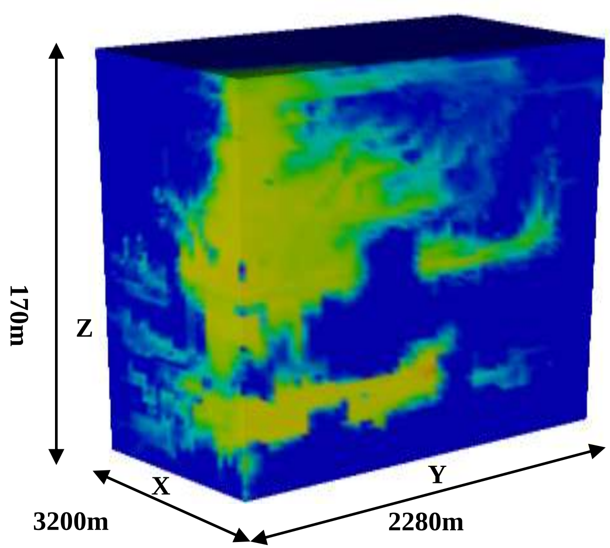


The CO_2-phase fractional flow f_g as a function of CO_2 (gas) saturation, S_g.

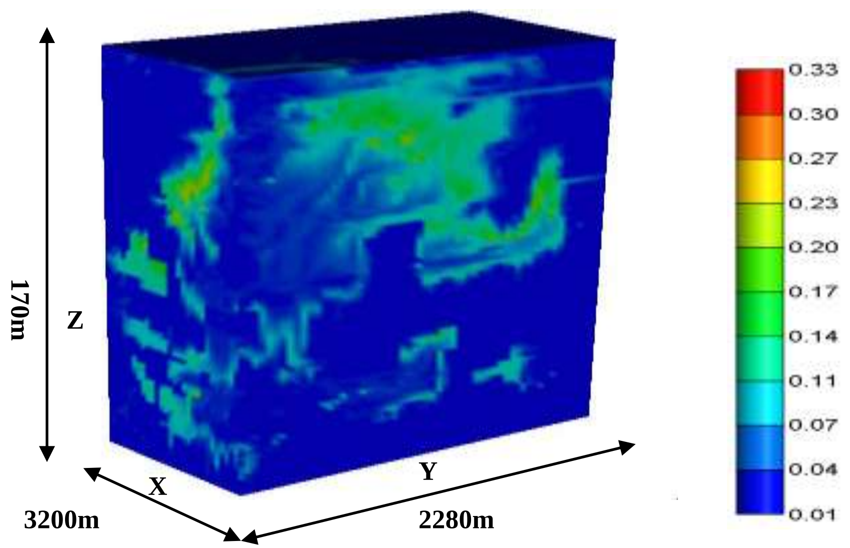
Qi, LaForce and Blunt., SPE 109905; *IJGGC* 2009

3D results for aquifer storage

20 years of water and CO_2 injection followed by 2 years of water injection in realistic geology



Trapped CO_2 saturation



Mobile CO_2 saturation

95% of CO_2 trapped after 4 years of water injection

Qi, LaForce and Blunt, SPE 109905; *IJGGC* 2009

Conclusions

- CO_2 can be trapped as pore-space bubbles surrounded by brine at representative storage conditions.
- Significant trapping is observed, but less than for an analogue strongly water-wet system, implying less water-wet conditions in the presence of super-critical CO_2.
- Curious non-monotonic trend for Doddington consistent with mixed-wet conditions.
- Less trapping in the one carbonate experiment: neutrally or CO_2 -wetting on calcite surfaces?
- Safe storage can be designed through co-injection of CO_2 and brine.
- Future work to explore more rocks, mineralogies and fluid conditions.
- Develop an experimental and simulation workflow for injection design.

Acknowledgements

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