Harbour Energy

Paper Number SPE-227891-MS

9/6-1 Havstjerne P&A Design – Long-term Study Of CCUS Cement Designs Under Static And Cyclic CO_2-Conditions

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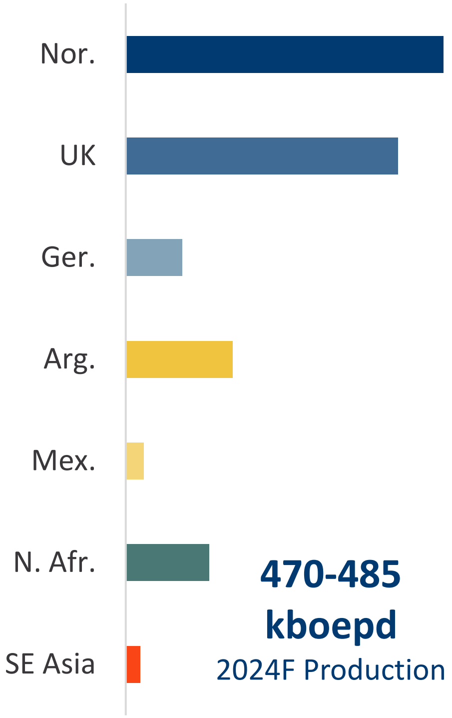
FORCE - CCS Legacy Wells Seminar 19 & 20.11.2025
Presented by Christian Allerstorfer

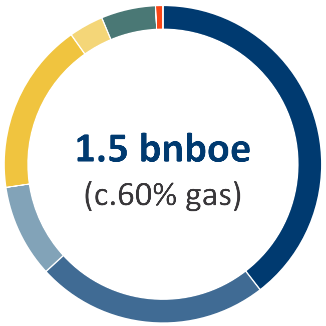
Harbour Energy at a glance

Harbour is one of the world's leading, global independent oil and gas companies

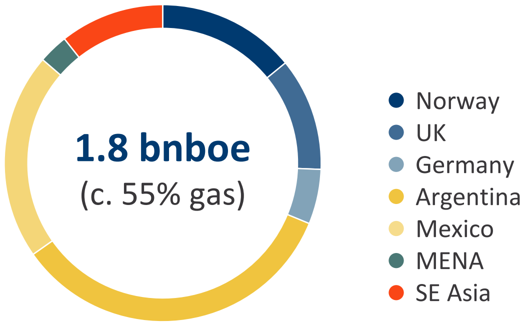
2024F production (proforma)[1,2]

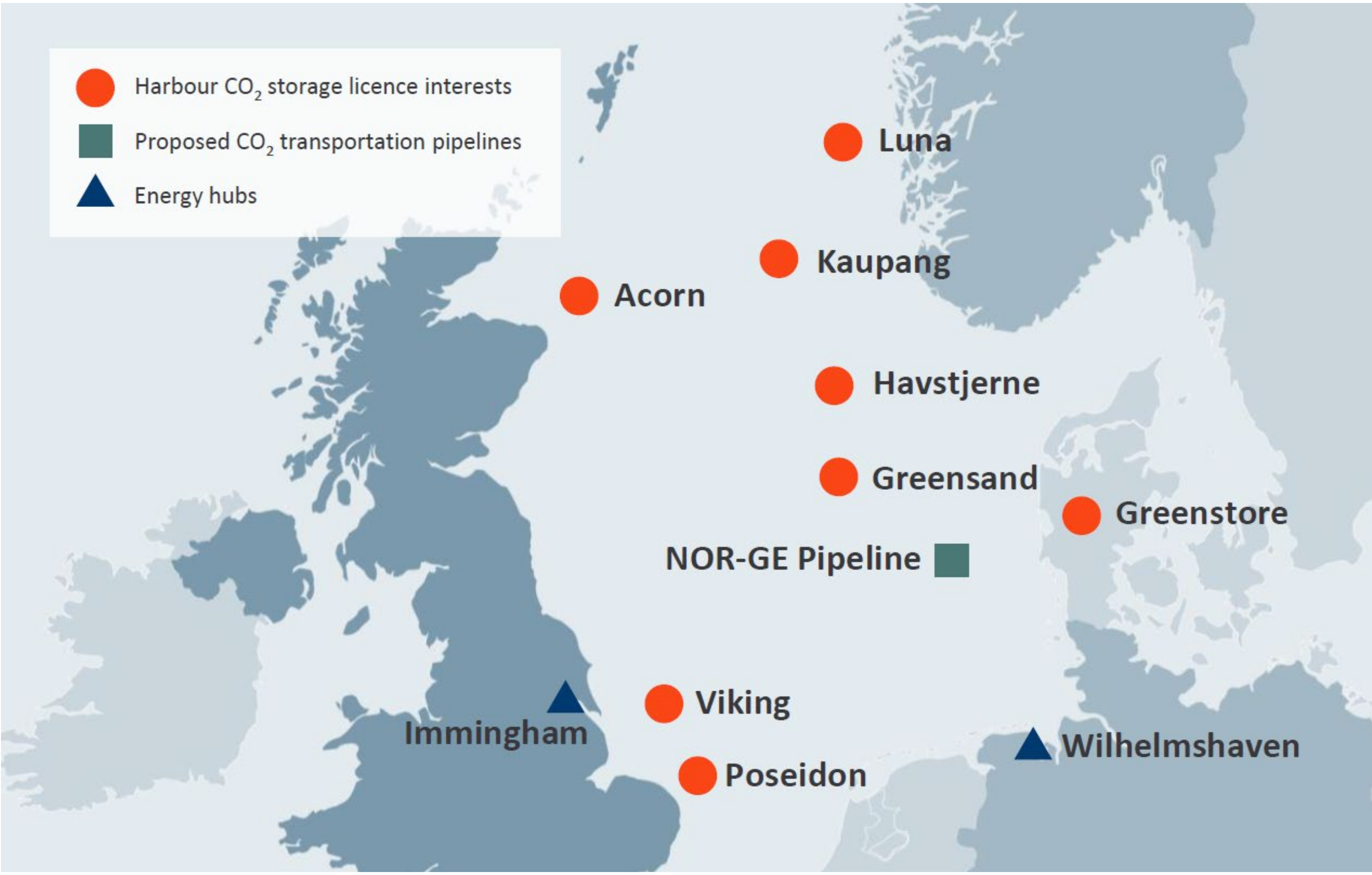


YE 2023 2P reserves[3]



YE 2023 2C resources[3]





c. 8 years
YE 2023 2P reserves life[4]

$455 million
Annual dividend

<15 $kgCO_2e/boe$
2024F GHGi proforma[1,5]

New CCS BU
Capitalising on leading CCS storage position in Europe

c. 5,000
Workforce (employees and direct contractors)

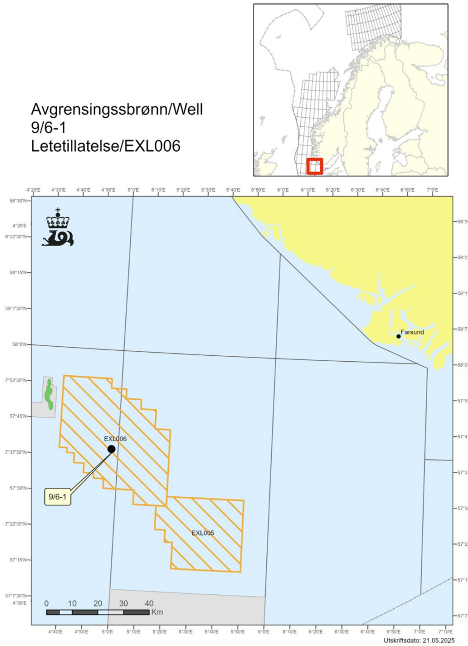
[1] Proforma reflects 12 months contribution from legacy Harbour assets and the Wintershall Dea portfolio. [2] Management estimates. [3] YE 2023 D&M CPR & management estimates.
[4] YE 2023 2P reserves, divided by mid-point of 2024 pro forma production. [5] Net equity share basis.

9/6-1 Havstjerne

Key Objectives:

Prove sufficient injectivity, capacity and containment for main reservoir by …

- Cap rock strength measurement
  - XLOT
  - Caprock core
- Acquire reservoir property data
  - E-line logging
  - Core
  - Side wall coring in all potential reservoirs
- Pressure and fluid samples
- Proof injectivity with injection test



Proved suitable properties for CO_2 injection and storage (9/6-1)

The well was drilled using the Deepsea Nordkapp drilling rig. (Photo: Odfjell Drilling)

6/2/2025 A wildcat well drilled by Harbour Energy Norge and licensees in the "Havstjerne" storage project confirmed a reservoir that is suitable for injection and storage of carbon dioxide (CO_2).

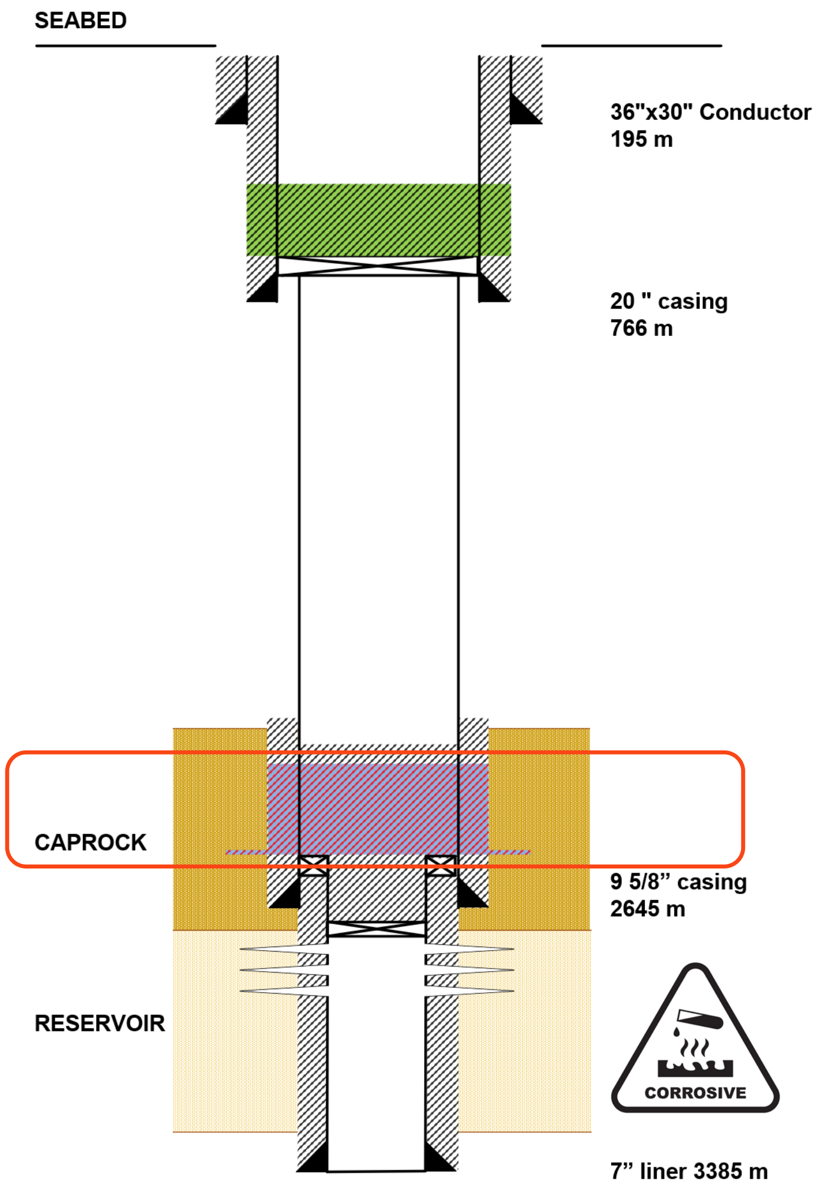
Well 9/6-1 was drilled in the North Sea around 30 kilometres southeast of the Yme platform and around 120 kilometres southwest of Farsund – the DeepSea Nordkapp rig was used in the drilling operation.

Well 9/6-1 is the first well drilled in exploration licence (EXL 006), which was awarded in May 2023. This is the fourth well drilled to investigate potential commercial storage of CO_2 on the Norwegian continental shelf (NCS).

Creating a Legacy … Well

- 9/6-1 Havstjerne has been permanently P&A'd in accordance with **Norsok D-010**
- Dedicated assessment to ensure P&A Design is fit for purpouse is required
- Restoring caprock integrity
  - Designed for future CO2 injection
  - Material selection and Barrier placement is key
  - Cement plug is the critical element to re-store caprock integrity

… but what's different in CCS?



Study Outline

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- Systems Tested:
  - System A: Reduced Portland cement
  - System B: System A + flexible additives
  - System C: System B + latex

- Key Findings:
  - All systems passed performance criteria
  - Cyclic conditions were less aggressive than static ones

Parameter	Criteria	System A	System B	System C
Visual appearance	No flaking, cracks, and micro cracks (MC)	MC	MC	MC
Volume	No shrinkage	Pass	Pass	Pass
Permeability	Low (<0.1 mD)	Pass	Pass	Pass
Compressive Strength	>500 psi	Pass	Pass	Pass

Sample Preperation

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- Designed at 1.9 SG with fresh water
- 31 samples for each system
- Cured for 96 hrs at 110 °C / 3000 psi in fresh water
- Aged in formation brine for 2 weeks
- Placed in curing chamber
  - Energized with CO_2 (pH ~5.0) in brine
- Subjected to both static & cyclic aging over 6 months
  - Alternating 110 °C ↔ 29 °C, 4200 psi
  - 1 cycle every 2 weeks
- Samples extracted for testing at
  - 1-month re-energized CO_2
  - 3-months re-energized CO_2
  - 6-months

System A – After 2-week brine cure

System A – After 6-months in carbonic acid

Mechanical Study

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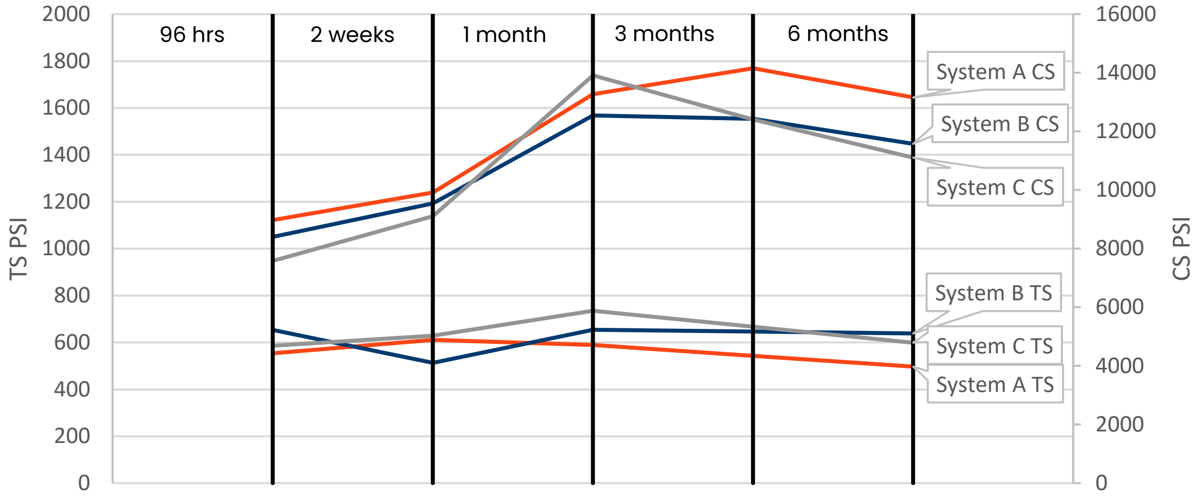
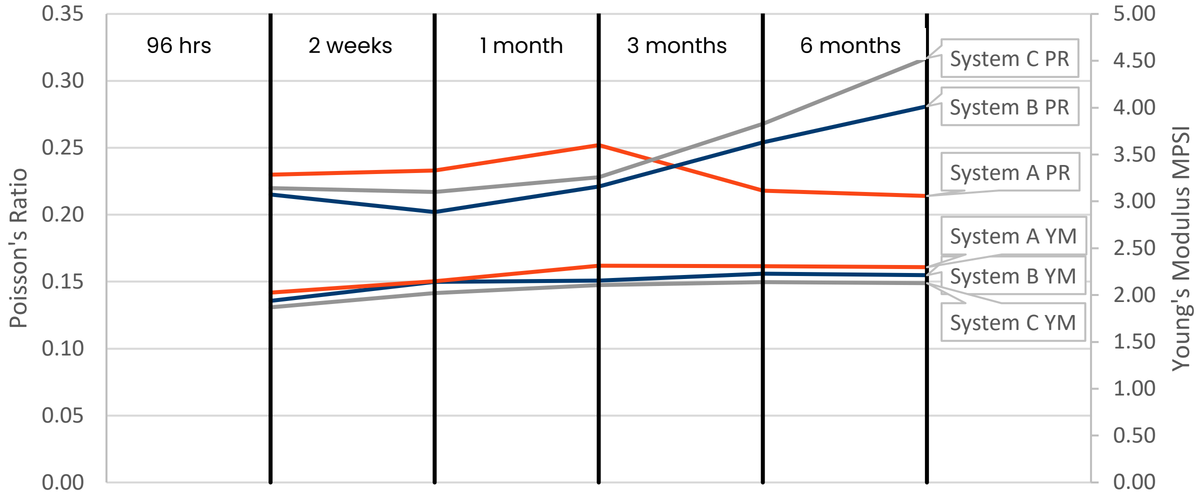
- Static Conditions:
  - Static conditions maximize reaction driving force advancing the carbonation front faster
  - Under static exposure expect lower CS than in cyclic testing at the same times

- Cyclic Conditions:
  - Early curing and exposure to CO_2 can enhance strength, but long-term exposure may lead to mechanical degradation.

- Material selection and additive use are critical to balance strength, flexibility, and durability.





Mechanical Study

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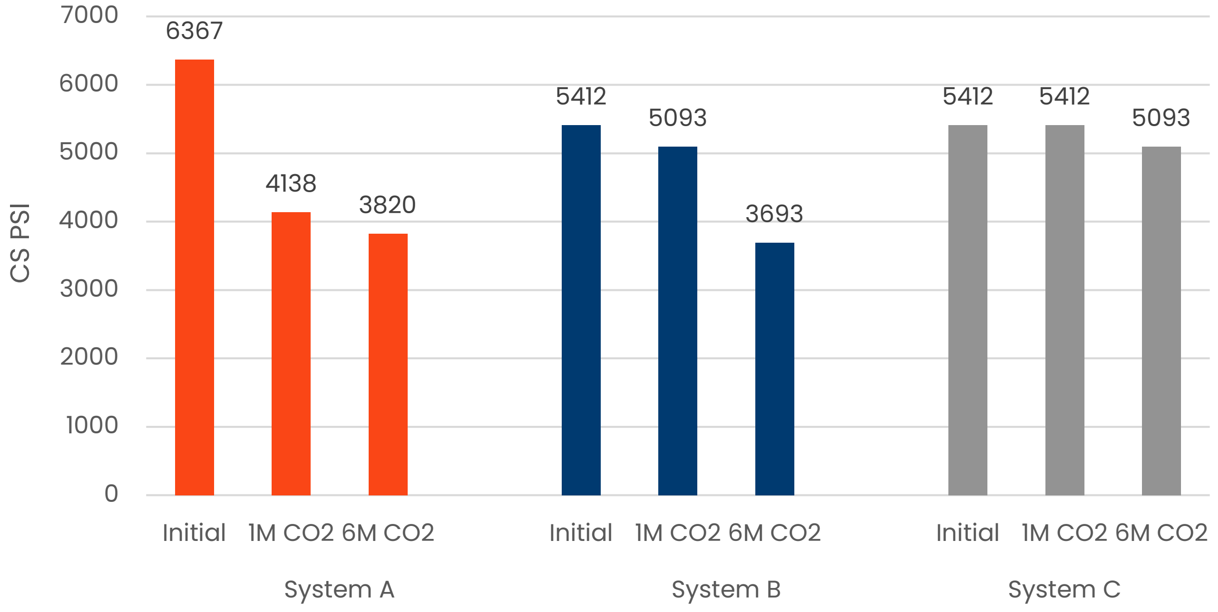
- Compressive Strength Confined (CS):
  - System A shows the strongest CS decline already by 1 month under static exposure
  - System C retains CS
- Outcome:
  - Static conditions maximize reaction driving force advancing the carbonation front faster
  - Under static exposure expect lower CS than in cyclic testing at the same times



Mechanical Study

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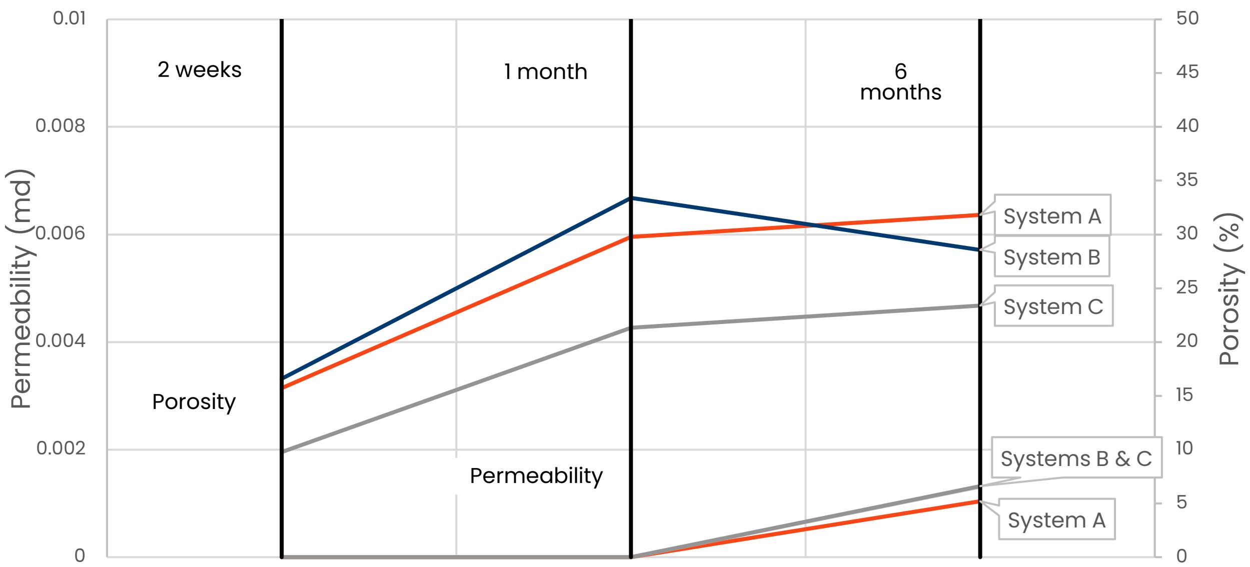
- Porosity:
  - All systems showed increased porosity after CO_2 exposure
  - Porosity stabilized after initial 1 month exposure
  - System C had lowest porosity overall
- Permeability N2:
  - Initial permeability < 0.0001 mD
  - Slight increase to ~0.0013 mD at 6 months



CT Imaging

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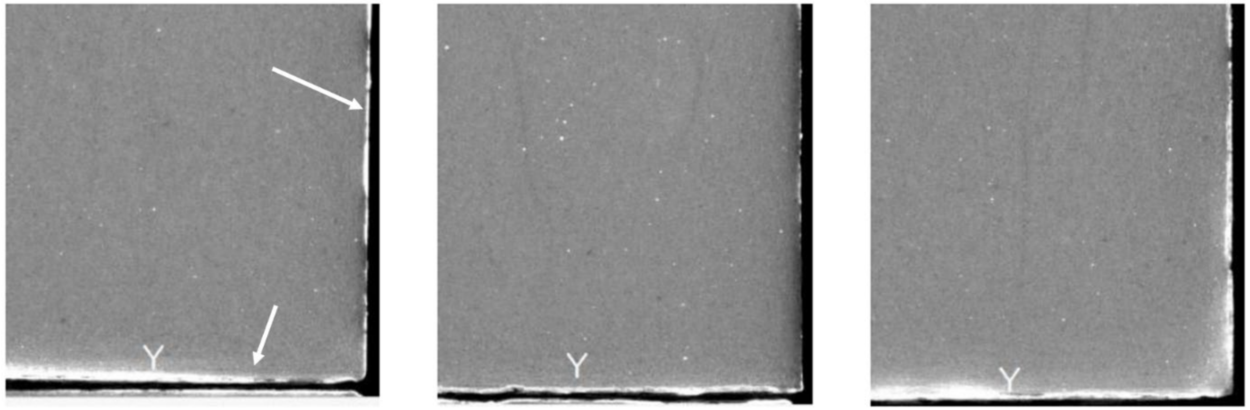
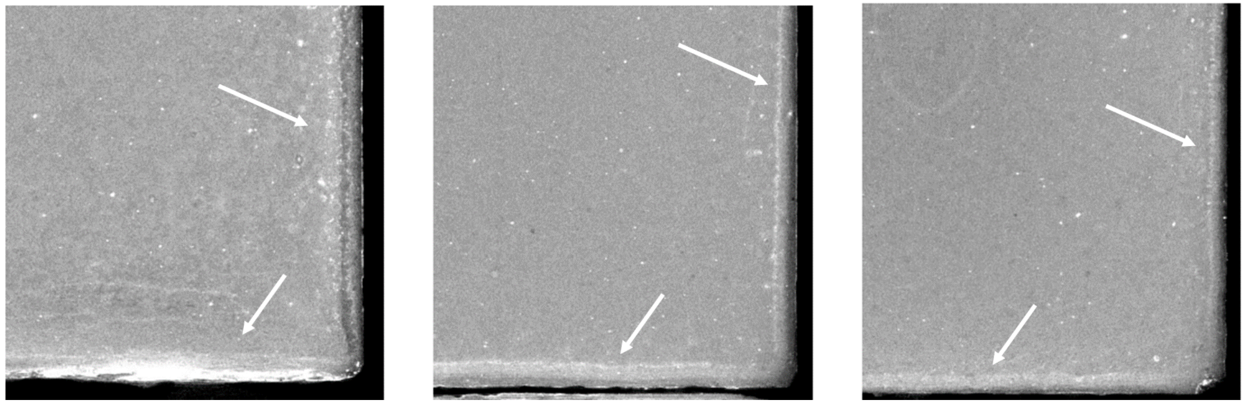
- Cyclic exposure (varying temperature/constant pressure):
  - Minimal visual degradation after 6 months
  - Surface and internal structure remained largely intact
  - Slower carbonation front progression
- Static exposure (constant temperature/pressure):
  - Clear visual signs of carbonation and degradation
  - More advanced reaction fronts, especially in System A
  - Greater material transformation and potential weakening
- Outcome:
  - Cyclic conditions are less aggressive, better simulating real well operations
  - Static conditions represent a worst-case scenario, accelerating cement degradation
  - All samples showed no loss of competence



Magnified comparison of the surface-near regio of System A (left), System B (middle) and System C (right) after 6 months **cyclic** CO_2-aging. Arrows indicate the front of carbonation.



Magnified comparison of the surface-near regio of System A (left), System B (middle) and System C (right) after 6 months **static** CO_2-aging. Arrows indicate the front of carbonation.

Harbour Energy

Stella Maris CCS
A Yinson Production company

"K" LINE
KAWASAKI KISEN KAISHA, LTD.

Funded by the European Union