

LEGACY project: mapping, monitoring, leakage modelling and mitigation of legacy wells



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Benjamin Emmel, Nicolas Barbosa, Alexandra Log, Elie Ngouamba, Simone Zonetti, Marcin Duda, Michael Jordan, Amir Ghaderi and many others

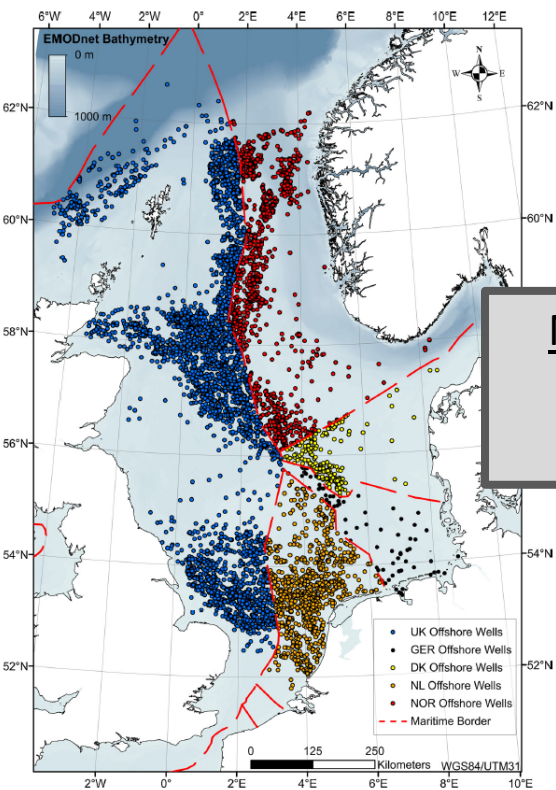
FORCE CCS Legacy Wells seminar, 19 November 2025



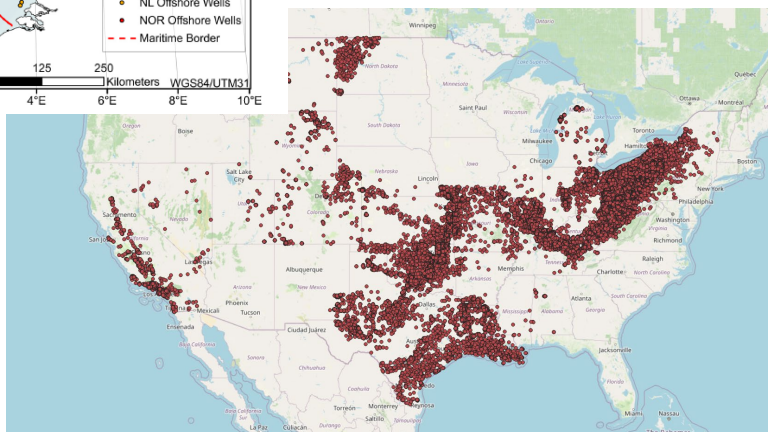
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Legacy wells



North Sea (Böttner et al., 2020)
Onshore USA (Merrill et al., 2023)

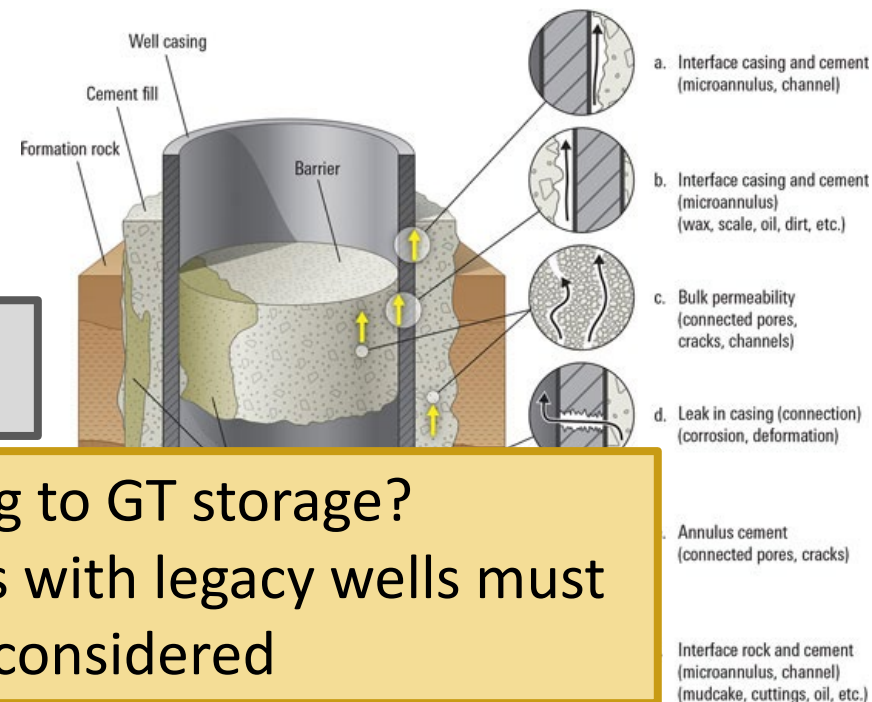


Several potential leakage pathways

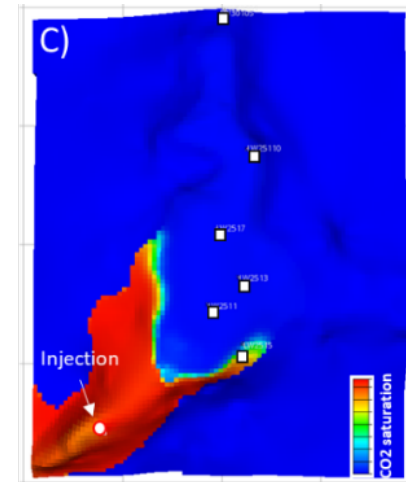
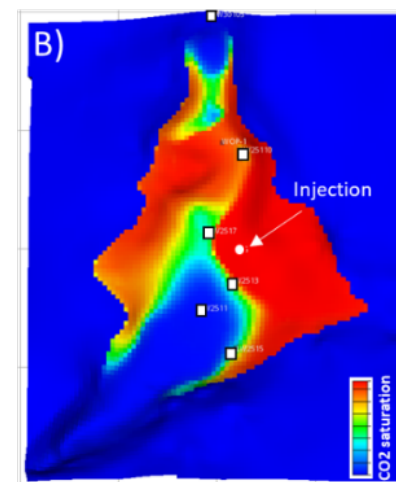
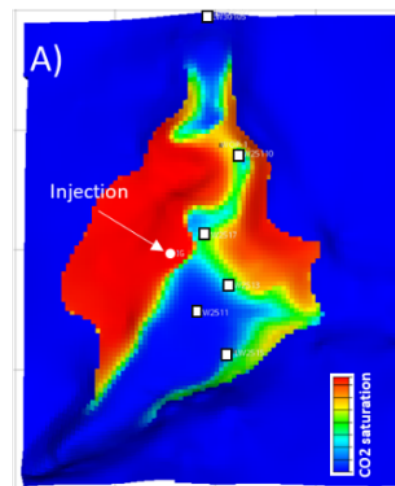
Upscaling to GT storage?

➔ storage areas with legacy wells must be considered

Location of legacy wells vs plume migration



Zonetti et al., 2023





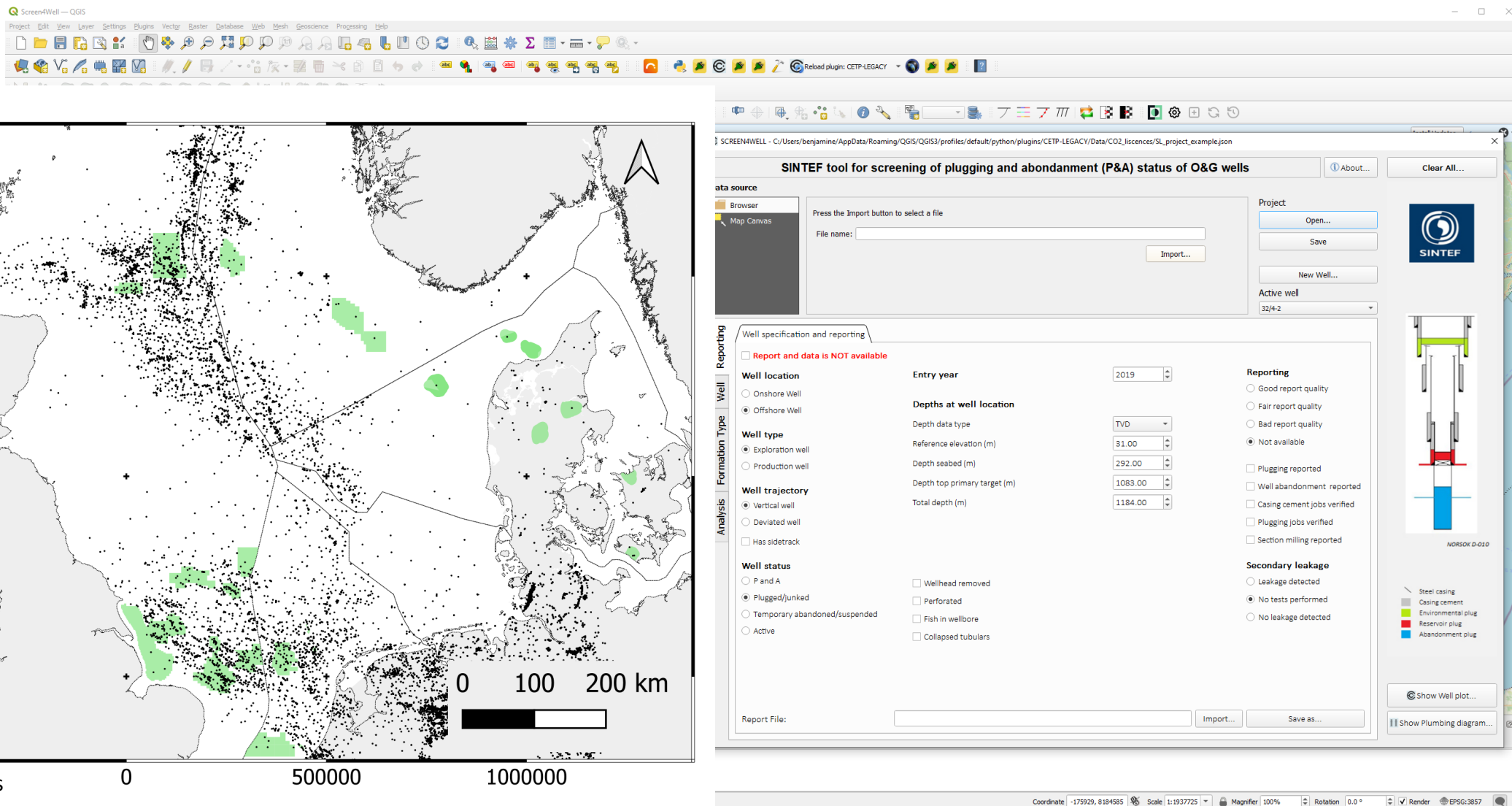
LEGACY project facts



- LEGACY: Field studies for de-risking existing wells and CCS
- Main objective: develop tools and technologies for **screening, modelling, monitoring, and mitigation of well integrity issues and leakage**, thereby **enabling** safe and cost-efficient, **large-scale storage** of CO₂ in areas with legacy wells
- Funding: Clean Energy Transition Partnership and industry funding
- Research partners: SINTEF Industry and SINTEF Energy (Norway), LBNL (US), LANL (US), Febus Optics (France)
- Industry partners: Equinor, AkerBP, Vår Energi, Exxon Mobil
- Duration: 2024 - 2026



SCREEN4WELL QGIS plugin





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Well architecture and visual inspection



Reset



Move



Zoom in



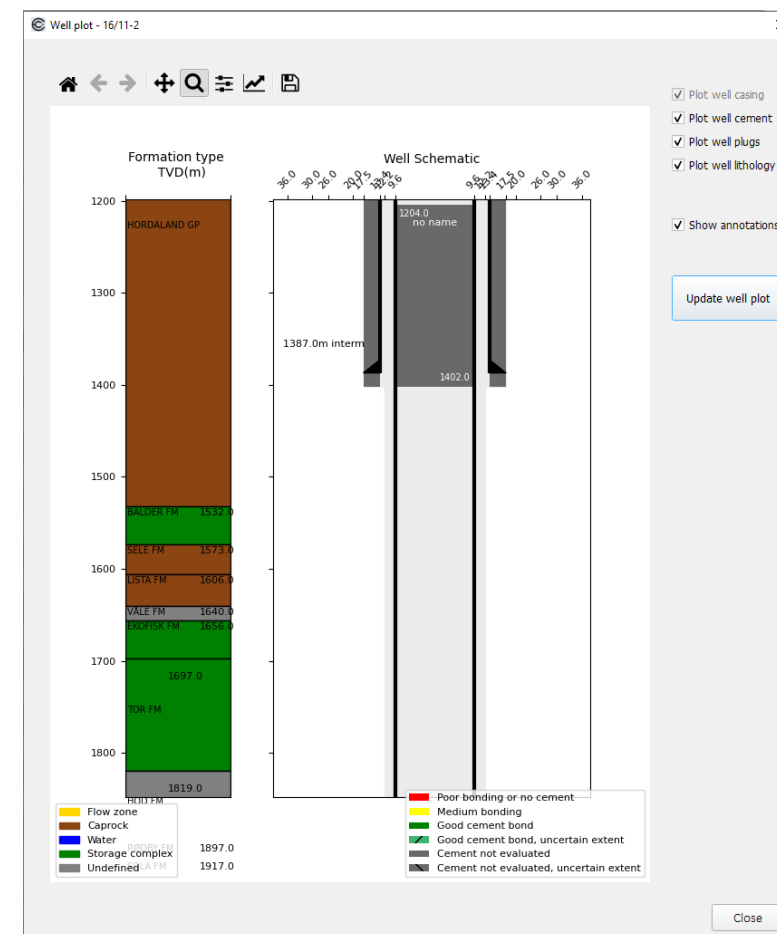
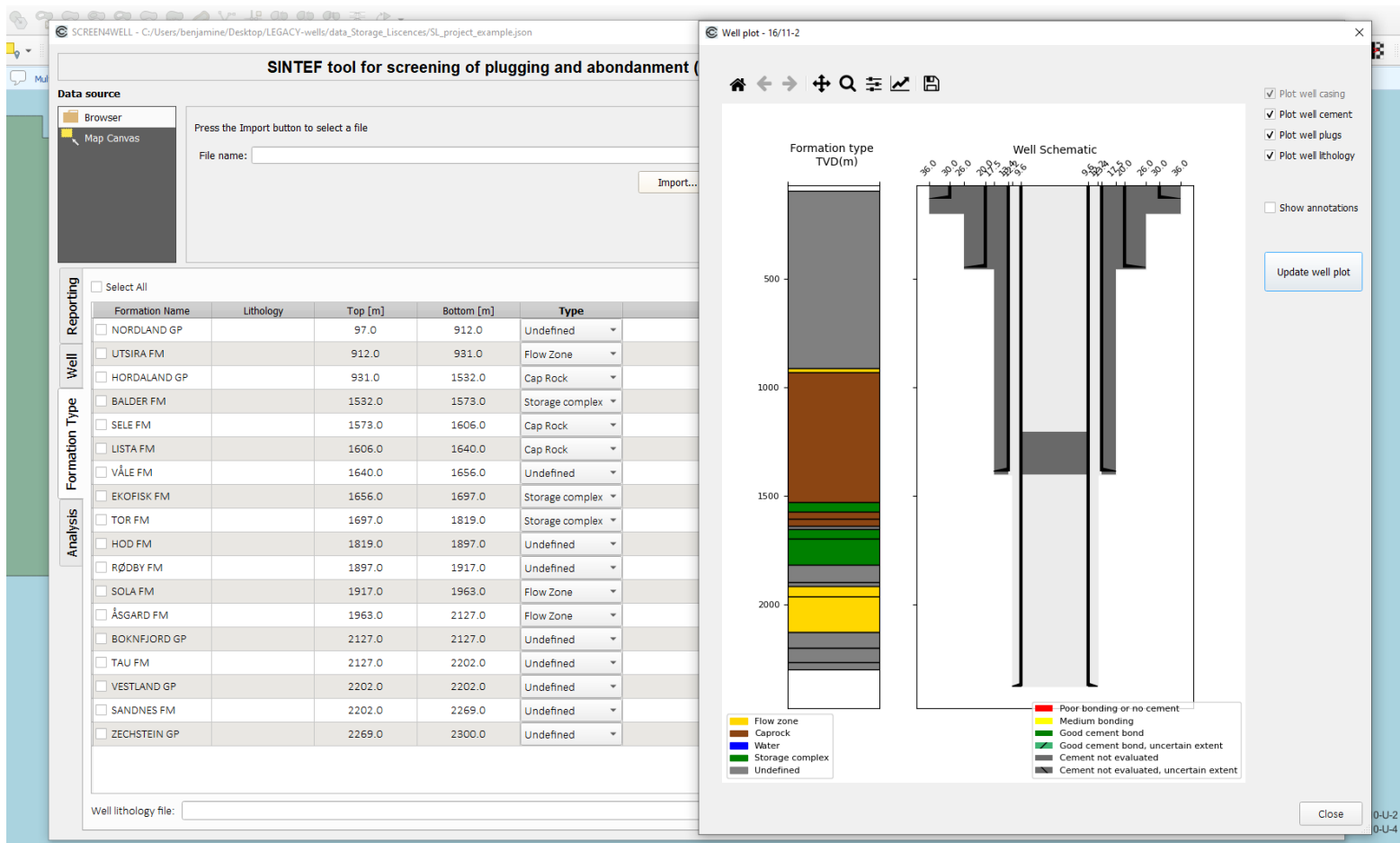
Configure subplots



Figure options



Savings



[illegible]



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Assessment/analysis methods

Assessments:

- Emmel & Dupuy, 2021
- Cahill & Samani, 2022
- Arbad et al., 2022
- Lackey et al., 2024

Methods

Method

Cahill and Samano 2022 Analyse...

Emmel and Dupuy 2021 Analyse...

Lackey et al. 2024 Analyse...

Arbad et. al 2024 Analyse...

Analysis result

Tier 3 of 6

Regulatory framework: Post 1953, Pre 1996
Well type: Exploratory
Deviated: No
Completed: Yes

Cahill and Samano 2022 - 16/11-2

Regulatory and technological framework: Post 1996 ☐ Post 1953, Pre 1996 ☒ Pre 1953 ☐

Well type: Exploratory ☒ Appraisal or development ☐

Deviated: ☐

Completed during intense drilling activity: ☒

Analysis result: **Tier 3 of 6**

Regulatory framework: Post 1953, Pre 1996
Well type: Exploratory
Deviated: No
Completed: Yes

Analyse Info... Close

Emmel and Dupuy 2021 - 16/11-2

	Well property	Value	Score	Comment
1	Status	P&A	3.0	Checked report well status
2	Drilling year	Before 1992	0.0	
3	Plugged date	Not reported	0.0	
4	Plugged and abandon date	Not reported	0.0	
5	Report quality	Good	3.0	Checked well report reporting quality
6	Casing cement job	Filled 87.15 % of volume to fill	1.5	
7	Casing cement job verification	All casing cement jobs verified	2.0	Cement volume must exceed the volume between the open hole and ...
8	Plugging job abandonment plug	Not installed	-2.0	Checking both availability and amount of cement
9	Plugging job reservoir plug	Not installed	-2.0	Checking both availability and amount of cement
10	Plugging job environmental plug	Not installed	-2.0	Checking both availability and amount of cement
11	Plug length	Environmental: 0.0m, Reservoir: 0.0m, Abandonment: 0.0m	0.0	The average score for Environmental, Reservoir and Abandonment plugs
12	Plug cement job verification	No tests	0.0	Checked well report plugging jobs verified
13	Milling, reaming or perforation	Not milled, reamed or perforated	0.0	Checked well report data
14	Secondary indication of well leakage	No tests performed	1.0	Checked well report data

Cement shrinkage factor: 0.66

Total score **4.5 of 30**

Analyse Info... Close

Analysis

Lackey et.al 2024 - 16/11-2

Formations

Geological CO2 Storage Target Storage complex 1656.0- 1697.0

Caprock Undefined 1640.0- 1656.0

Plug design

Surface plug Not reported 1204.0- 1402.0

Intermediate plug Not reported 1204.0- 1402.0

Reservoir plug Not reported 1204.0- 1402.0

Well hazard assessment

Element	Description	Type
Casing	One casing in GCS target	1
Plugging	Unknown plug design	4
Annular cement	Unknown estimate top annular cement	4

Corrective action feasibility 3

Well ranking: **Group 4 B**

Analyse Info... Close

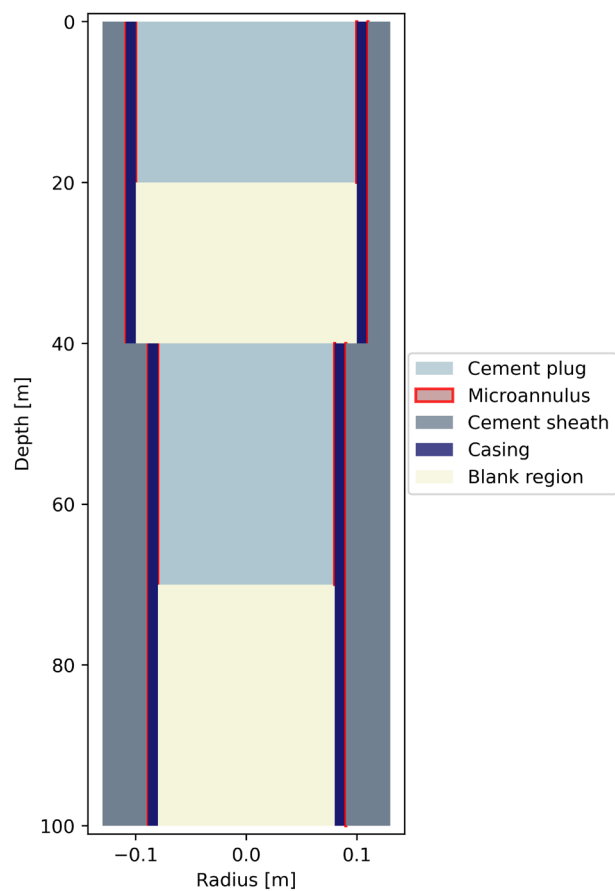


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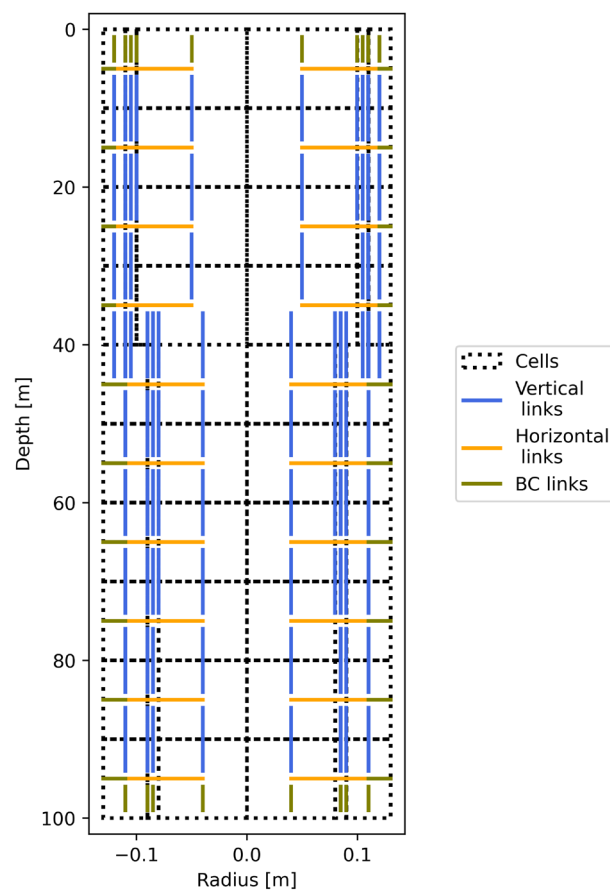
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Leakage modelling tool

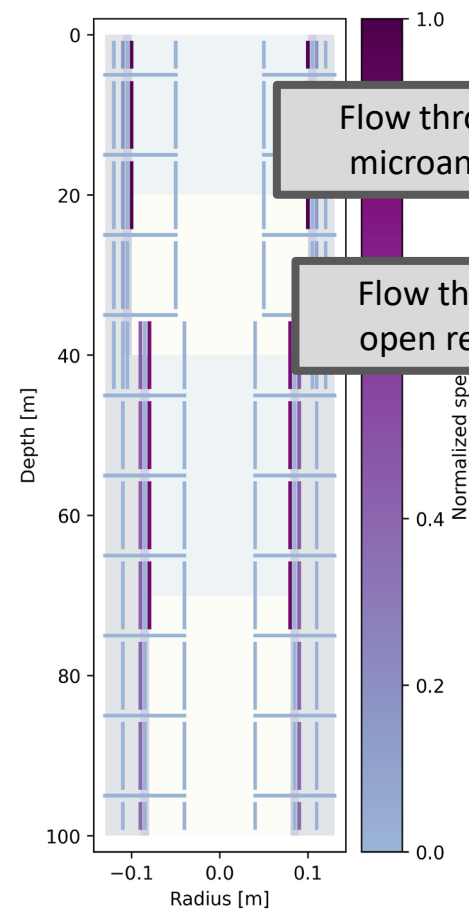
Well structure:



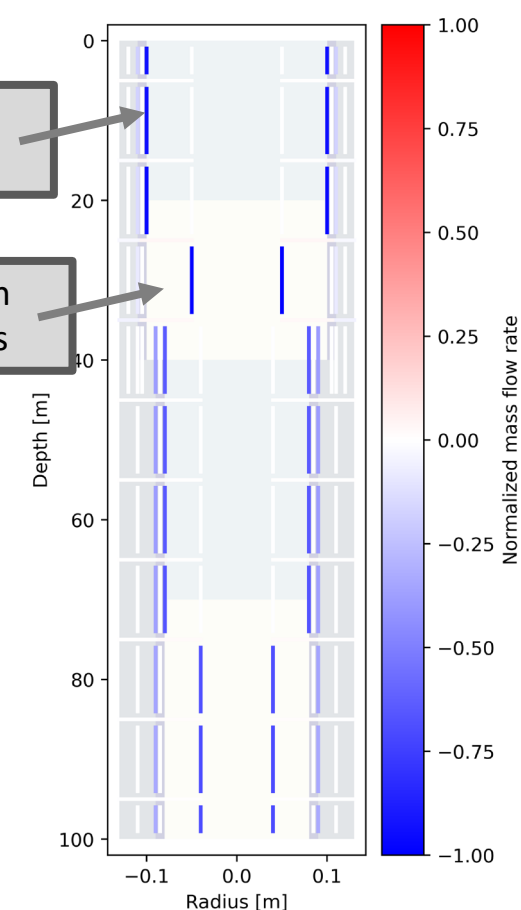
2D network :



Calculated flow speed:



Calculated mass flow:



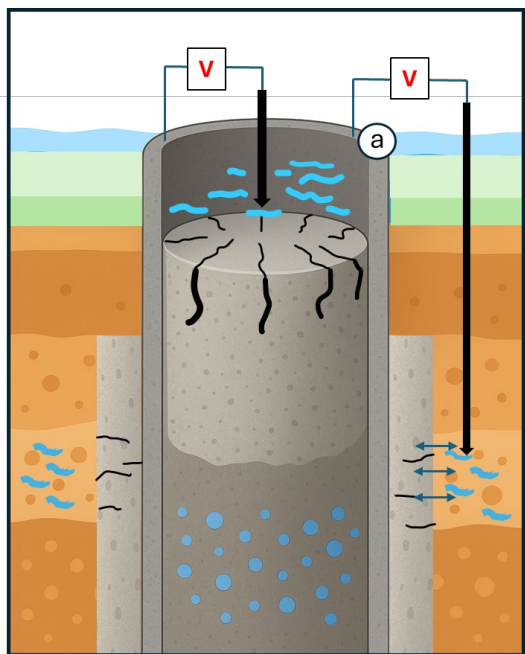


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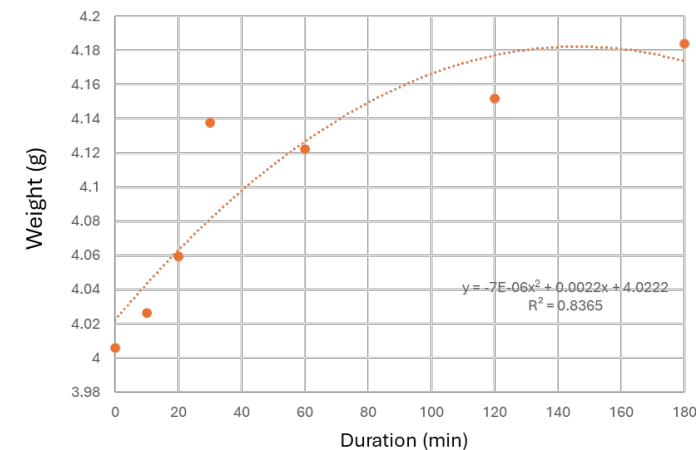
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Electrochemical simulation of scale

Scale from synthetic formation water



Scale at cathode using Smeaheia FW



Electrolysis splitting of water:



Main mineral reactions at cathode:

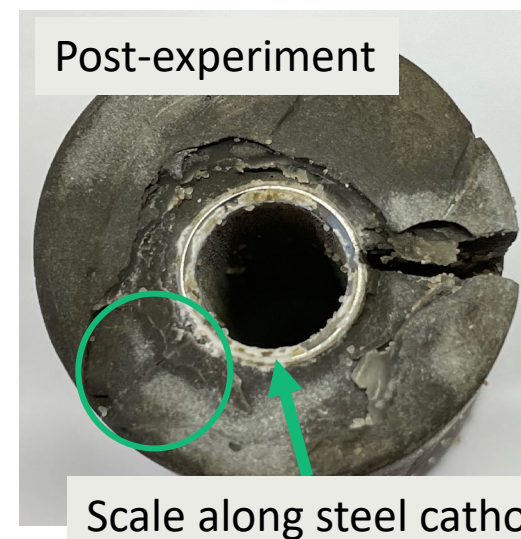
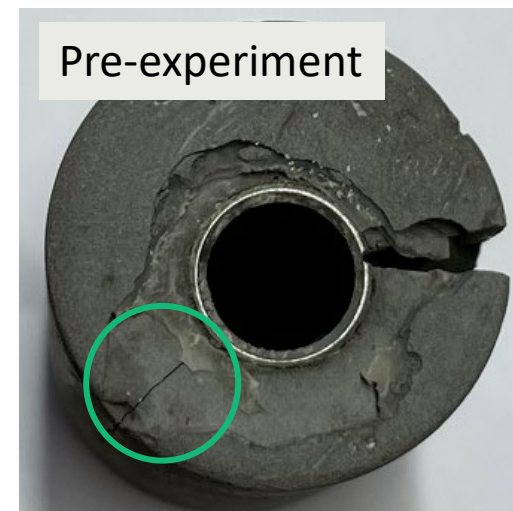
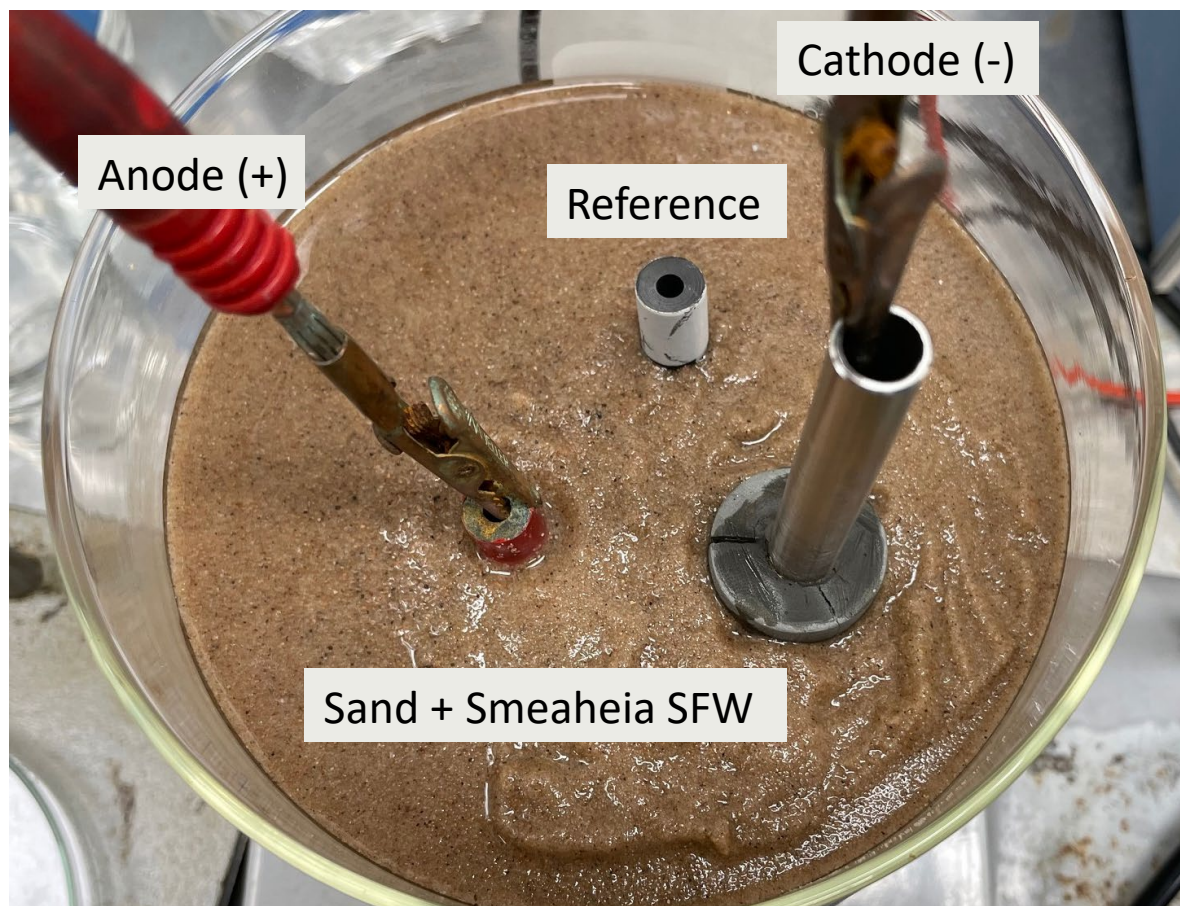




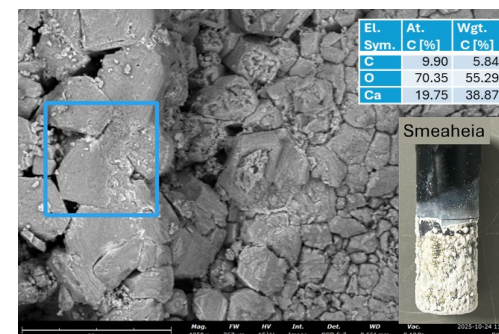
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Electrochemical simulation of scale



Scale along steel cathode



- 24 hrs electrochemical experiment
- Post experimental characterisation of scale via XRD and SEM-EDS



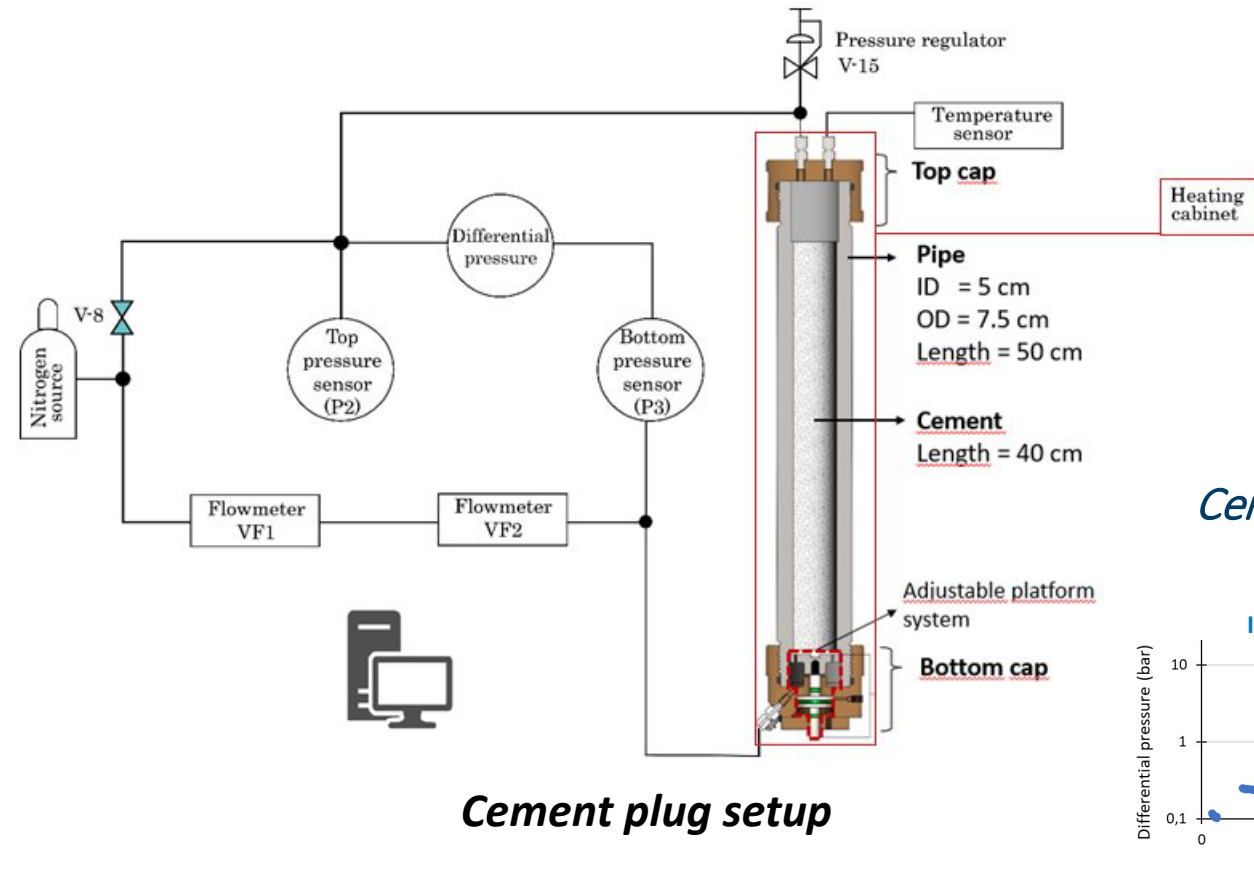
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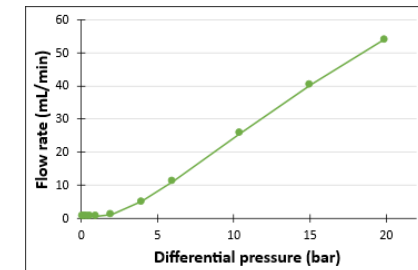
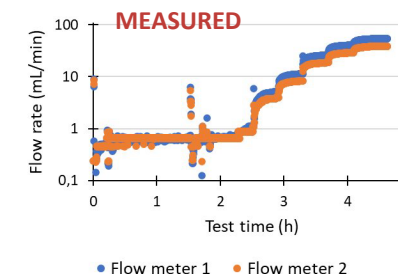
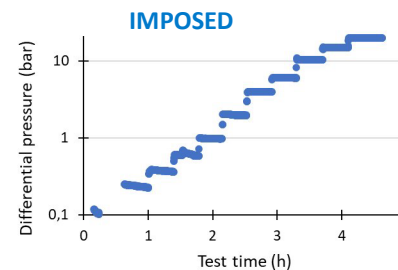
Leakage tests of cement plugs with and without monitoring optical fibers

Can the presence of optical fibers (for monitoring) in cement barriers affects leakage rate ?

- Cement plug cured 20 bar, 66°C for 4 days
- 2 optic fibers (Ø 1mm) placed in the middle
- Neat cement G
- Cement with expansive agent (*ongoing*)



Cement plug sealability: relationship between flow rate and differential pressure over plug

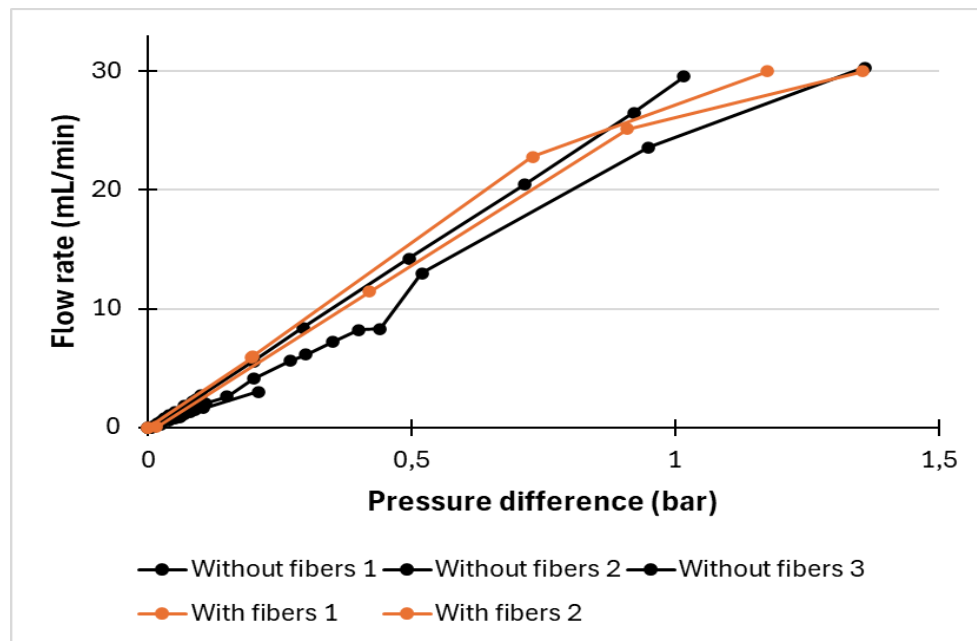




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Leakage tests: results



Most of leakage seems to occur at the microannulus (casing-cement interface)

- Presence of optical fibers does not affect the leakage rate in the case where the initial cement plug has a high leakage rate (regular cement)
- Ongoing tests:
 - initial cement plug with a relatively low leakage rate (expansive cement)
 - Fiber close to the wall (different configuration)
- Next: presence of optical fibers in annulus cement barrier

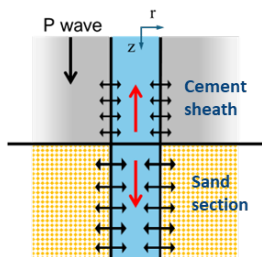


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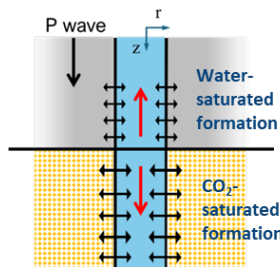
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Non-invasive monitoring

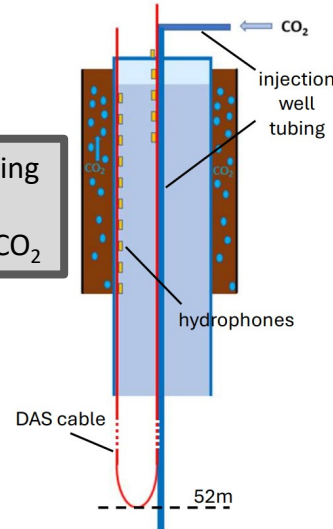
Sensitivity to cement integrity behind casing



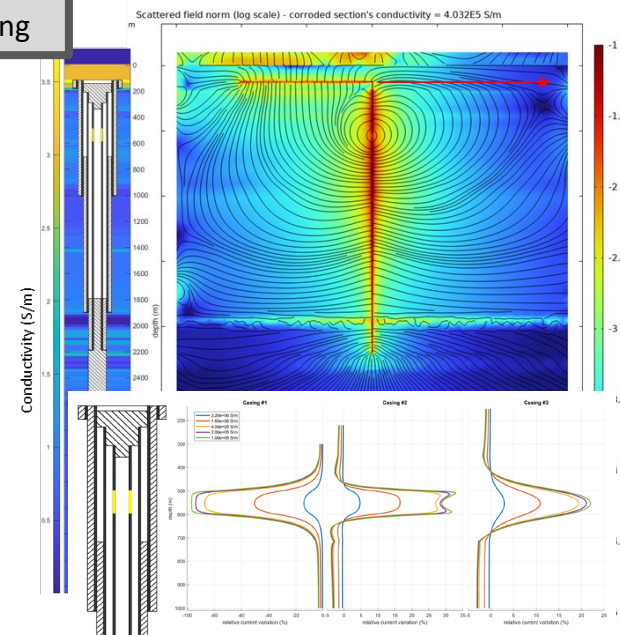
Sensitivity to CO₂ behind casing



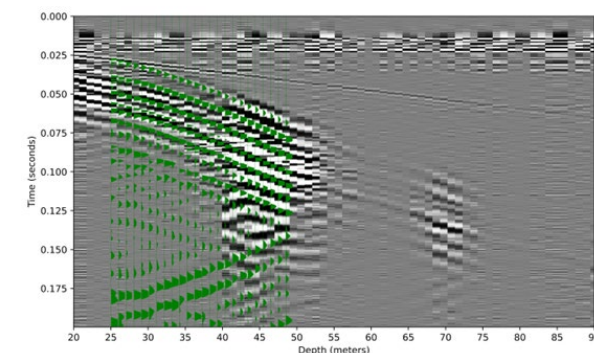
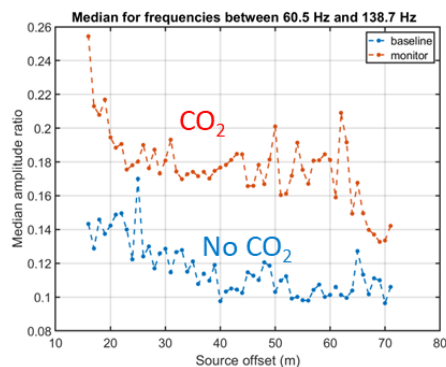
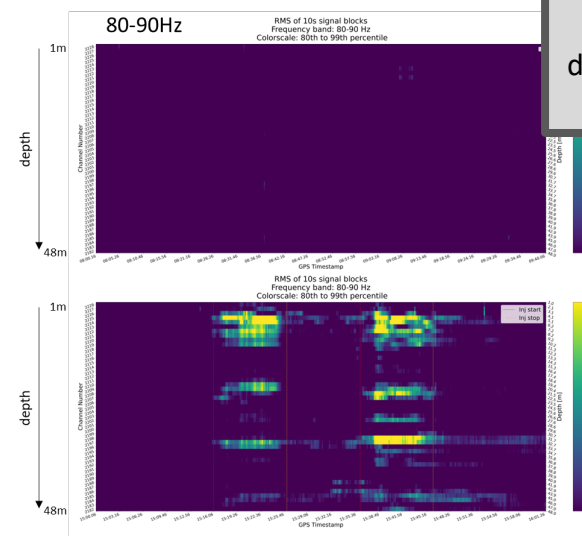
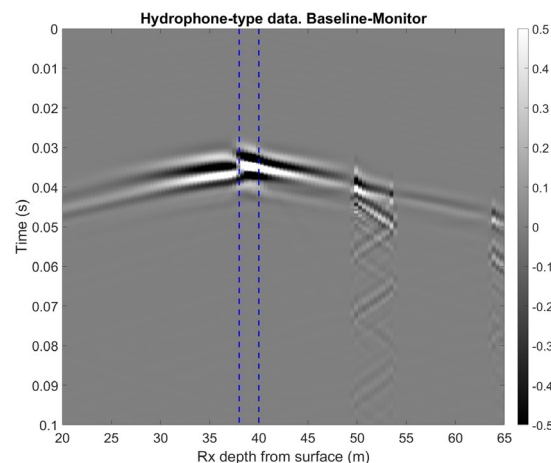
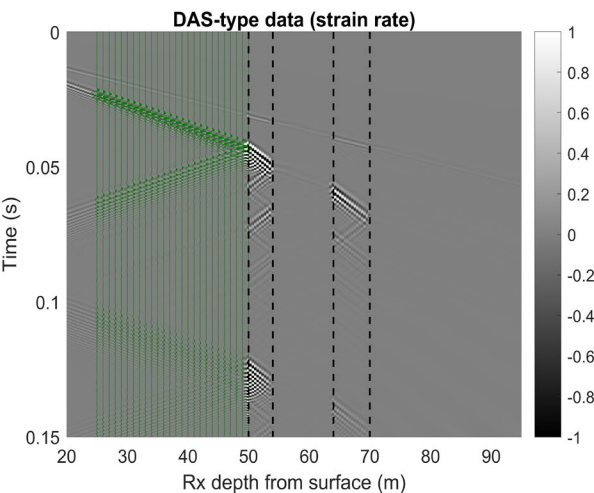
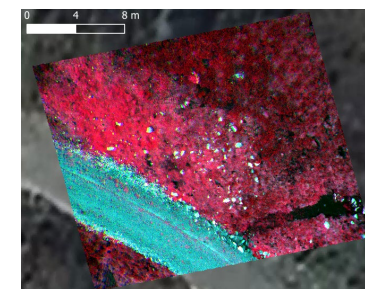
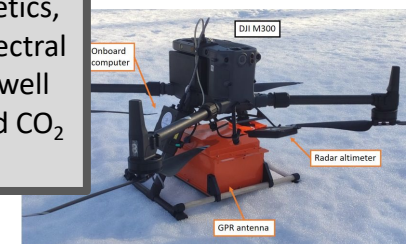
Passive listening of vertical migration of CO₂



Casing corrosion monitoring



Drone magnetics, GPR, multispectral imaging for well detection and CO₂ seepage





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Field campaigns

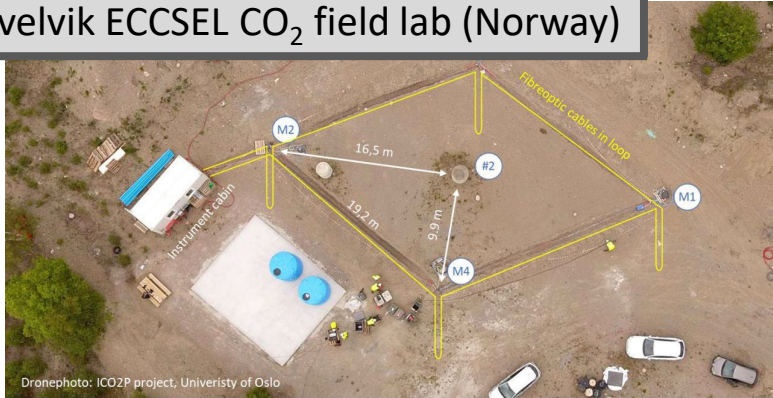


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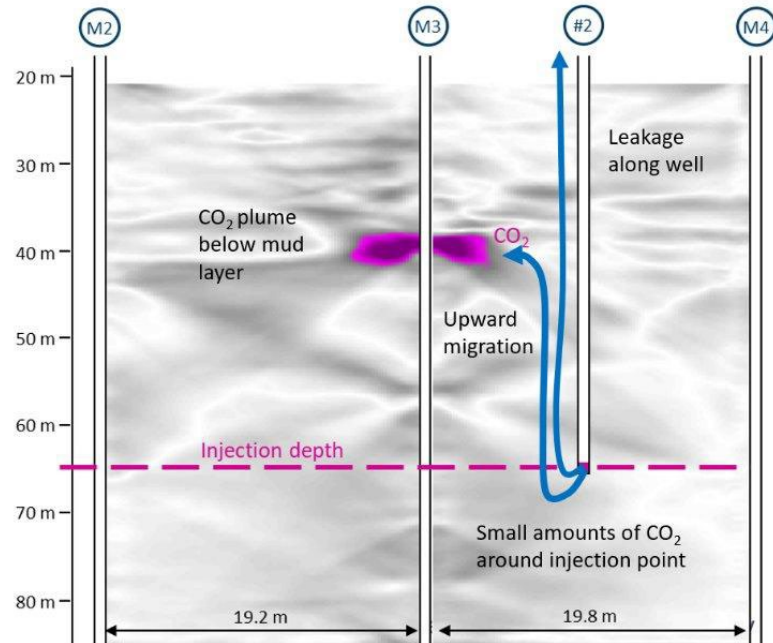


Svelvik: 24th September – 8th October 2025

Svelvik ECCSEL CO₂ field lab (Norway)

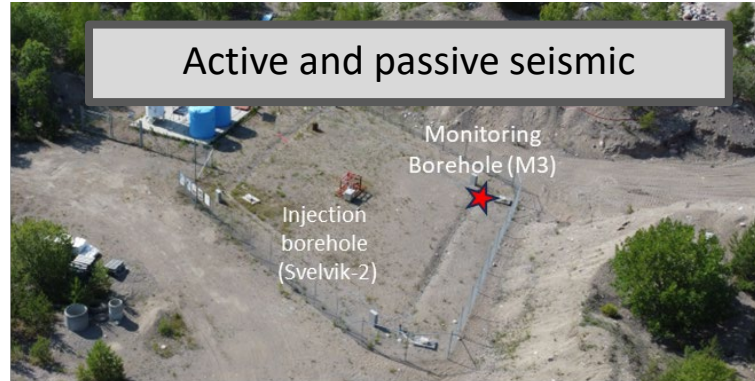


Dronephoto: ICO2P project, University of Oslo

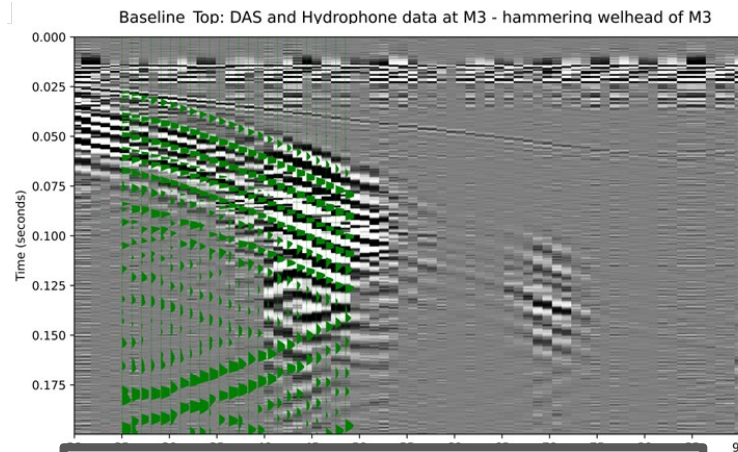


Jordan et al., 2022. EAGE Geotech, London

Active and passive seismic



Zero offset VSP data for tube wave analysis was collected before ("Baseline") and during CO₂ injection ("Monitor").



DAS, DTS, DSS, hydrophones,
surface geophones

3D printed
engineered plug



Future field campaigns:

- Rio Vista end 2025 (California): 6000 ft well (tube waves, TDR, energized casing)
- Mt Terri 2026 (Switzerland): near and far field characterization
- Possibly Svelvik 2026: more realistic plug tests

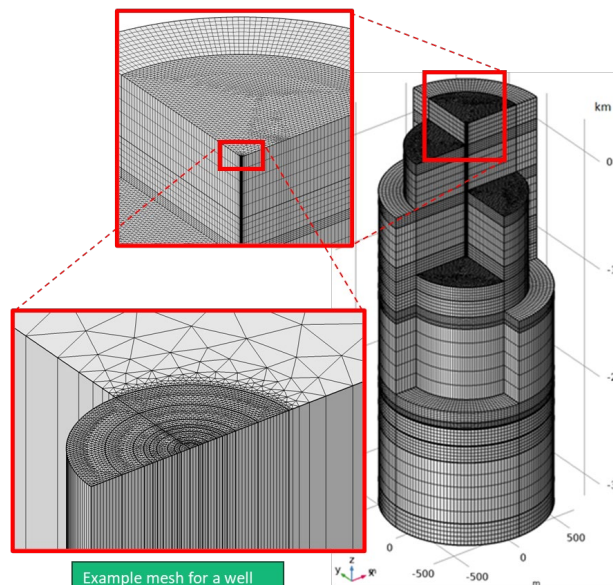
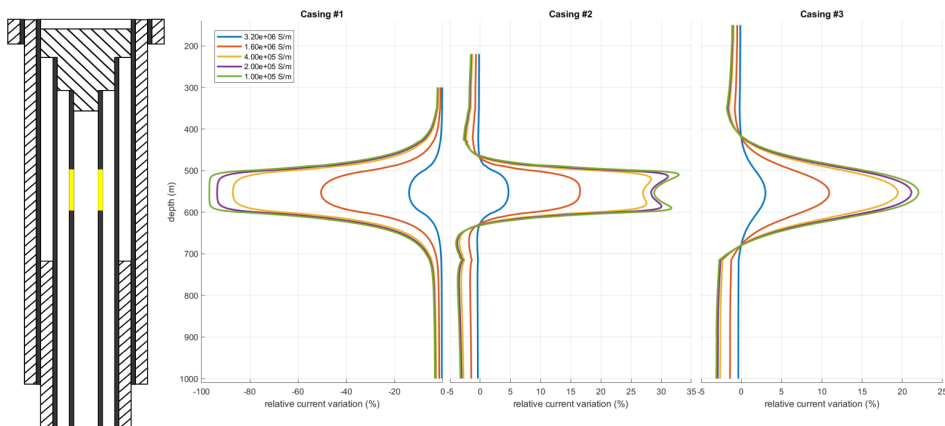


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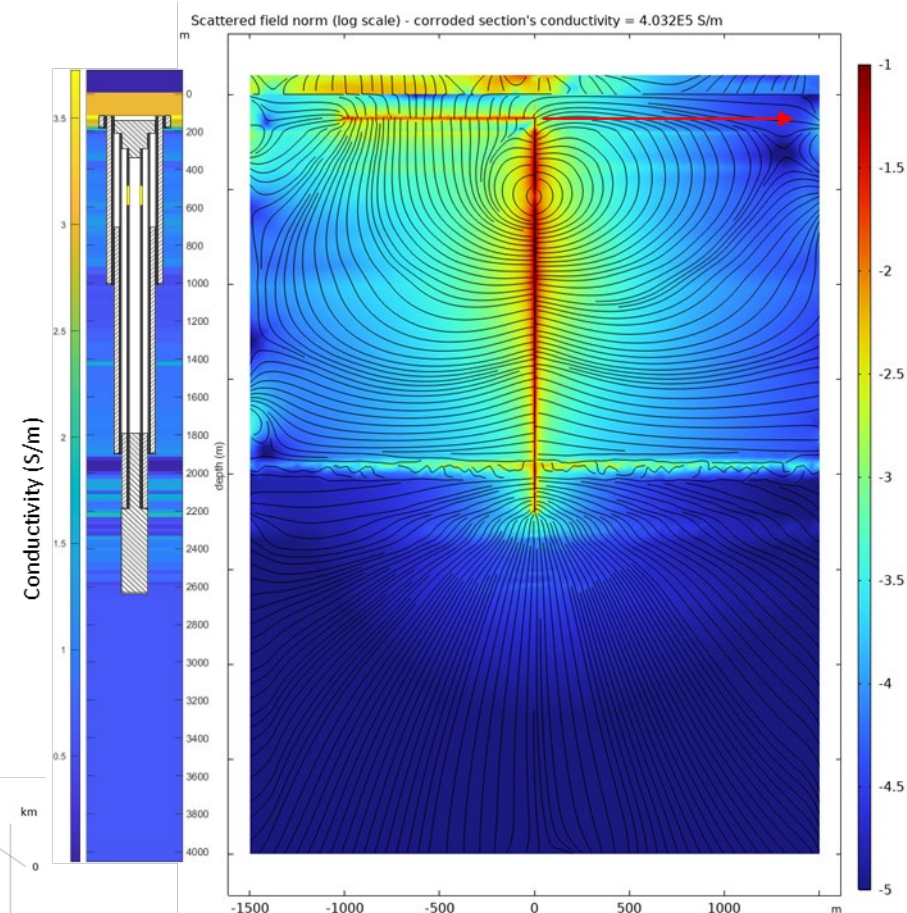
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Electromagnetic methods

- Promising modelling showing effect of corrosion of steel casing on EM fields.
- Use of casing as an antenna for enhanced plume migration monitoring
- Time-domain EM reflectometry (Rio Vista, LBNL)



Example mesh for a well with complex telescopic casing



Zonetti et al., *The Leading Edge* (2023)



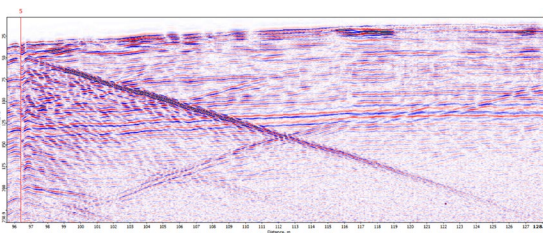
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Drone remote sensing: wellheads, seepage

Ground Penetrating Radar

1 m AGL flights pre- and post-injection at 4 frequencies.



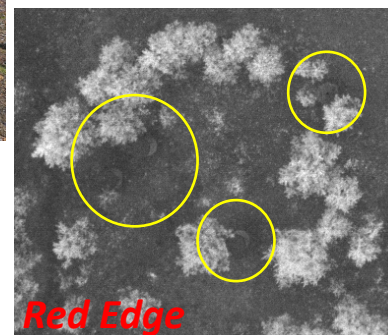
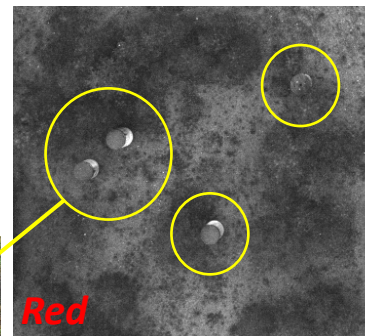
Aeromagnetics

High (60 m) and low (15 m) altitude flights



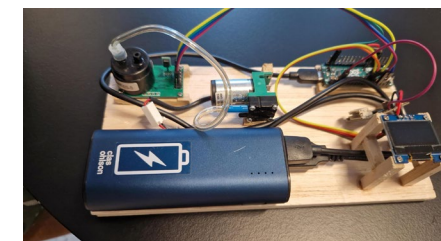
Multispectral

High (60 m) altitude flights
(coincident with magnetics)



CO₂ measurements

Ground measurements of CO₂





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LOCATE project initiative

- Application to CETP funding
- Aim to start by end of 2026
- Gathering leading researchers on the subject from Europe (4 research institutes and 5 universities) and 9 industry partners
- Involvement of service providers
- Increase TRL by field-scale validations

➔ Quantitative risk management toolbox

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