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Monitoring of Greensand Pilot Injection Project

Results from the offshore operations

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Greensand Monitoring Pilot Injection

Content

- Overview Greensand
- Pilot Injection
- Monitoring and modelling
- Focused seismic

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Greensand Project Status and Outlook

Safe CO_2 Offshore Transport and Storage Project in the North Sea

A project by INEOS Energy, Wintershall Dea and Nordsøfonden (IRIS License)

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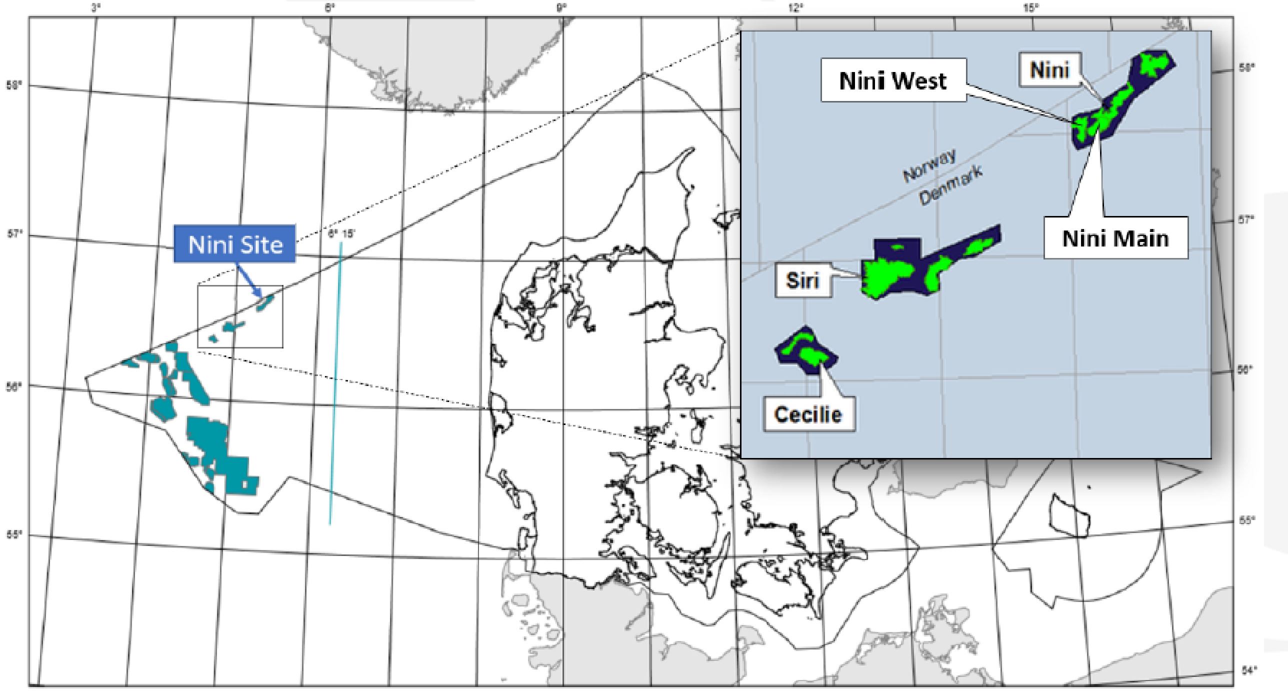

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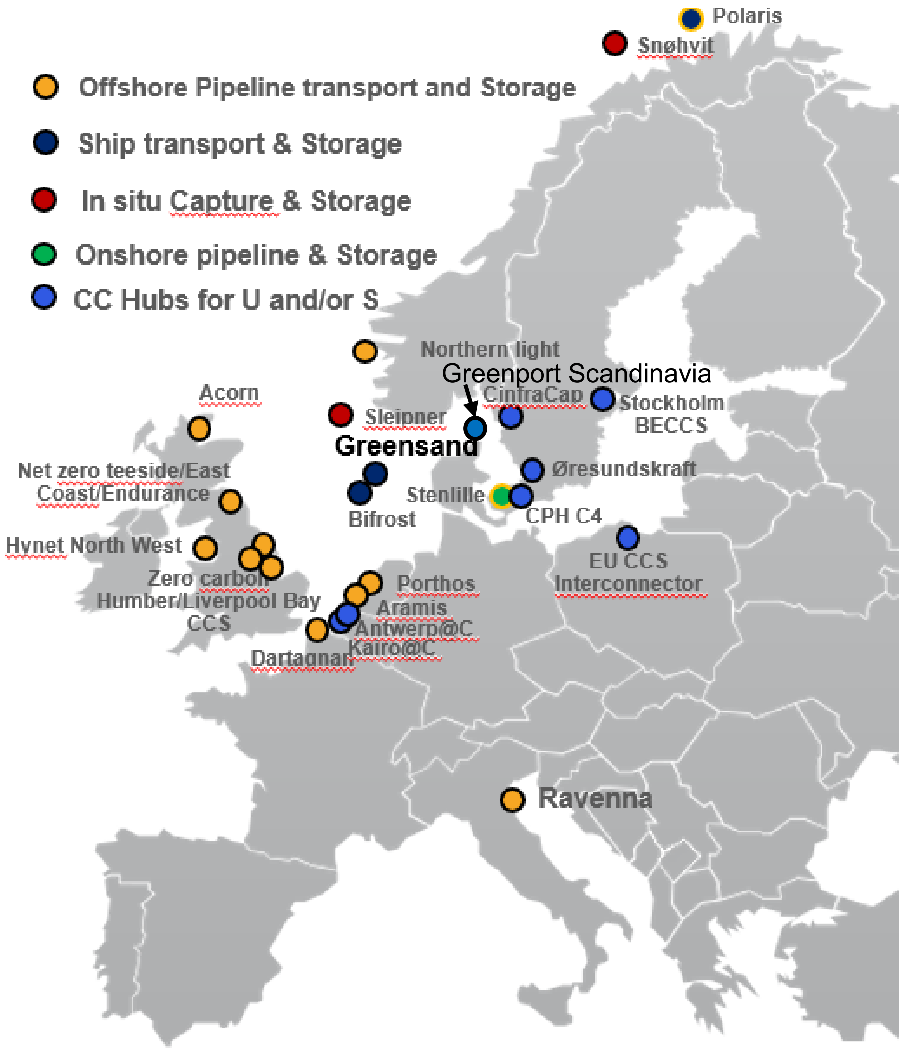
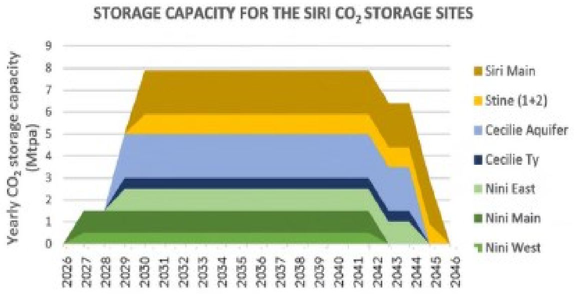
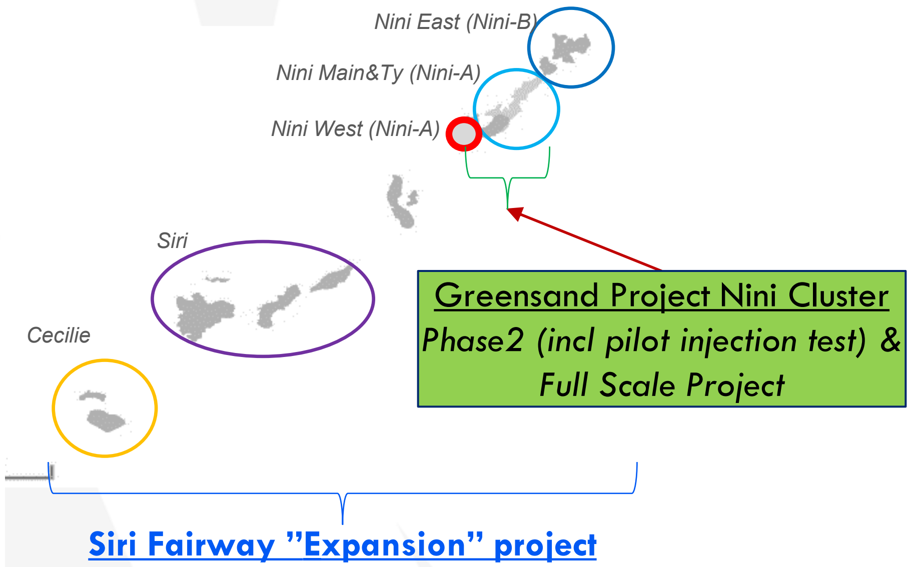
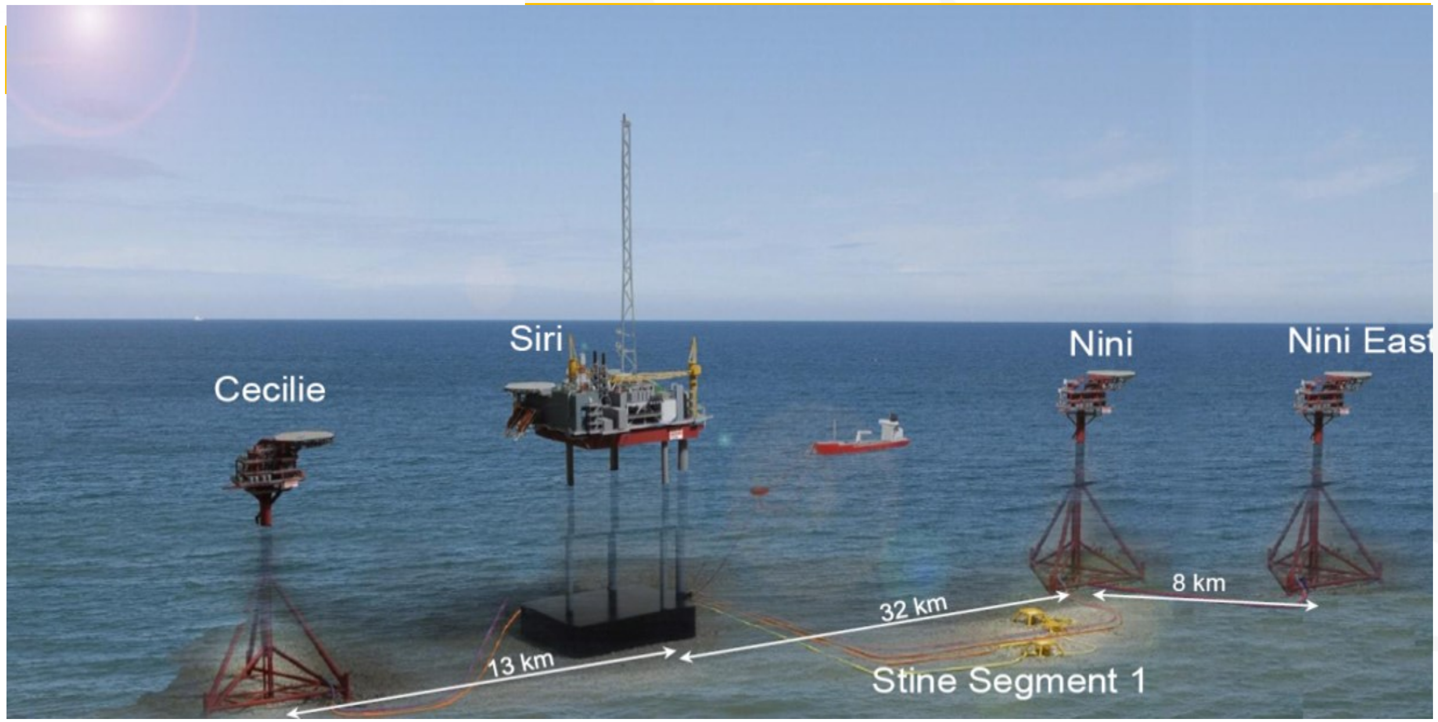
Greensand Project
Overview









Disclaimer: Map produced by Greensand Project based on available public data, not complete and only illustrative

Greensand Developent Phases – building competence, mitigate risks and harvest economies of scale

Aktivitet	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	Capacity
Phase 1 _Nini West storage feasibility												
Phase 2 - Pilot injection and Monitoring - in Nini West		Funding	Execution	Offshore operations								Injected 4100 tons liquid CO2
Fast Track – Proof of industrial scale Store CO2 in Nini West							Start Storage					Up to 0.5 MTPA (Biogenic CO_2)
Full Scale – Nini storage complex Nini West, Main and East reservoirs									Start Storage			Up to 3 MTPA
Greensand Greater Area Expansion Include Cecilie, Stine and Stine reservoirs												Up to 8 MTPA (Incl. Aquifers)

Greenport Scandinavia

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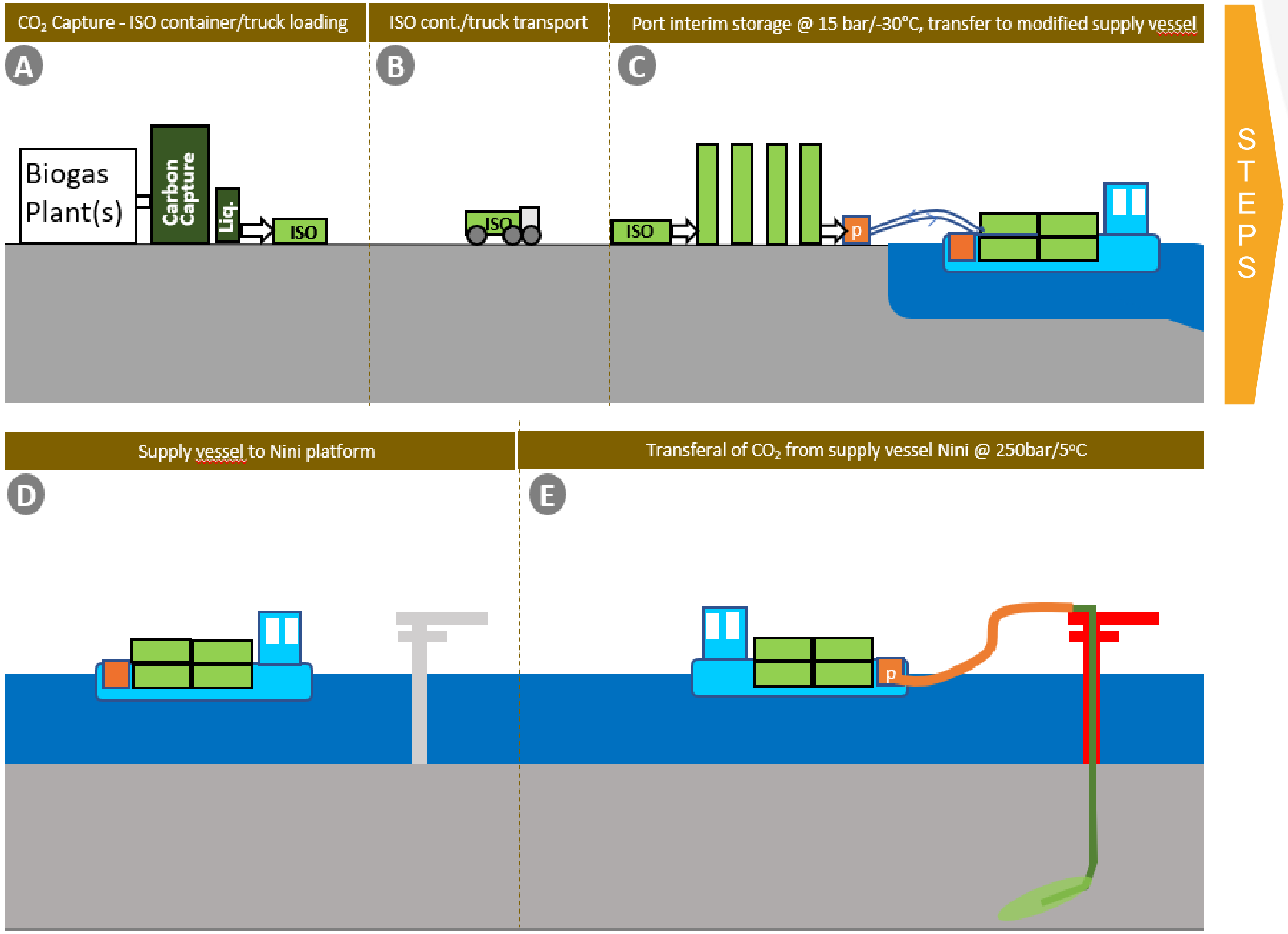
Greensand Fast track concept – Proof of industrial scale

Based on operational set-up and learnings from Greensand pilot (Phase 2)



A. Installing capture and liquefaction plant

B. Delivery of CO_2 via trucks in port

C. Installing interim storage facility in port

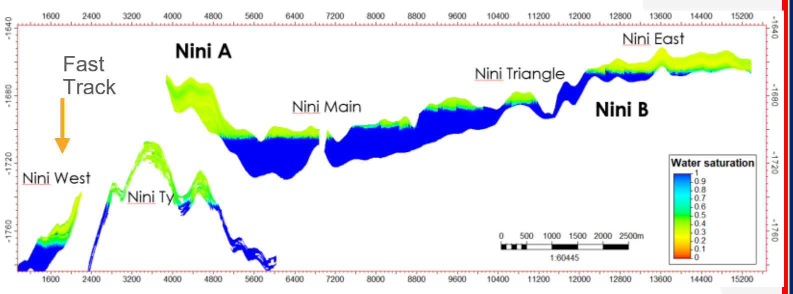
D. Rebuilding supply vessel. Exp. equipment size approx. 3.000 tCO_2/trip

E. Minor topside modification needed on Nini. Use of existing well

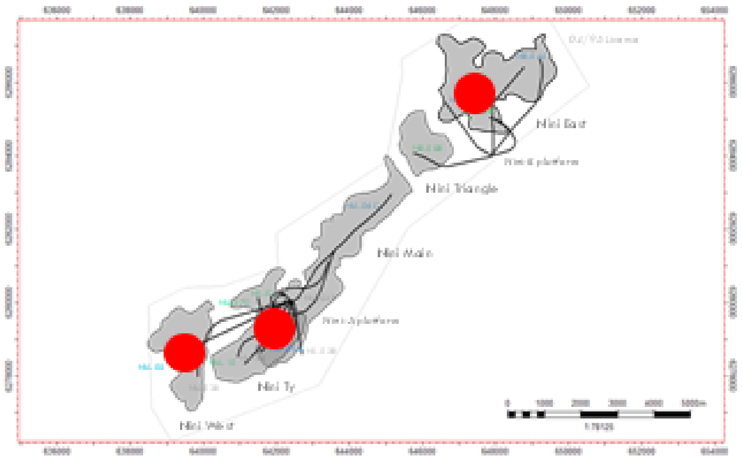
Greensand Project – Full Scale Concept Selection Phase

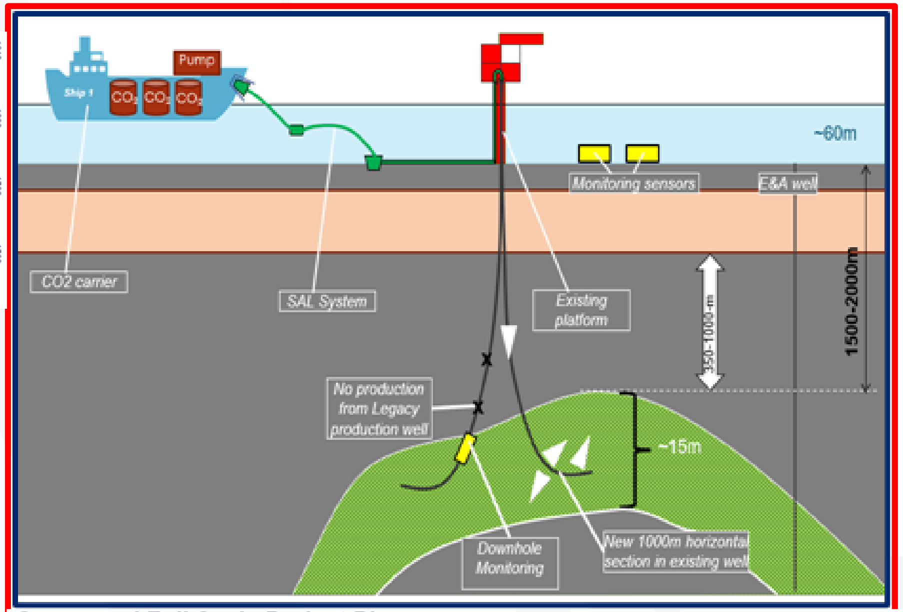
Project Activities in Concept Selection Phase – Proof of commercial scale

- Well Design – new vs. re-use, P&A philosophy
- Ship design – size, power, P&T
- Ship Offloading System
- Platform modification on Nini
- Metering set-up
- Monitoring Plan – During and post injection
- Permitting – PDO and EIA
- Commercial model vis-a-vis the CCS value chain
- Verification (ISO 27914, EU Directive, National Laws)
- CO2 specification
- Aquifer storage maturation

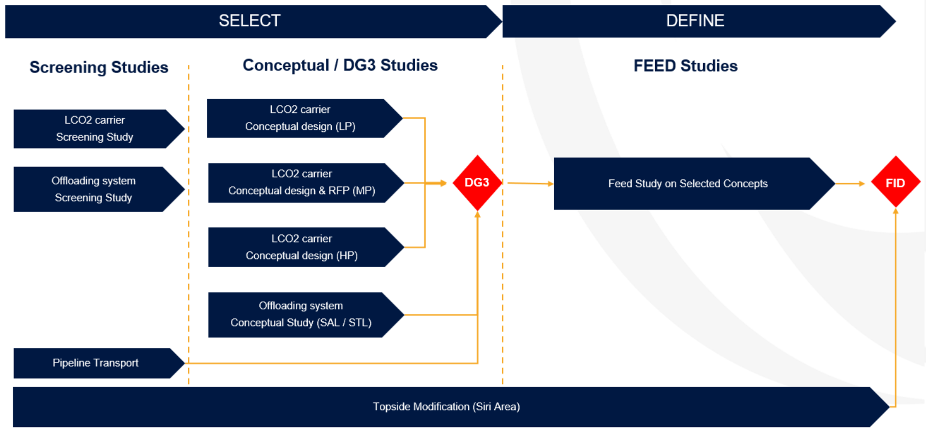


Full Scale – Nini Area complex





Greensand Full Scale Project Phases



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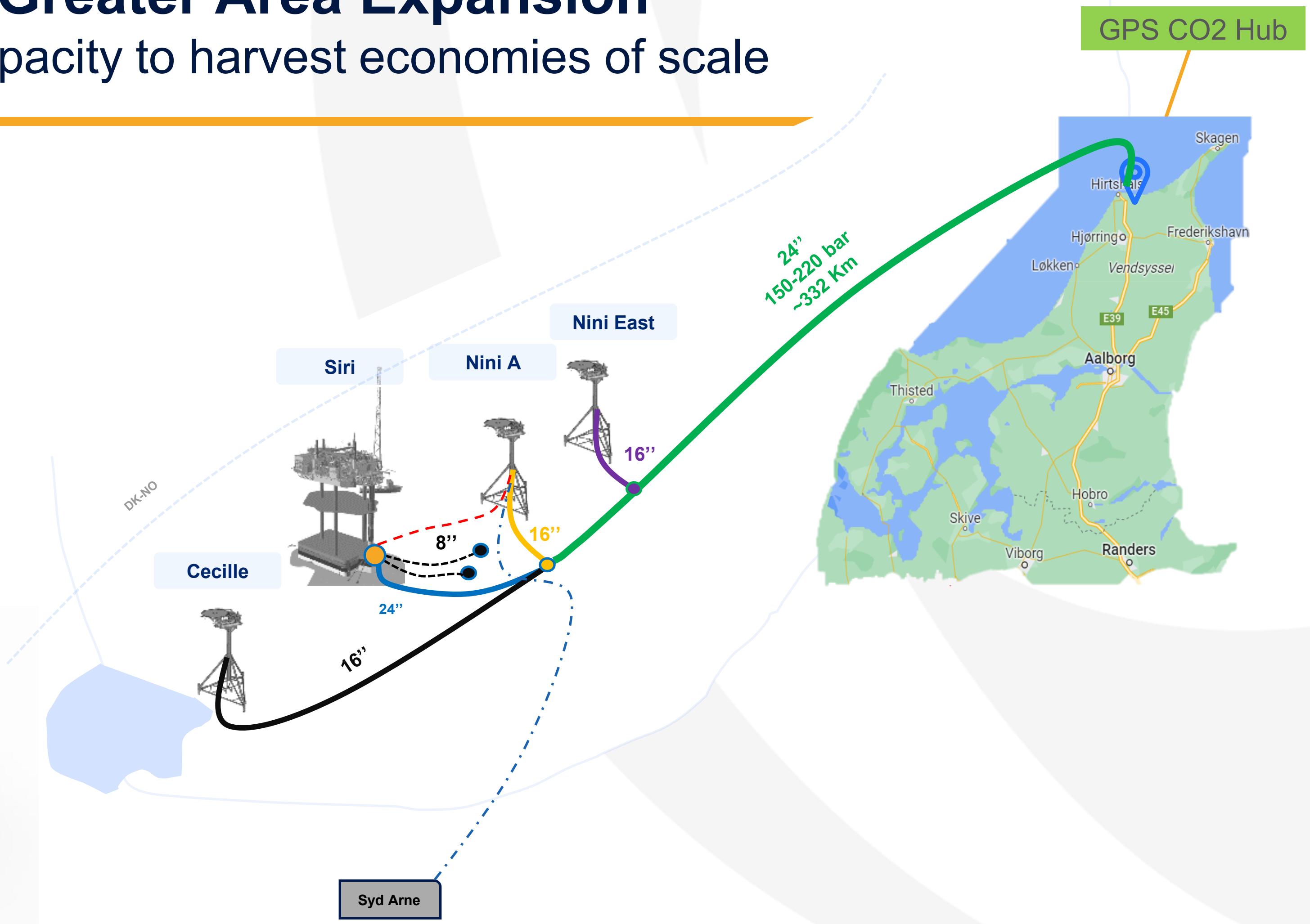
Greensand Project – Greensand Greater Area Expansion

Conceptual considerations – Scaling of capacity to harvest economies of scale

- Build upon learning from Full Scale project
- Transportation mode – ship **and/or** pipeline
- Control of Operations
- Legacy wells P/A or Use?
- Use of existing facilities
  - Direct Pipeline injection
  - Ship injection



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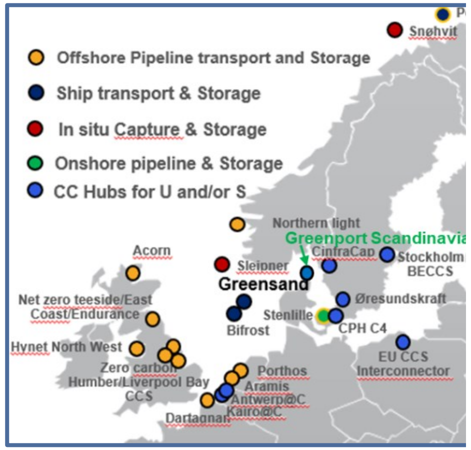
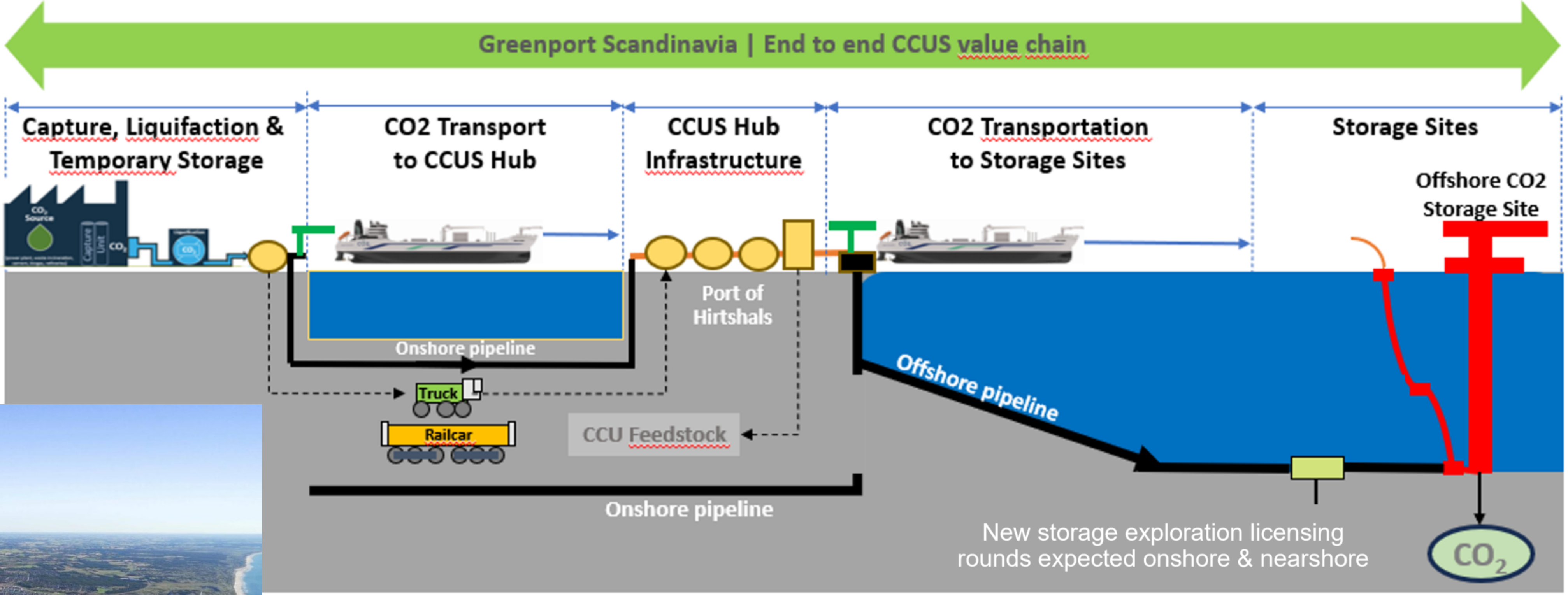
The Greenport Scandinavia Multi CCS Value Chain

Creating a CC(U)S hub to Harvest the Economies of Scale throughout the Value Chain





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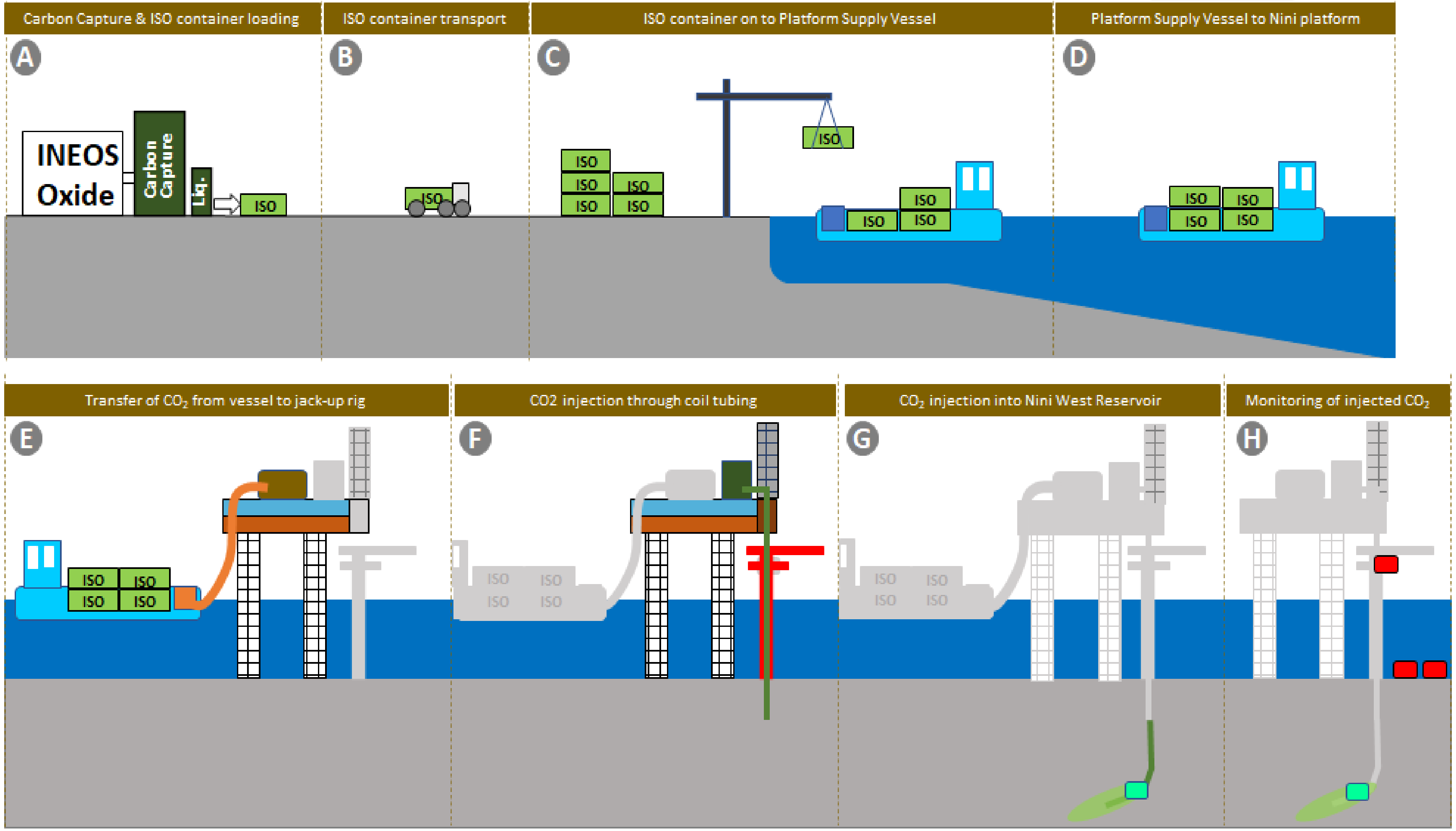
Greensand Pilot Injection Project - Overview



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- Sourcing batches of liquified CO_2 and handling them between the CO_2 capture plant and port
- Transporting liquified CO_2 in ISO containers between plant, port and the Nini Platform using a Platform Supply Vessel (PSV)
- Injecting liquified CO_2 in several batches into the Nini West reservoir using discharge equipment placed on both the PSV and a jack-up rig with a coil tubing unit installed in NA-05 well
- Monitoring reservoir performance before, during and after these cyclic injections

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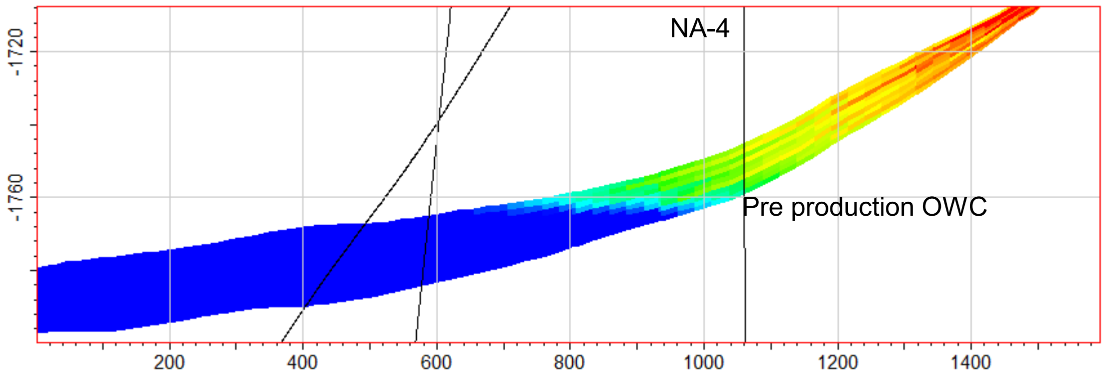
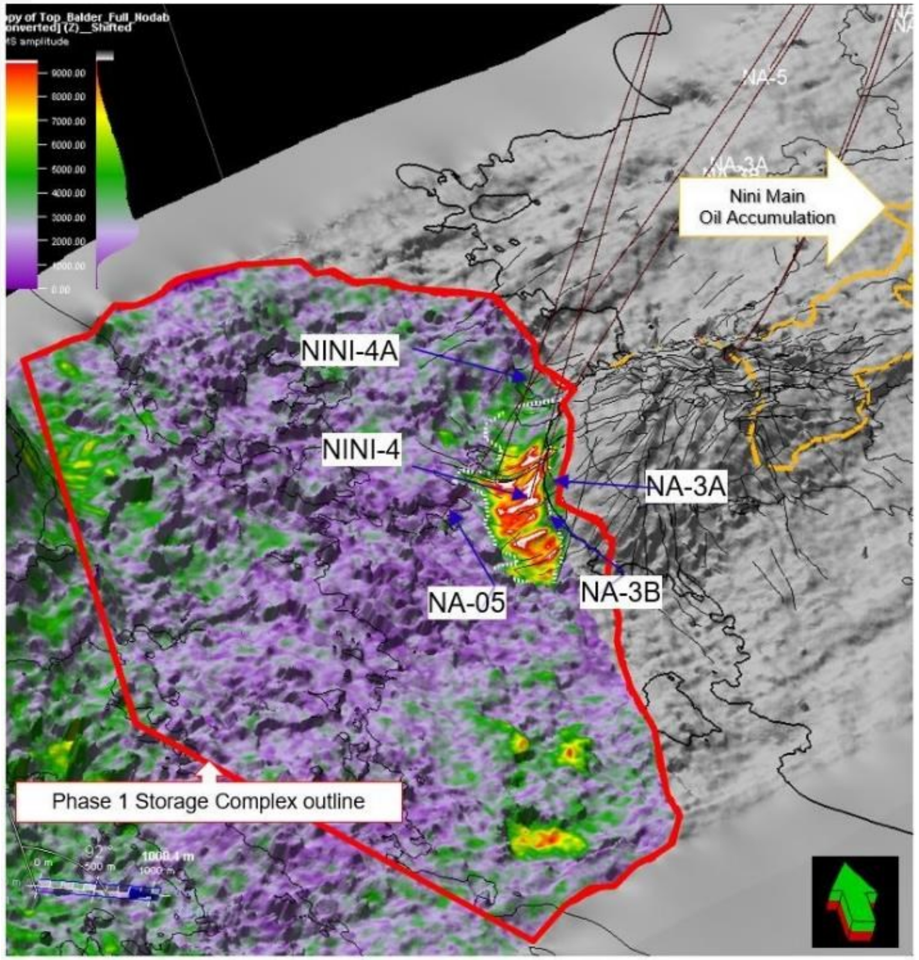
Pilot Injection into Nini West Field

Definition of Storage Complex

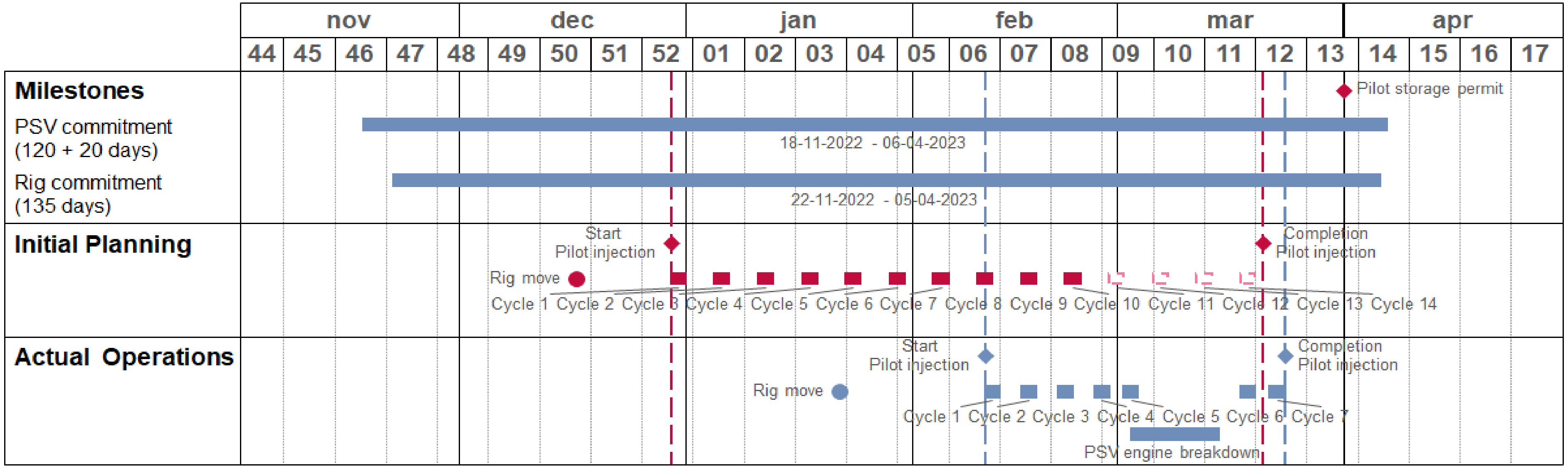
- Nini West – oil depleted reservoir (2003-2018), isolated
- 1 exploration well + 1 sidetrack (P&A'ed)
- 1 producer + sidetrack (inactive), 1 water disposal well (active)
- Paleocene-Eocene deep marine sands
- Porosity 30-35%, permeability 100-1500mD
- Homogenous reservoir with excellent connectivity, strong aquifer
- More than 300m marine shale forming primary cap rock



Cross-section from Nini west model



Greensand Pilot Injection Project - Timeline



	Initial planning	Actual operations
Rig move	15/12/2022	19/01/2023
1st injection start	30/12/2022	11/02/2023
Last injection	21/03/2023	23/03/2023
Injection period	Up to 90 days	42 days
Number of cycles	10 + 4 optional	7
Batch size	750 tons	585 tons
Total injected volumes	≈ 10,500 tons	≈ 4,100 tons

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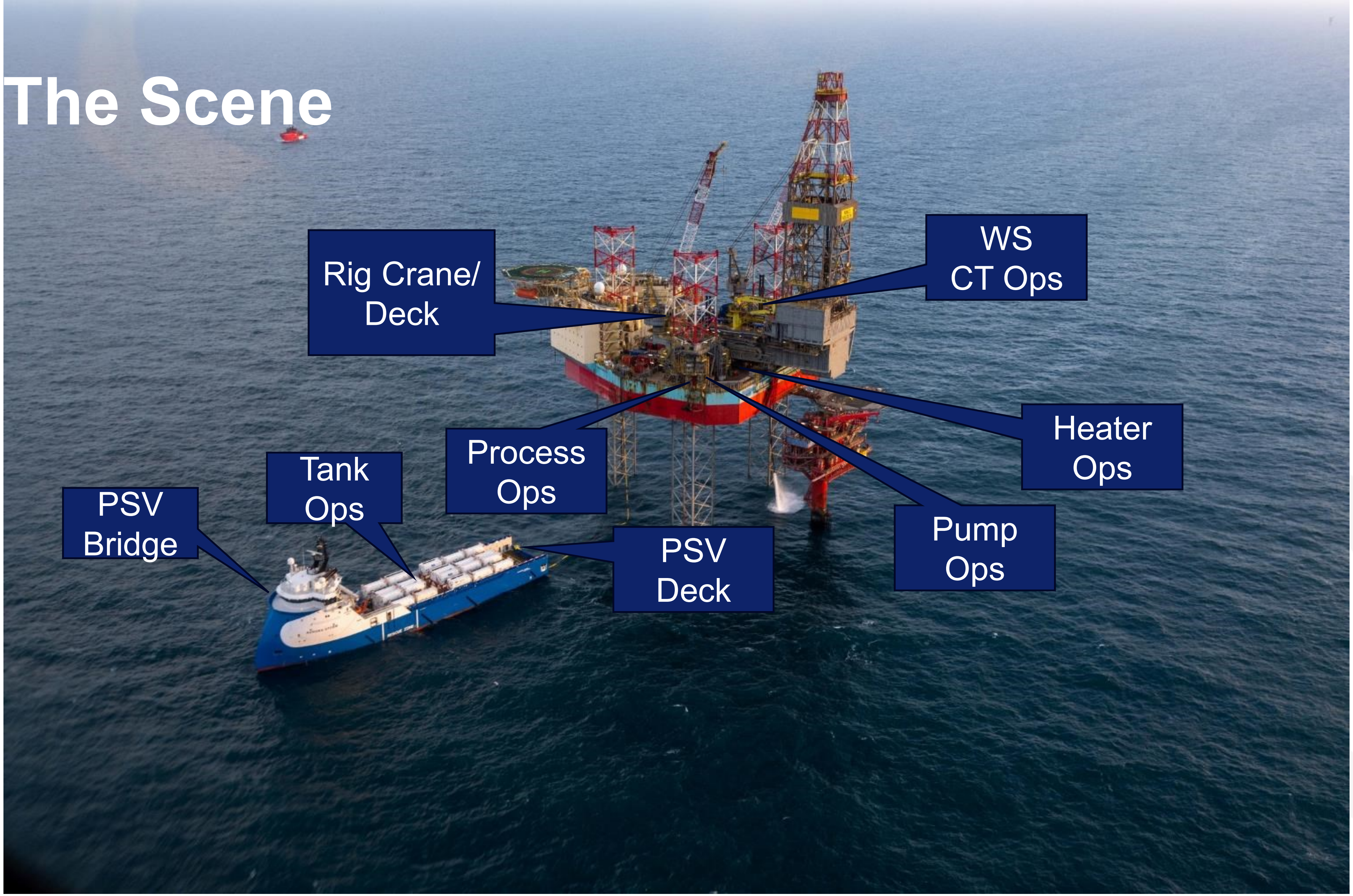
The Scene



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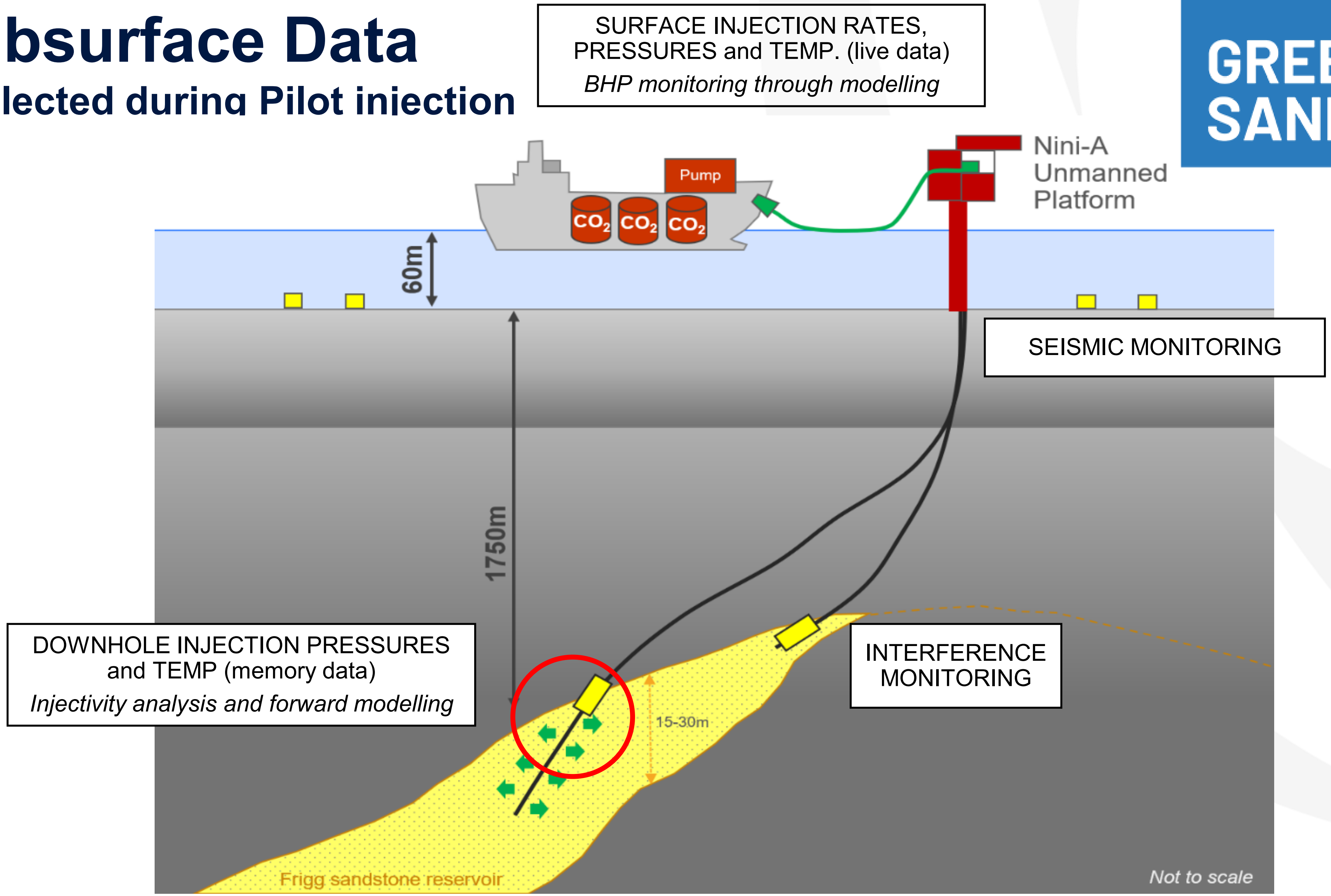
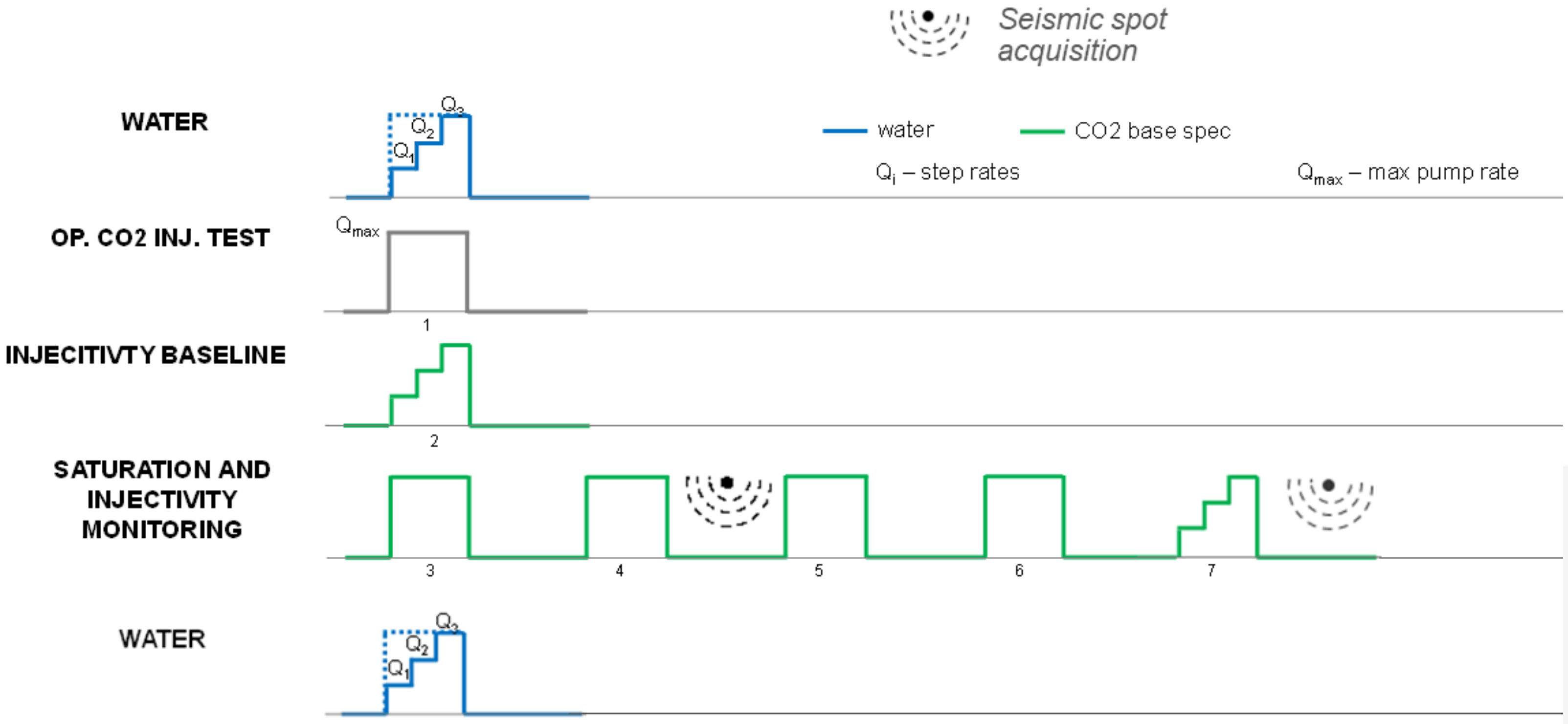
Pilot Subsurface Data

Key data collected during Pilot injection



Pilot CO_2 injection program (actual)

- 7 injection cycles
- Water injectivity test pre and post pilot
- CO_2 step rate test at start and end of injection
- Seismic baseline and 2 monitors



Durations of injection to shut-in periods not to scale

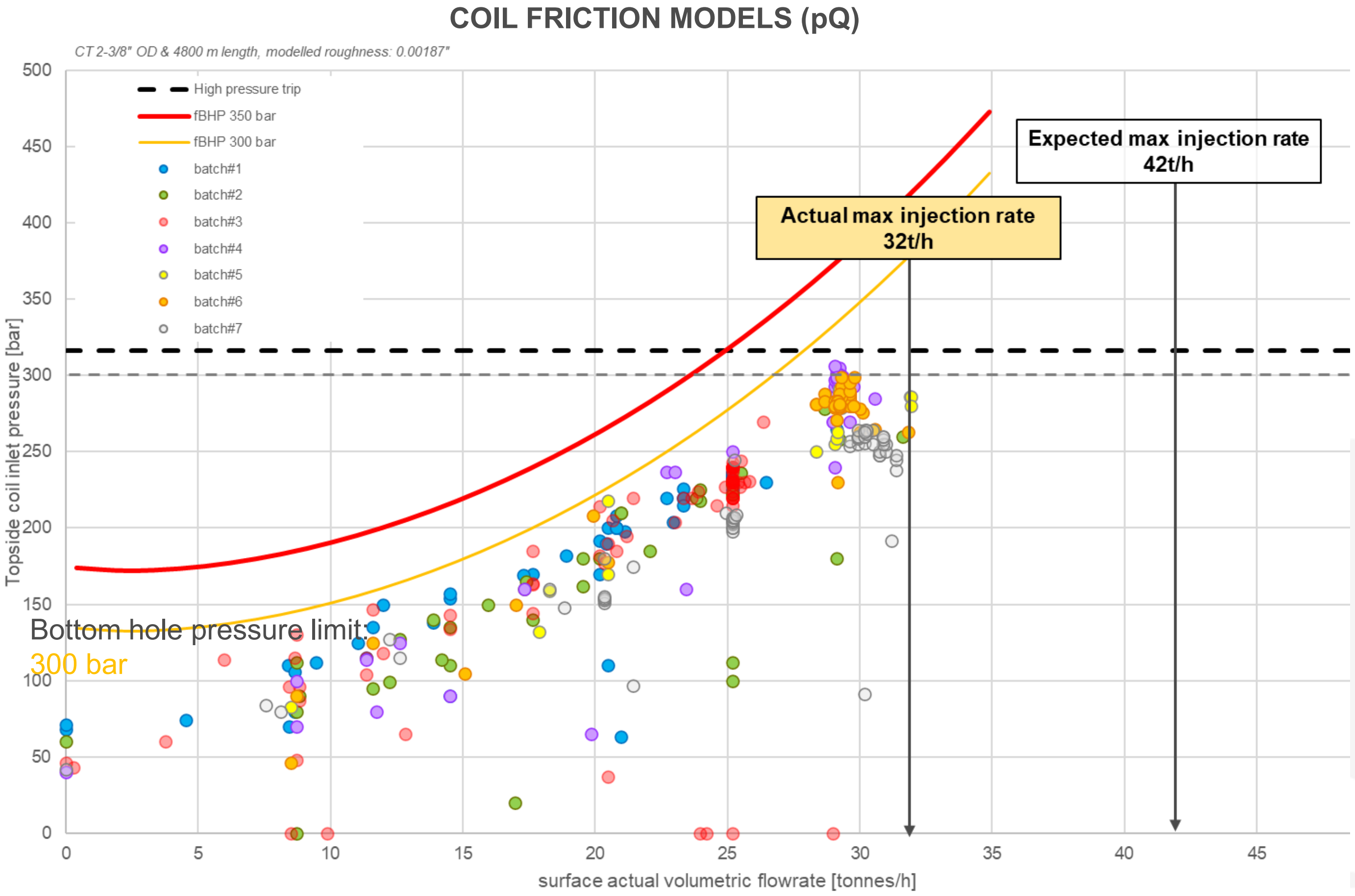
Pilot Data

- Coil friction calibration (water test) and BHP monitoring
- Injectivity monitoring
- Assess potential formation damage after CO_2 injection
- Fine tune reservoir and near wellbore model

Surface Injection Pressure – Operating Envelope

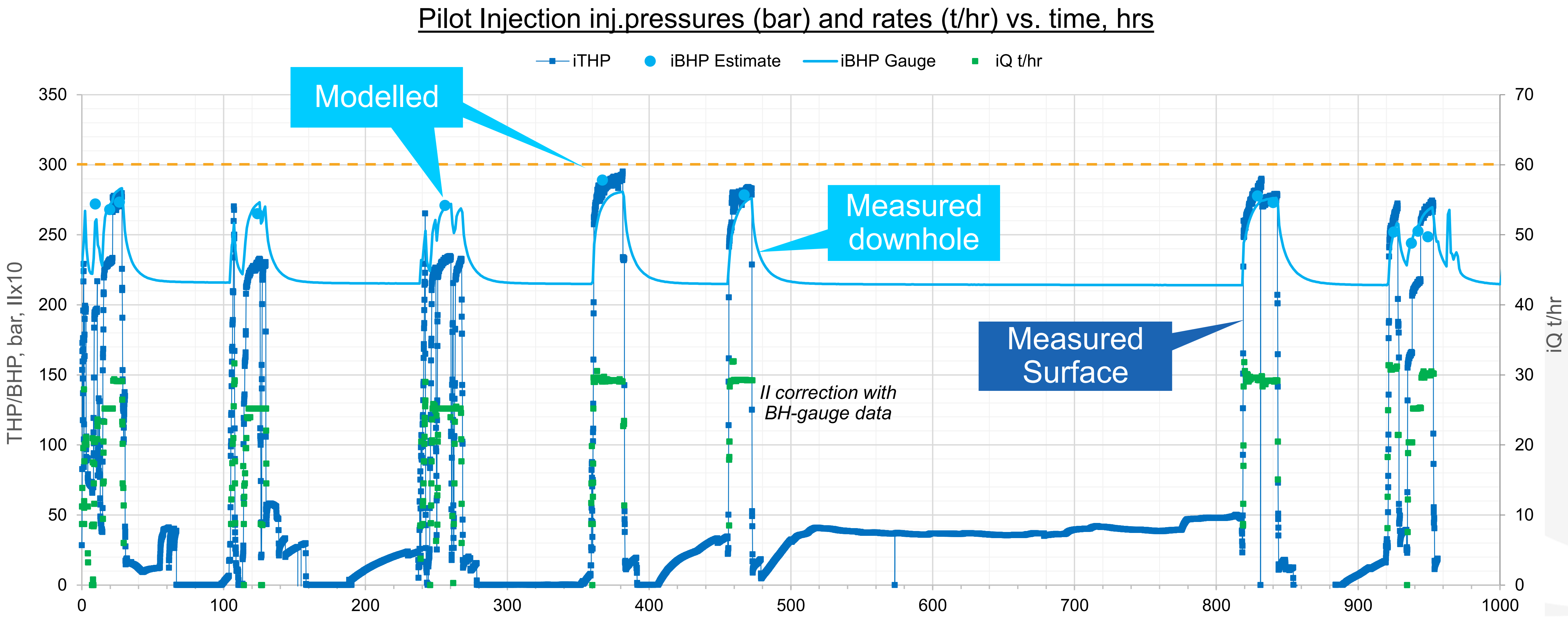
Translating surface pressure to bottom hole pressure

- Coil modelling performed to enable surface live data (pressure) to be translated to Bottom Hole Pressure
- Operating envelope for surface injection pressure defined in order not to compromise cap rock integrity
- Topside injection pressures and rates maintained below subsurface BHP limit at all times
- Excellent match between the estimated BHP and actual BHP (gauge) data **(next slide)** – confirmed robust pQ curve modelling and calibration



Reservoir injection pressures recorded by downhole gauge

BHP readings confirm BHP estimates from coil modelling



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Dynamic Modelling – History Match
Extensive Knowledge Database from Late Life Oil reservoir

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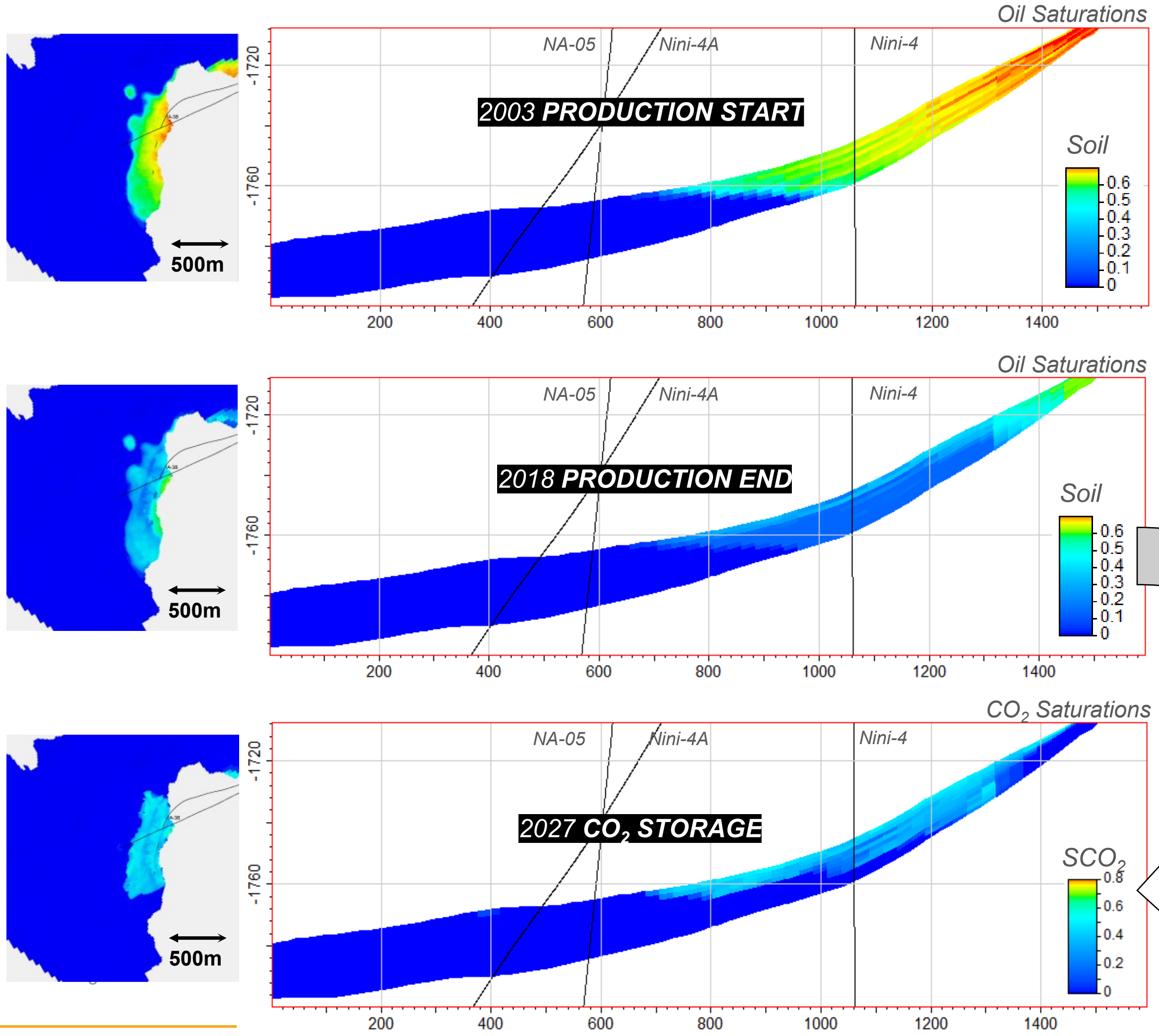
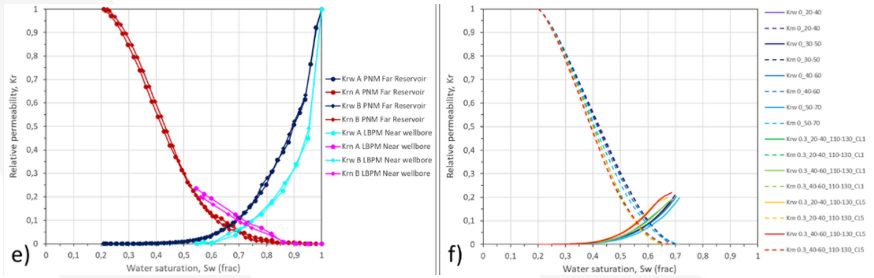
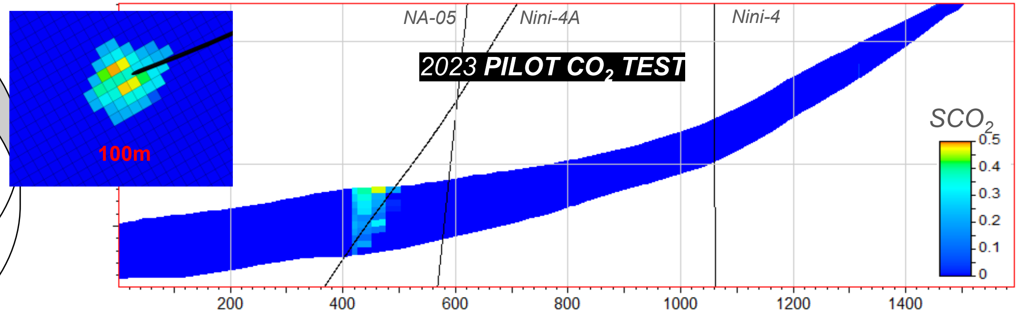




CO_2/brine relative permeability calibration



Post-injection modelling: CO2 plume within 100m radius around injection site

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Focused Seismic Monitoring (Spot Seismic)

Motivation and Concept

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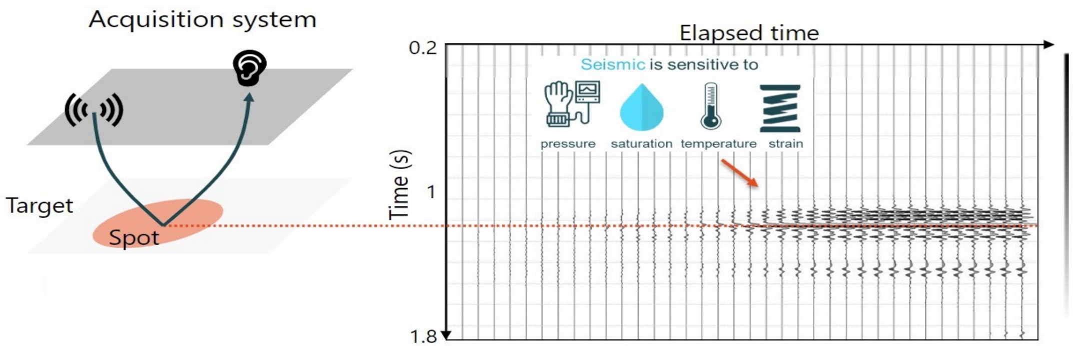
Challenges of CO_2 plume monitoring

- Conventional 4D seismic bears high cost and environmental impact, years between measurements
- Simulation models have intrinsic geological uncertainties
- No surprise wanted → Frequent subsurface monitoring needed
- Need to reduce environmental impact and cost
- Utilize on CO_2 generating a fast & strong seismic response



Optimal seismic antenna differences – Synthetic seismic 4D effect

Focused seismic concept

- Stacking reflected energy over trace and time. Repeatability and S/N ratio is key.
- Requires 3D seismic for full wave field analyses to find the ray pathes with highest S/N ratio.
- Simulation model shall predict where and when to focus the CO_2 plume measurement in key areas (Spots).
- More frequent & focused measurements can reduce uncertainties and increase accuracy of probabilistic fluid flow model over time (Predictive Maintenance Concept)
- By measuring absence or presence of CO_2 in single spots the plume front (speed) can be delineated and high-risk spots (e.g. entry point legacy wells) covered permanently

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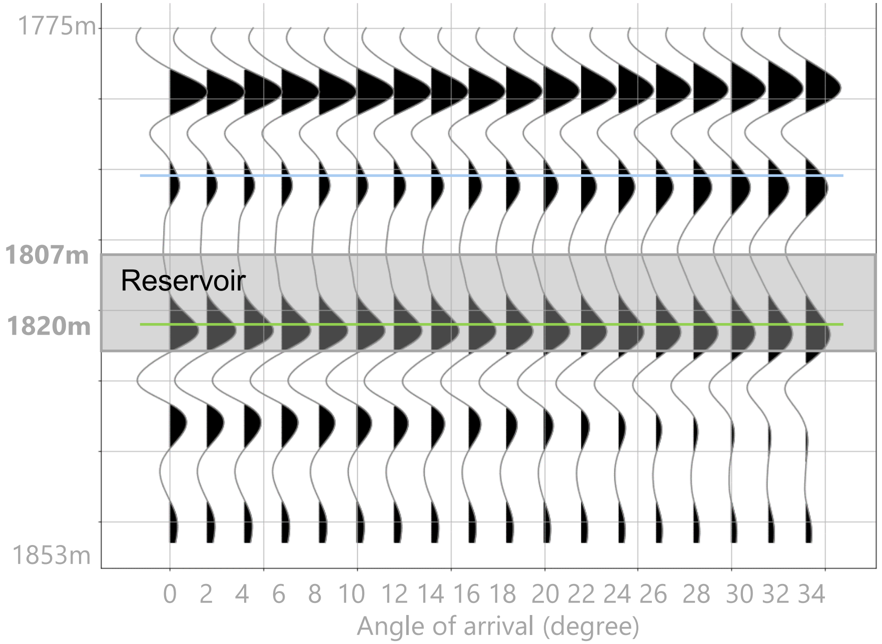
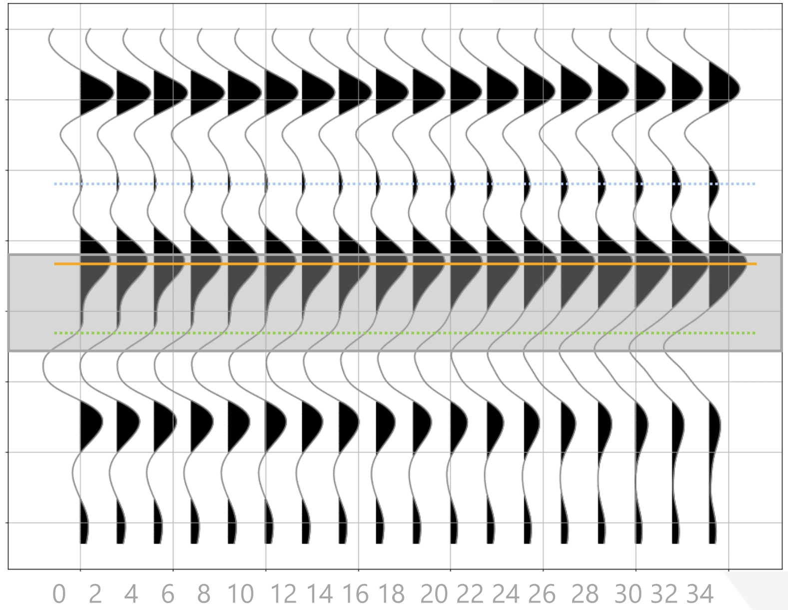
Spot Seismic Monitoring

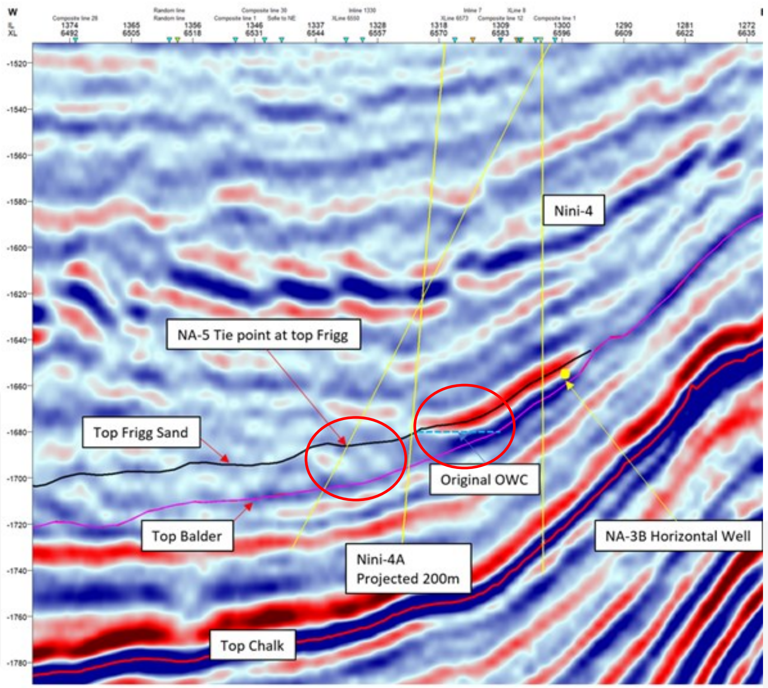
Fluid substitution modelling to assess CO_2 response



Synthetic AVA gather in water leg



Synthetic AVA gather in water leg with 1% CO_2 saturation



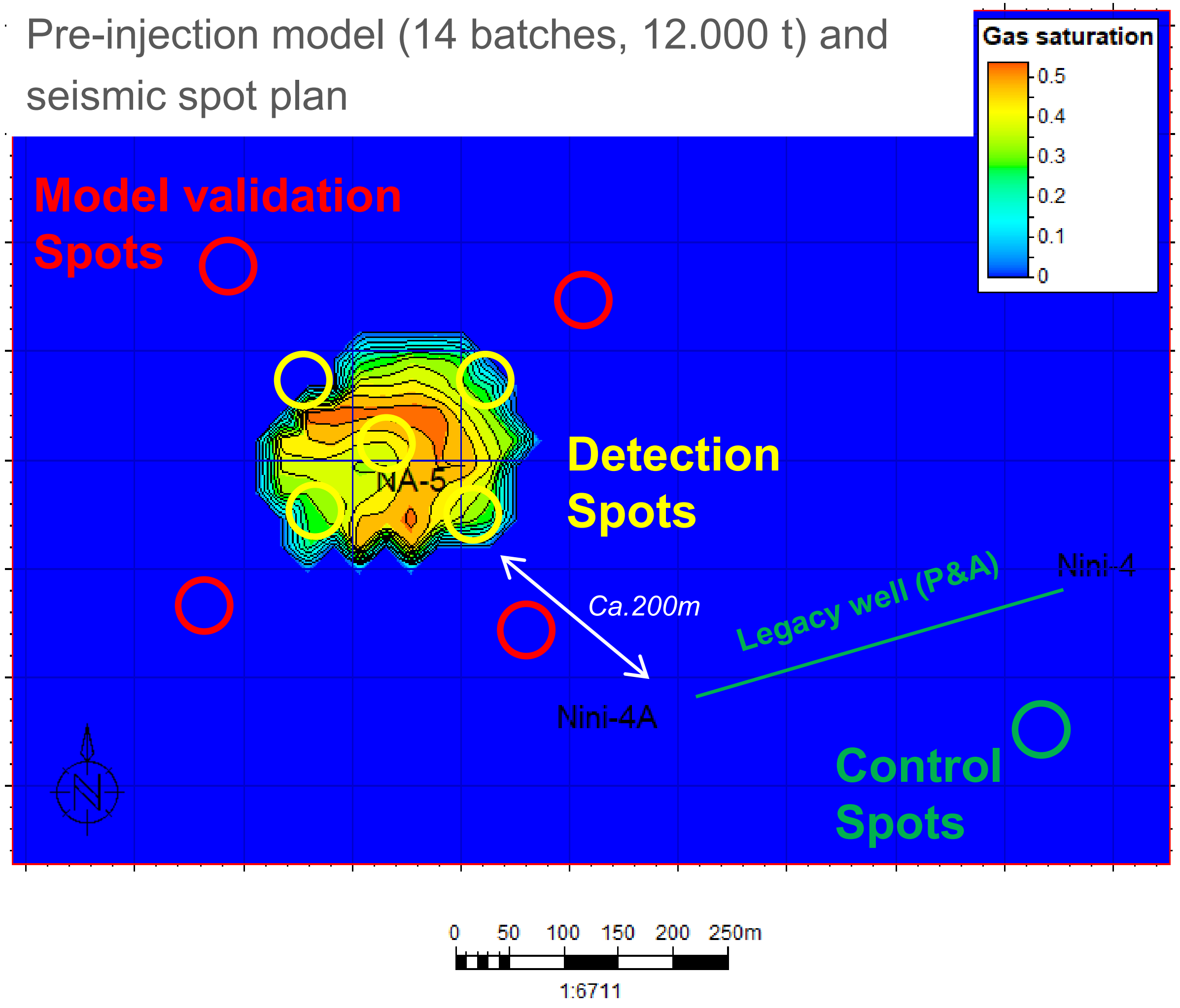
W-E seismic section through injection point

- Synthetics based on Density/Sonic from Nini-4a
- Full water saturation does not create any reflection on top reservoir (weak trough)
- Modelling implies: 1-2% CO_2 saturation in the water leg creates a reflection at top reservoir (strong peak),
- 3D vintage seismic shows a clear oil response in the oil leg in the reservoir.

CO2 Plume Monitoring by Spot Seismic

- Seismic spots placed geometrically around the injection point to cover entire plume.
- Detection Spots should confirm CO_2 presence.
- Model validation Spots should confirm absence of CO_2 according to simulation model during project time.
- Control Spots are measuring the noise level and repeatability out of reach of the plume.
- Spot diameter is approximately 40m.
- Detection threshold modelled to 2.000 t
- Realized Monitor#1 after c. 2000 t CO_2 injected, Realized Monitor#2 after c. 4100 t CO_2 injected
- CO_2 plume is much smaller than in the pre-injection modelled 14 shipments (10.500 t)

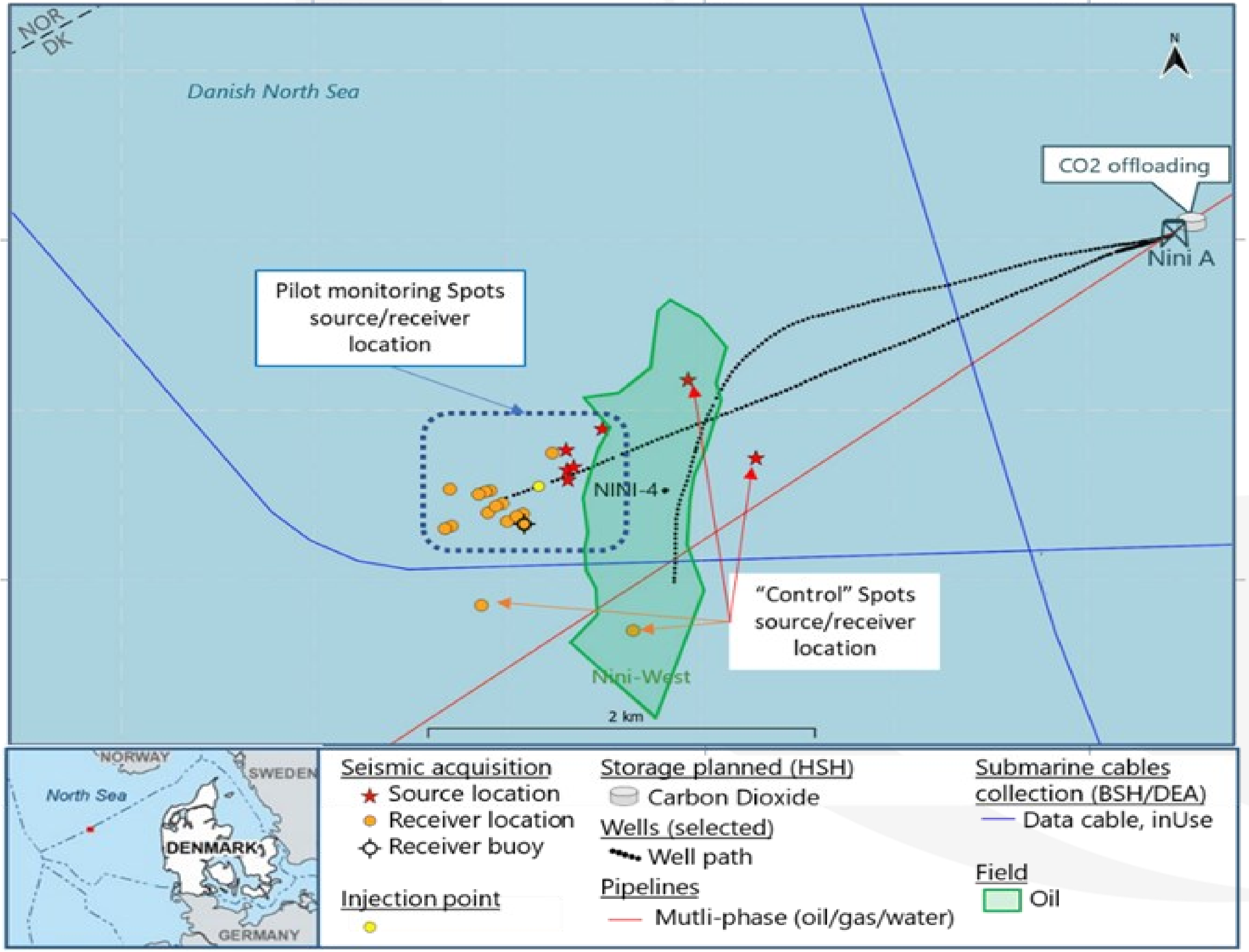
Pre-injection model (14 batches, 12.000 t) and seismic spot plan



Focused Seismic Survey

Key Objectives

- Demonstrate detectability of CO_2 by means of focused seismic,
- 1st offshore trial of static marine seismic acquisition. High accuracy of positioning required
- Low energy air gun (600 cu inch) selected
- 16 receiver -, 7 source locations planned. 80 shots planned per source location (c. 12 hrs shooting)
- Learn to acquire seismic from a platform supply vessel (ESVAGT INNOVATOR)
- Magseis Fairfield (TGS) MASS III nodes used



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Spot seismic CO_2 Plume Monitoring

Operational impact

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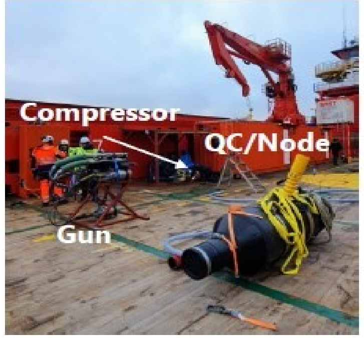
Key Learnings

- Safe operations / crane handling / ROV up to 2.5 m wave height.
- Agile setup, able to utilize <24h weather windows, enabling seismic acquisition in winter.
- Accurate positioning of source and receiver
- Significant reduction of emissions and operational time.
- PSV vessel used in combination with routine cargo runs provided synergies and further cost reduction (e.g. shared transit cost)
- No fisherman liaison representative needed (static acquisition)
- No issues with marine traffic

Comparison 4D vs focused seismic



	Full 4D (streamer baseline)		SpotLight (for 3 monitors)
Obstruction area	370 km²		12 km²
Duration	33 days	-83%	5 days
CO_2 emitted	4,500 tons	-91%	400 tons
Airgun size	3 600 Cui		600 Cui
Number of shots	60,000		3,780

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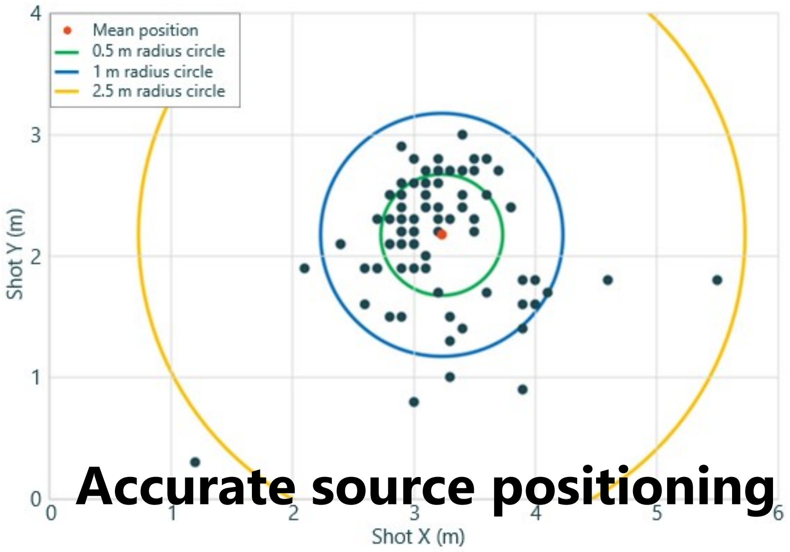
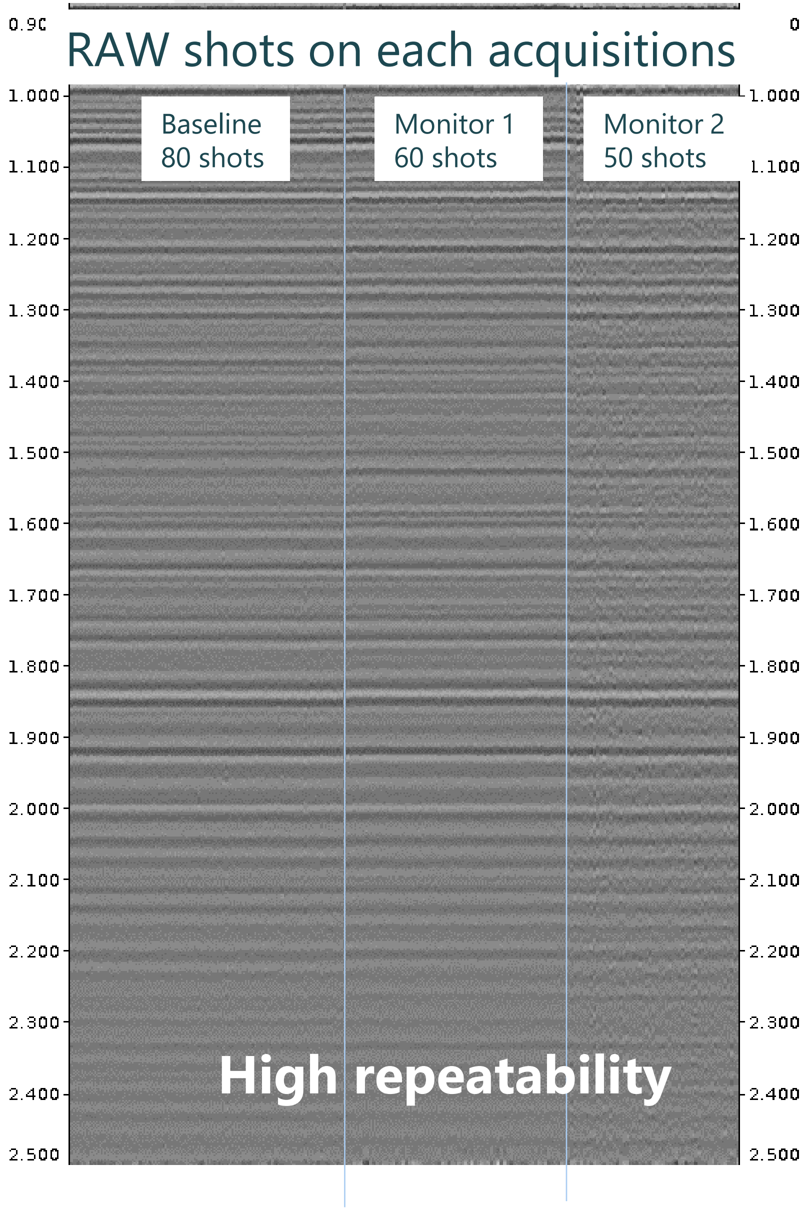
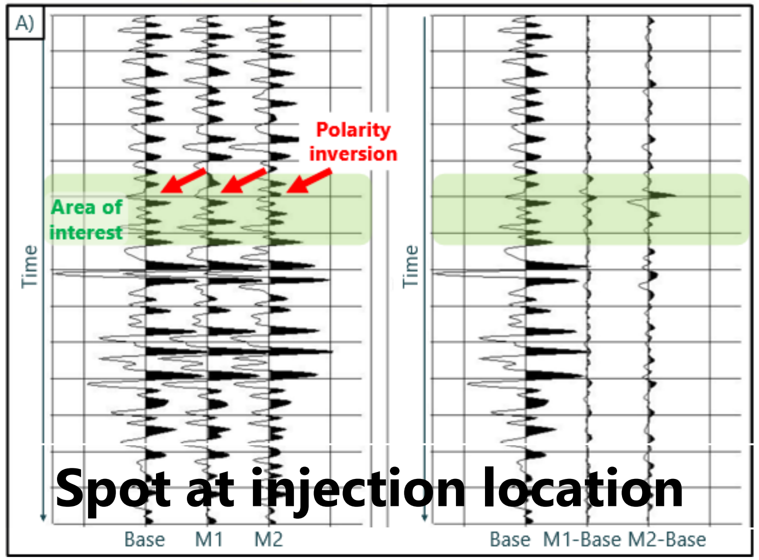
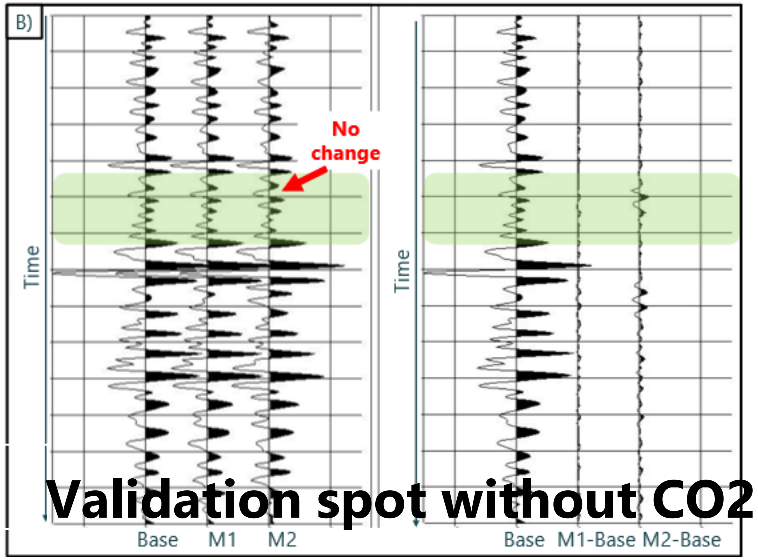
Raw Data Analyses

Stunning accuracy of positioning and repeatability of seismic traces resulting in very high S/N ratio.
CO_2 effect seen as polarity inversion at top reservoir and confirms fluid substitution model.









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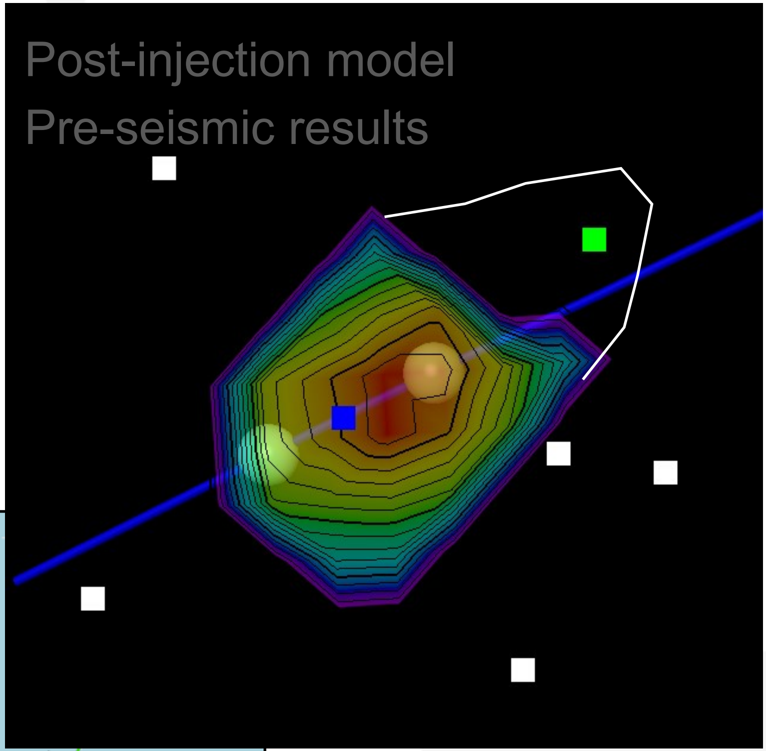
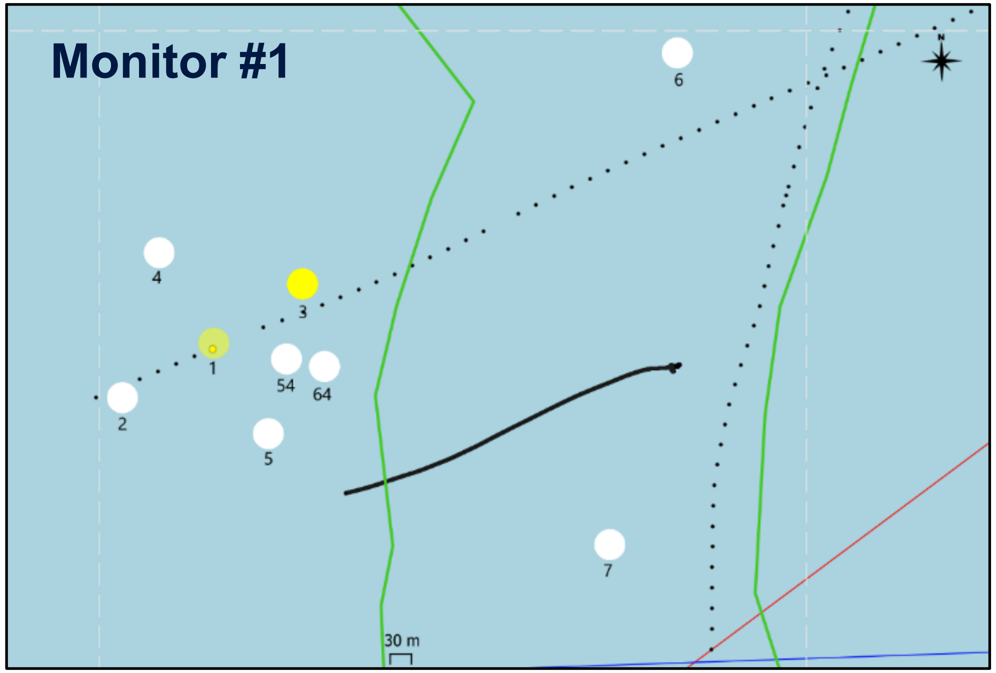
Spot Seismic Results

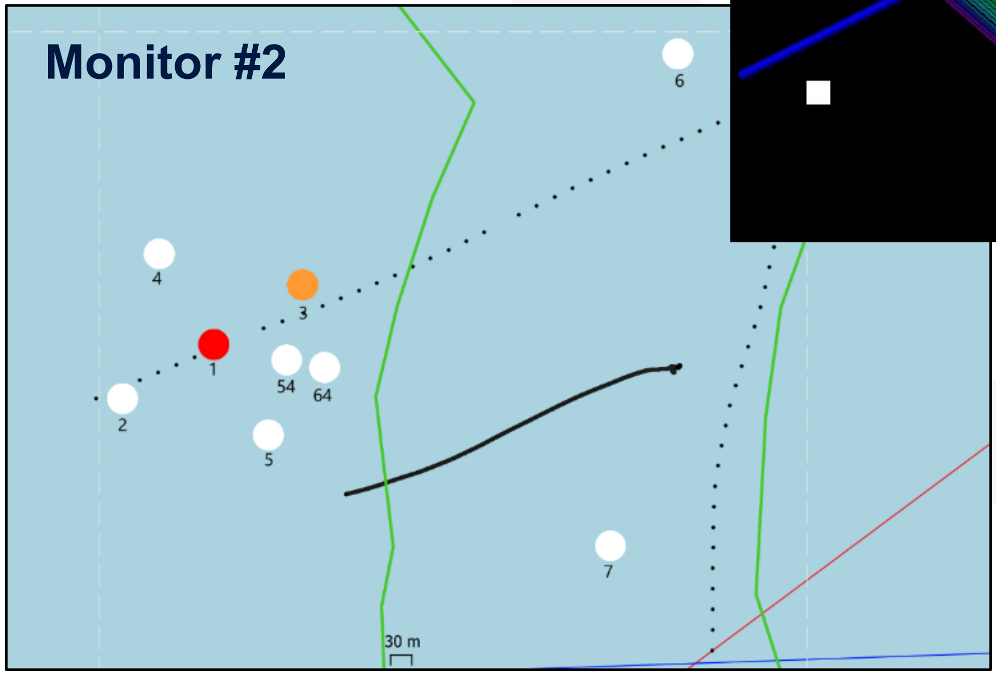
- Strong effect
- Medium effect
- Small effect
- No effect

We see the plume!
Good correlation to dynamic simulation

Predictive maintenance
CO_2 plume mainly at top reservoir, migrates updip
Re-calibration of plume modeling







Greensand Pilot Project – Conclusions

Subsurface observations

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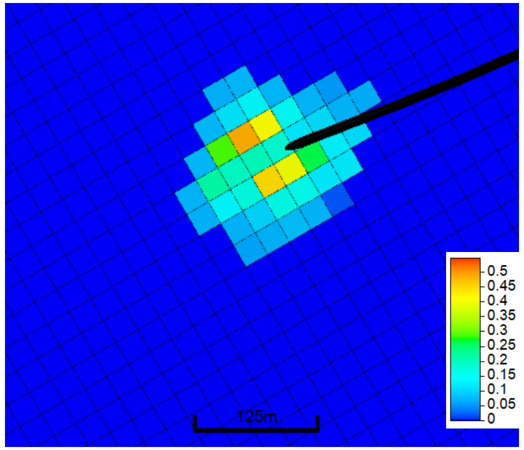
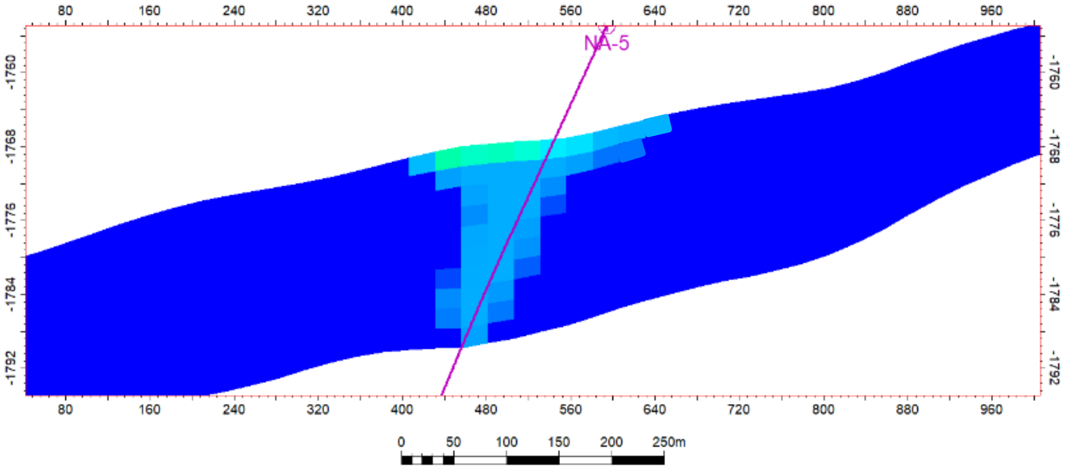
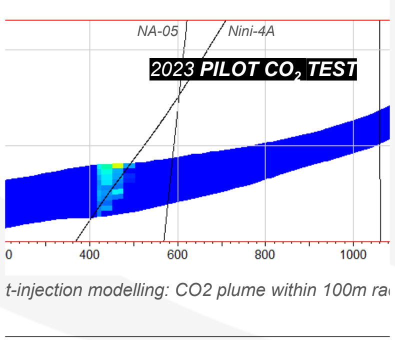
- Main Pilot objective achieved demonstrating full value chain
- No formation damage observed during pilot
- Injectivity performance stable throughout the 7 cycles
- CO_2 injectivity lower than expected, but within uncertainty range in the pre-injection modelling
- Spot seismic data confirms CO_2 detection and detection threshold. Predictive Maintenance concept confirmed







Post-injection modelling: CO2 plume within 100m radius around injection site, calibration with seismic data pending

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Acknowledgements / Thank You / Questions

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