Department of Physics and Technology

Increased Carbon Sequestration in CO_2 Foam EOR

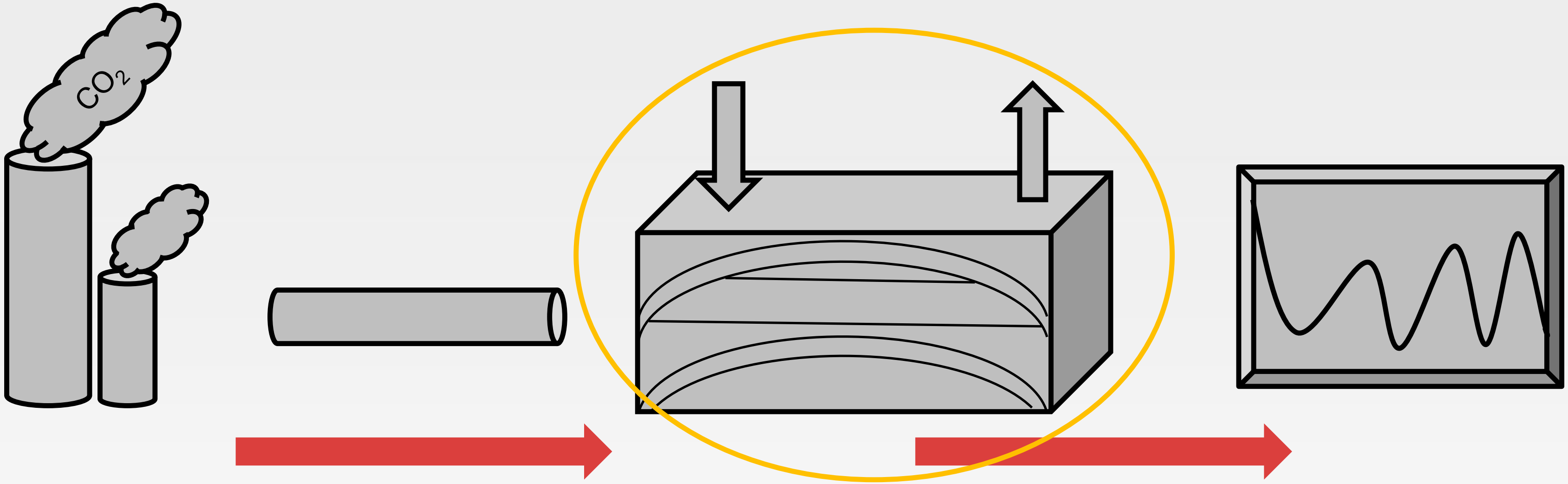
From Laboratory to Field

Zachary Paul Alcorn

CCUS Workshop
University of Houston
September 23-24, 2019

UNIVERSITY OF BERGEN

Carbon Capture, Utilization, and Storage (CCUS)



Capture CO_2

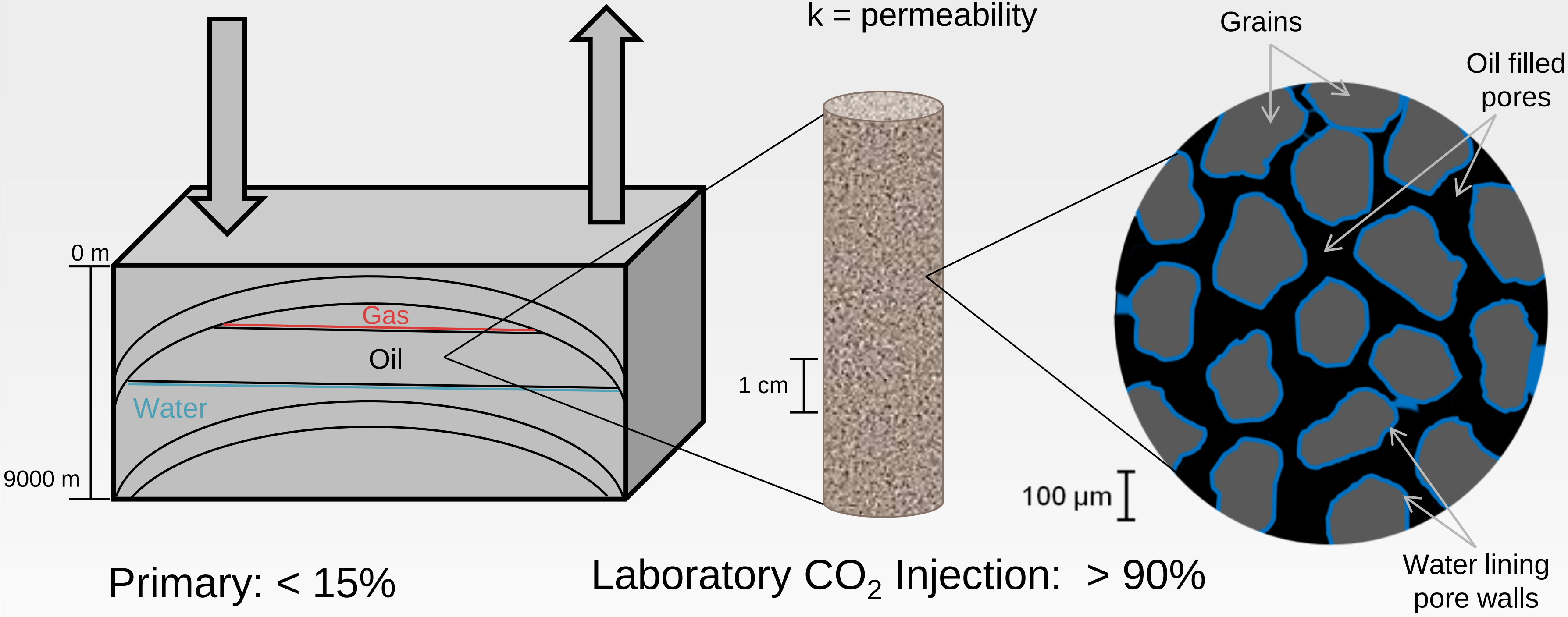
Transport

Injection into subsurface reservoirs for **energy production and CO_2 storage**

Monitoring

Φ = porosity

k = permeability



Primary: < 15%

Secondary: < 50%

Laboratory CO_2 Injection: > 90%

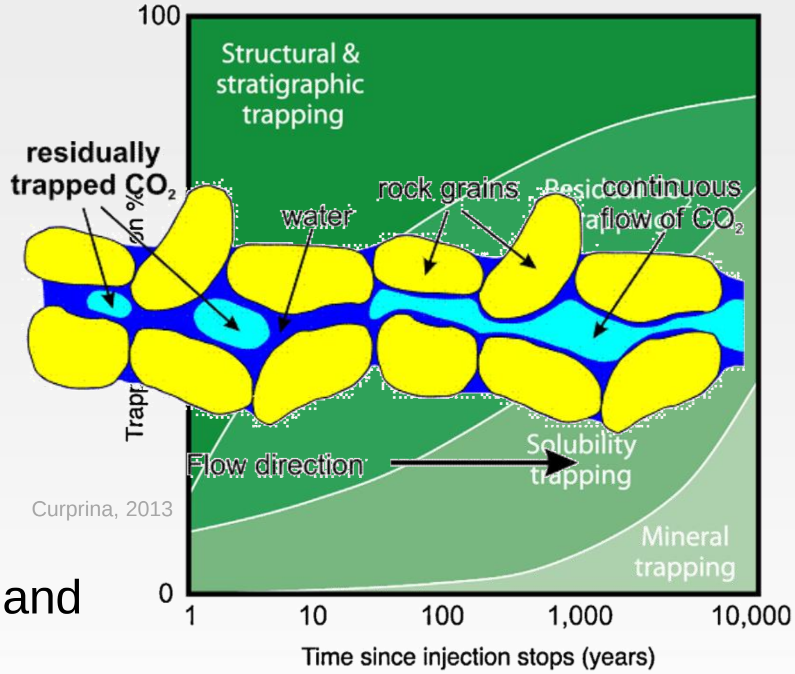
Enhanced recovery and storage potential

CO_2 Enhanced Oil Recovery

Advantages	Disadvantages
Low MMP	Corrosion
Oil Swelling	Low Availability
Emissions	High Mobility

CO_2 Storage

- Trapping Mechanisms
- Residual Trapping
  - large capacity
  - efficient
- Wettability impact on CO_2 trapping
- Sealing capabilities, plume migration, and leakage rate estimation



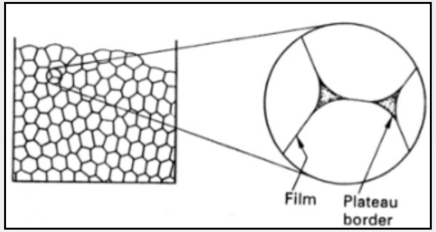
Curprina, 2013

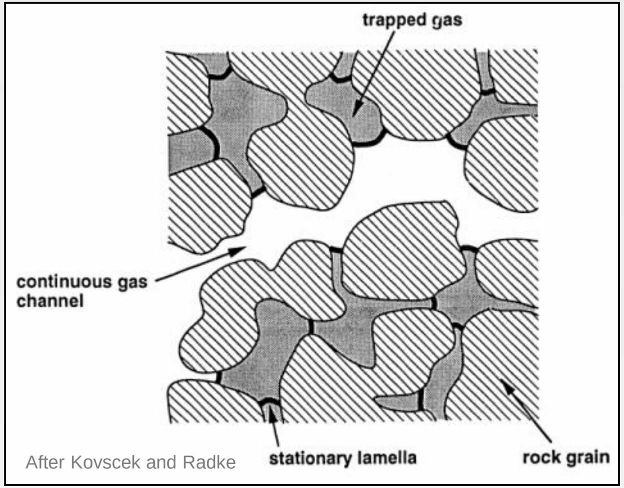
Benson et al. 2012

CO_2 Foam

What?

Dispersion of gas in liquid
Stabilized by surfactant





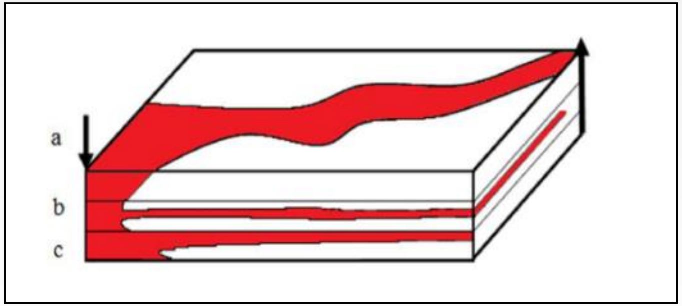
After Kovscek and Radke

How?

Decreases relative permeability
Increases viscosity
Injection strategy: SAG or co-injection

Why?

Conformance and mobility control
Increase reservoir sweep and displacement
Additional CO_2 storage



Sc-CO_2 EOR mobility challenges: a) poor aerial sweep, b) gas channeling, c) gravity override (Hanssen et al., 1994)

Objectives

Develop a combined CO_2 EOR and CO_2 storage technology to increase CO_2 storage potential, security, and recovery as part of CCUS.

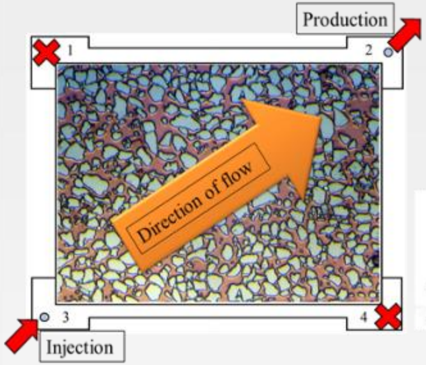
- Visualize pore-scale CO_2 foam generation and stability
  - Static and dynamic
- Evaluate CO_2 foam EOR and CO_2 storage at the core-scale
  - Quantify storage potential during EOR
- Increase CO_2 retention in ongoing field pilot

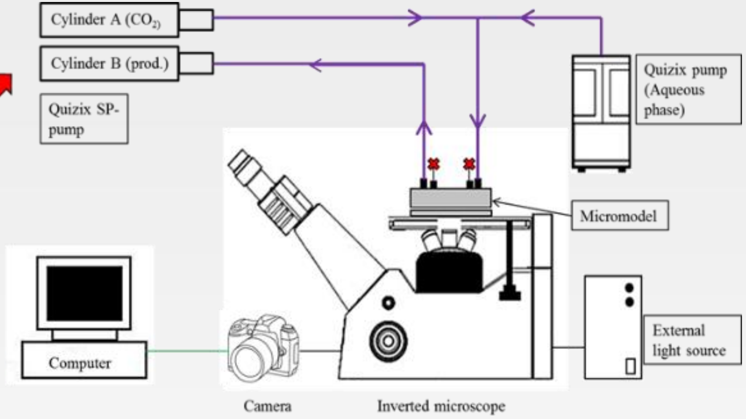
Laboratory Scale: Technology Testing and Verification

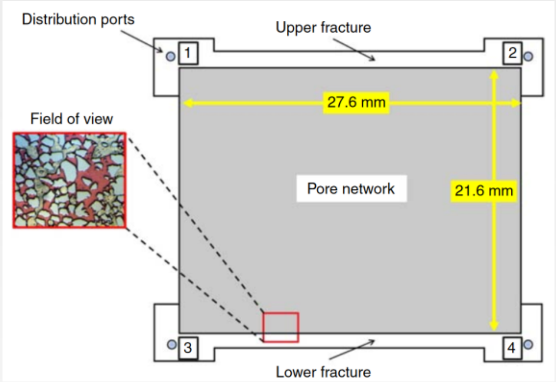
Pore-scale CO_2 Foam

Core-scale CO_2 Foam Displacement and CO_2 Storage

Micromodel Set-up and Properties

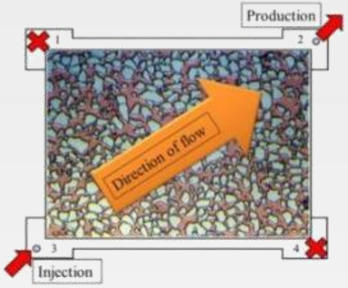






Length [cm]	Width [cm]	Coordination number	Porosity [%]	Permeability [mD]	Grain size [μm]
2.76	2.16	1-6	~60	2.9	10-400

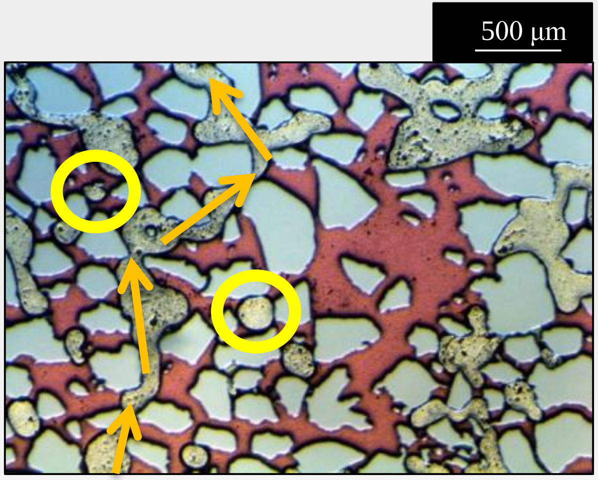
Pore-Scale Baseline (no surfactant)

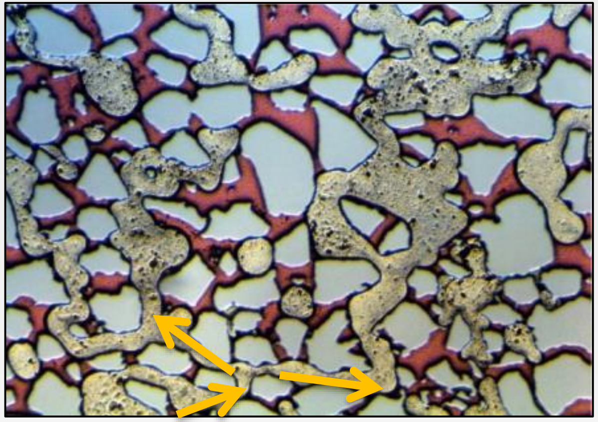


9.0 Mpa (1305 psi), 20ºC

100% brine saturated

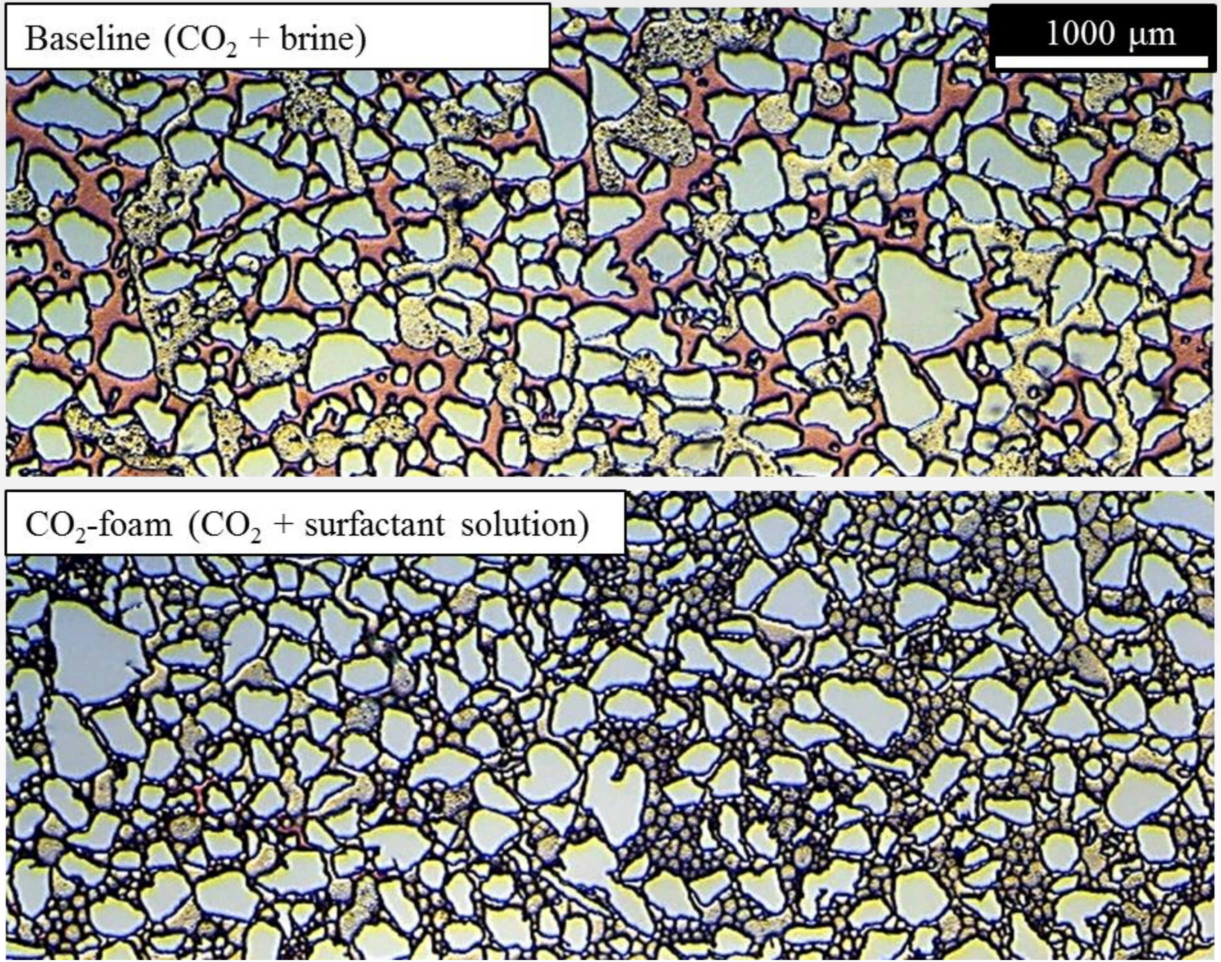
Gas fraction (f_g) = 0.70





Red is water
Light blue uniform areas are grains
Brown textured areas are CO_2

CO_2 phase spanning over several pores without being separated by liquid films, indicating low CO_2 mobility reduction



Comparison between co-injection without (top) and with (bottom) surfactant at 9.0 Mpa (1305 psi), 20ºC, with fg= 0.70.

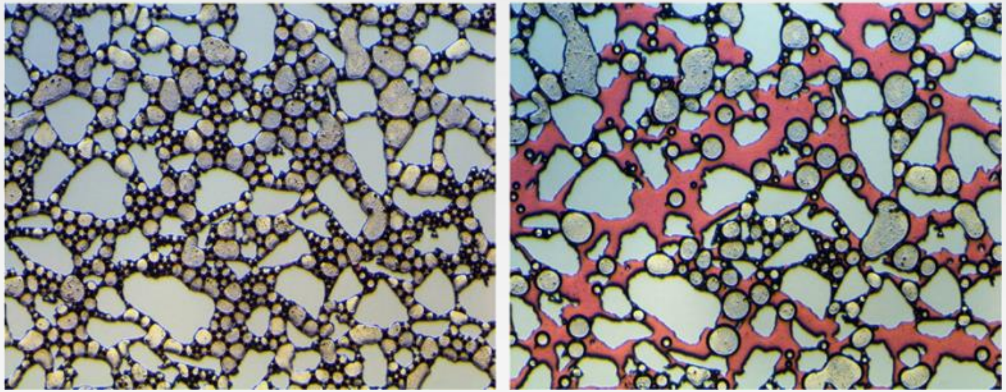
Red is water, the solid matrix grains are light gray uniform colored areas with black outline, and darker gray bubbles are CO_2.

Bubble density is 2-3 orders of magnitude higher for the runs with surfactant, hence the lamella concentration is significantly higher tying up most of the water.

The distribution of water without foam is "free" mainly present in the smaller pores and covering the (water-wet) grains.

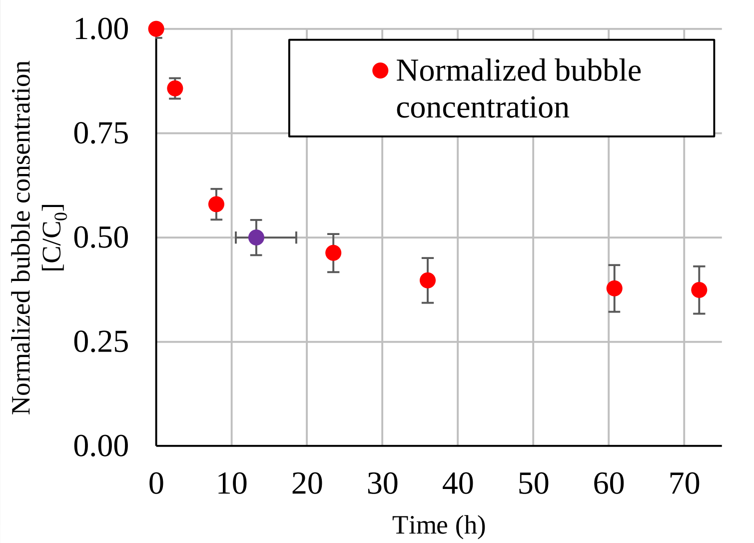
Static foam strength (thermodynamic stability)

Start at T = 0 End at T = 72 h



Foam coalescence and half-life test during static (no-flow) conditions at 9.0 MPa and 20ºC. Left: start of static test (T = 0 h). Right: end of static test after 3 days (72.0 h).

Red is surfactant solution, uniform grey islands are grains and spherical gray bubbles are CO_2 emulsions.



Normalized bubble concentration (red dots) within FOV plotted as a function of time from dynamic flow conditions was ended and static (no-flow) conditions initiated.

Purple dot represents the half-life of the emulsions and is calculated from a best fit regression analysis.

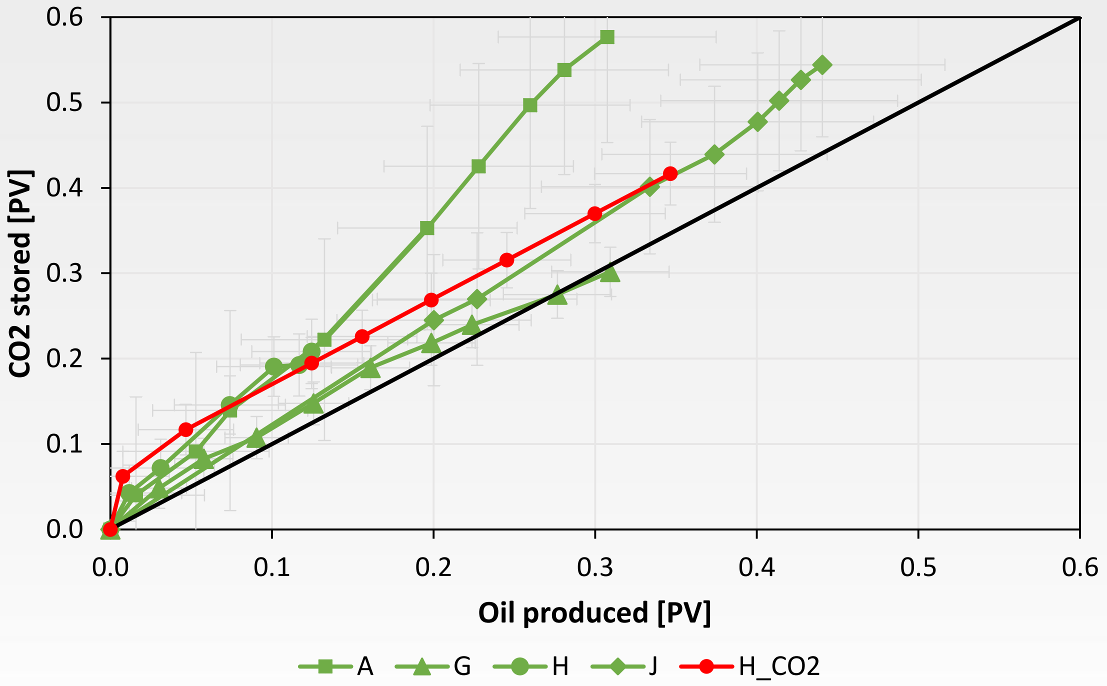
Associated CO_2 Storage – Reservoir Cores

CO_2 storage during CO_2 foam displacement (after WF)

40^0C, 172 bar

Oil-wet

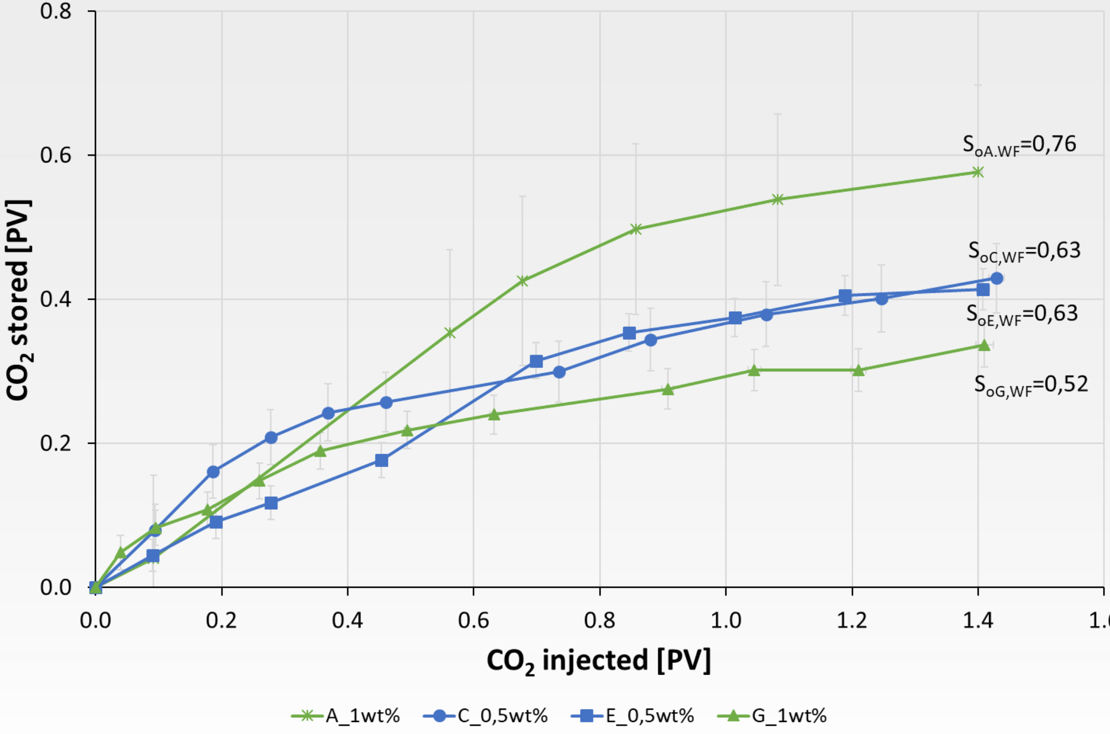
Foam displaces water in favor of CO_2 storage



CO_2 Storage – Reservoir Cores

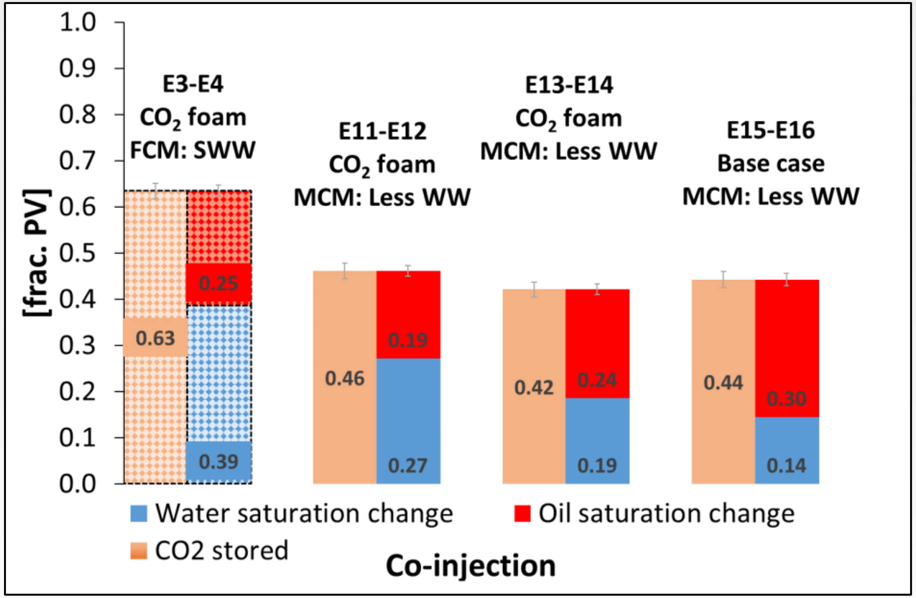
The storage potential will depend on the amount of residual oil (S_{or})

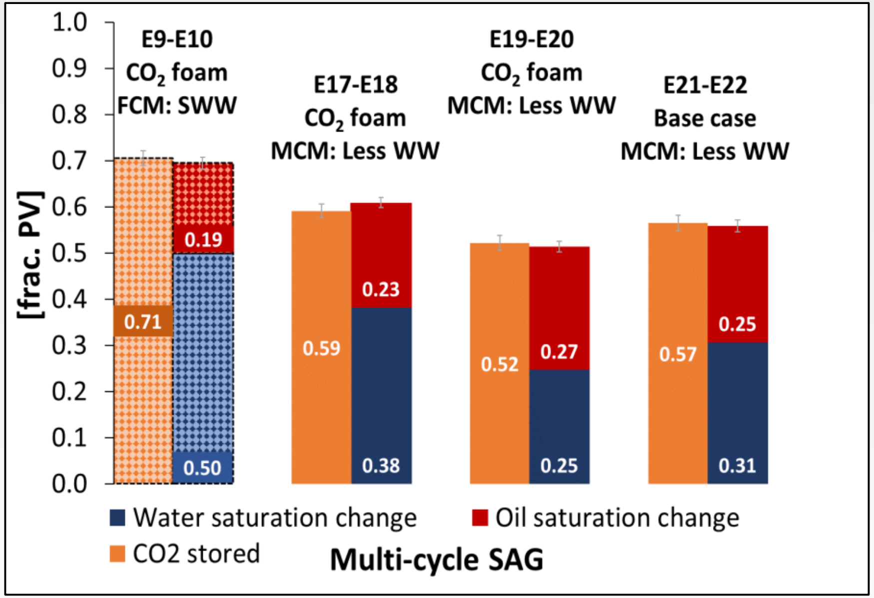
Storage potential greatest in the unswept zones where S_{or} is highest, providing a valuable target for sequestration during mobility control by CO_2 foam.



Associated CO_2 Storage - Limestone

Impact of injection strategy, miscibility, and wettability





CO_2 storage potential was 17% greater at FCM conditions (for either injection strategy), compared to MCM, due to **improved CO_2 foam displacement and increased CO_2 trapping by capillary forces in more water-wet core plugs.**

Field-Scale CO_2 Retention

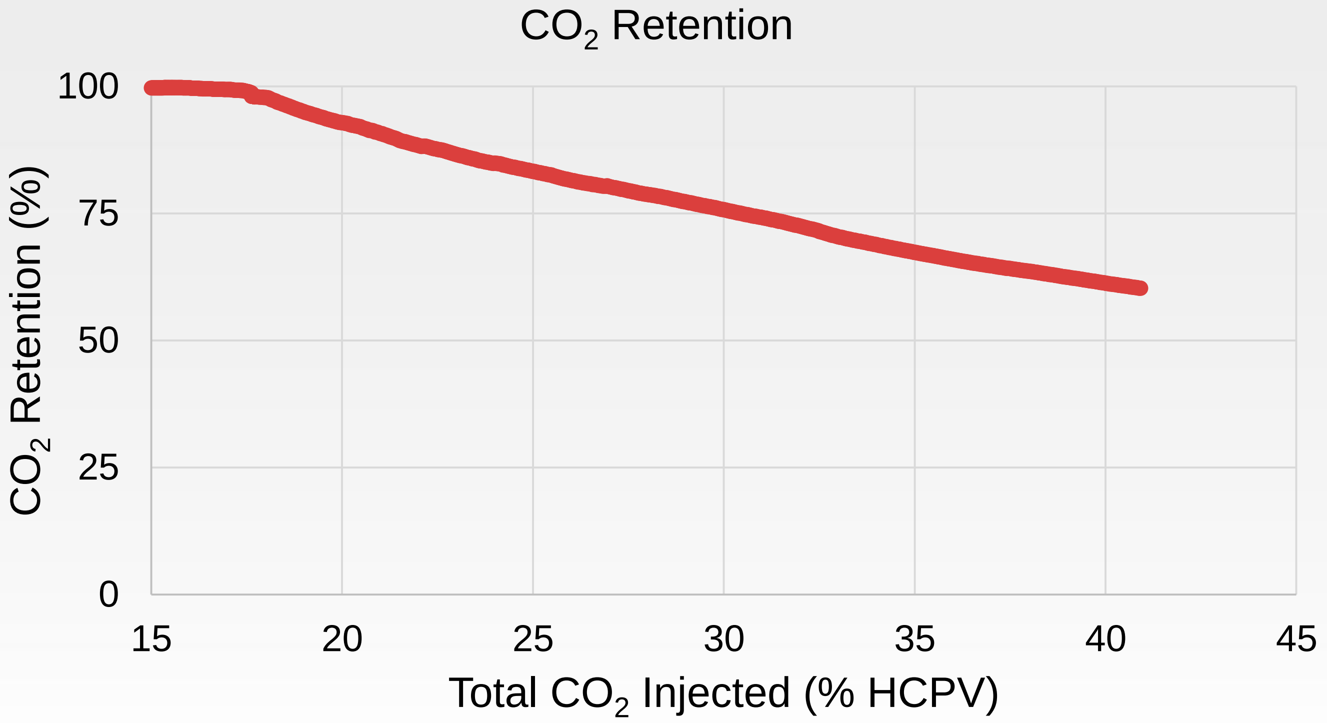
The surveillance strategy focuses on obtaining relevant data from wells and reservoir to meet the following pilot objectives:

- Verify *in-situ* foam generation
- Increase oil production
- **Increase CO_2 Retention**

$$CO_2\ Retention = \frac{CO_2\ Injected - CO_2\ Produced}{CO_2\ Injected}$$

Closed-loop system: produced CO_2 is recompressed and combined with purchased CO_2 and injected

Pattern CO_2 Retention



Conclusions

- **Pore-scale**: validation of foam formulation

- **Core-scale**: Increased displacement by CO_2 foam
  - CO_2 storage is oil and water displacement dependent
  - CO_2 storage potential was greater in more water-wet cores, due to increased displacement by CO_2 foam and CO_2 trapping by capillary forces.

- **Field-scale**: increase CO_2 retention with foam

Acknowledgements

Norwegian Research Council **CLIMIT Program** for financial support under grant number 249742 - *CO_2 Storage from Lab to On-Shore Field Pilots Using CO_2 Foam for Mobility Control in CCUS*

equinor

TOTAL

OXY

The Research Council of Norway