Northern Lights

A European CO_2 transport and storage network

Evaluation of the CO_2 plume migration for the Northern Lights project

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Northern Lights – transport, injection and permanent storage of CO_2

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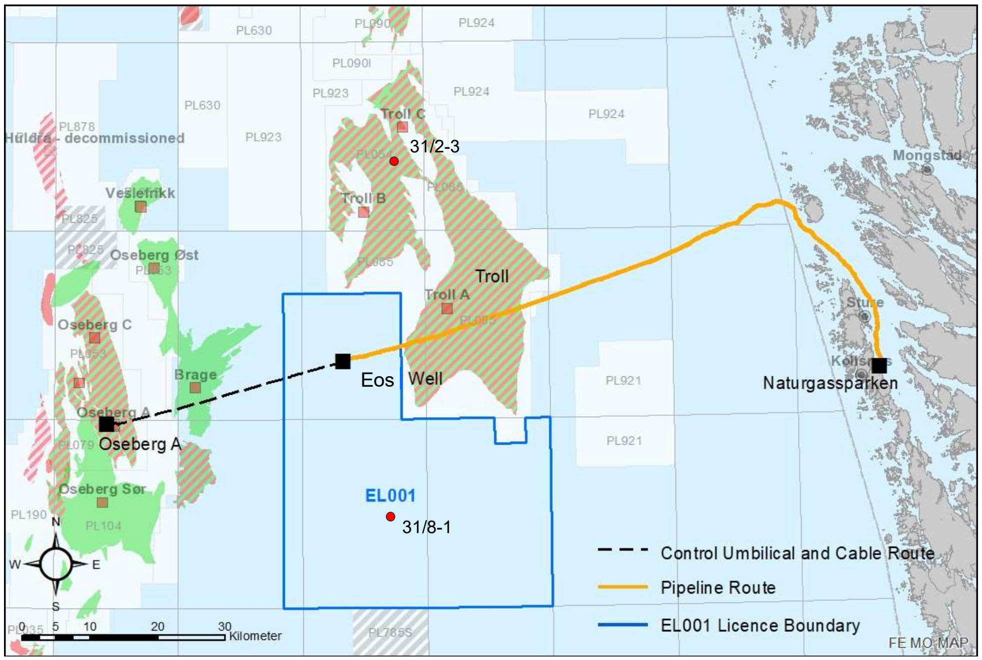
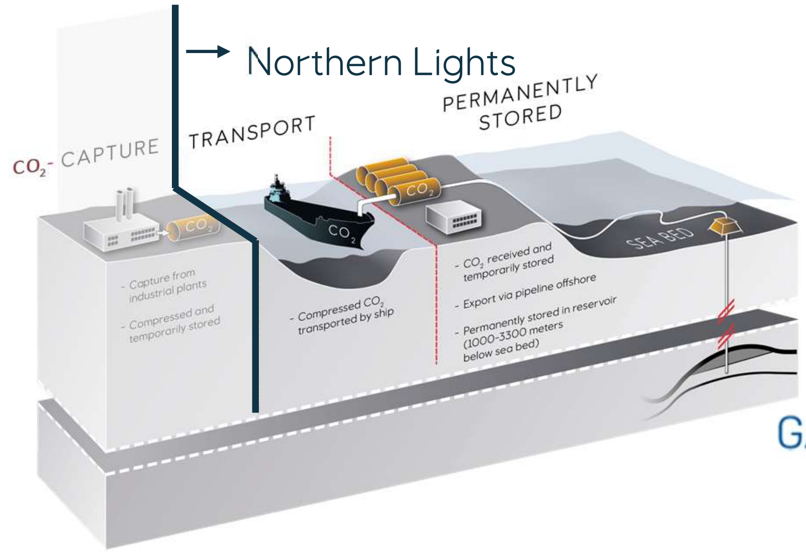


Volume ambitions and timeline are pre-set
Pre-investment for onshore storage location made



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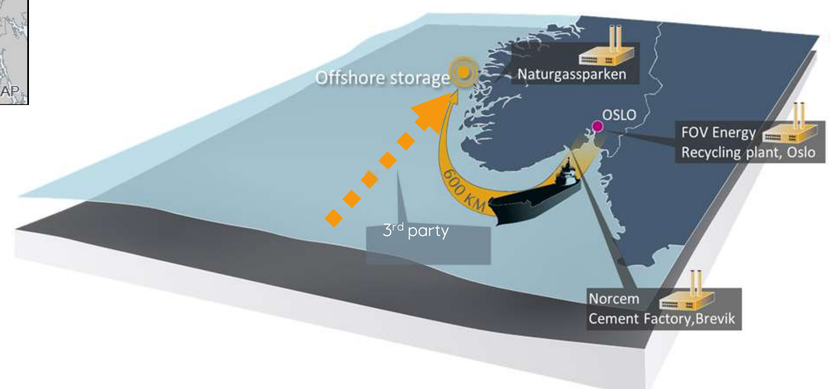

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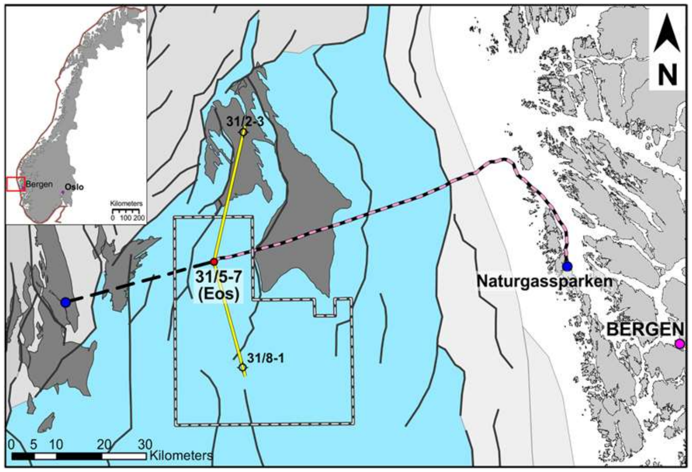
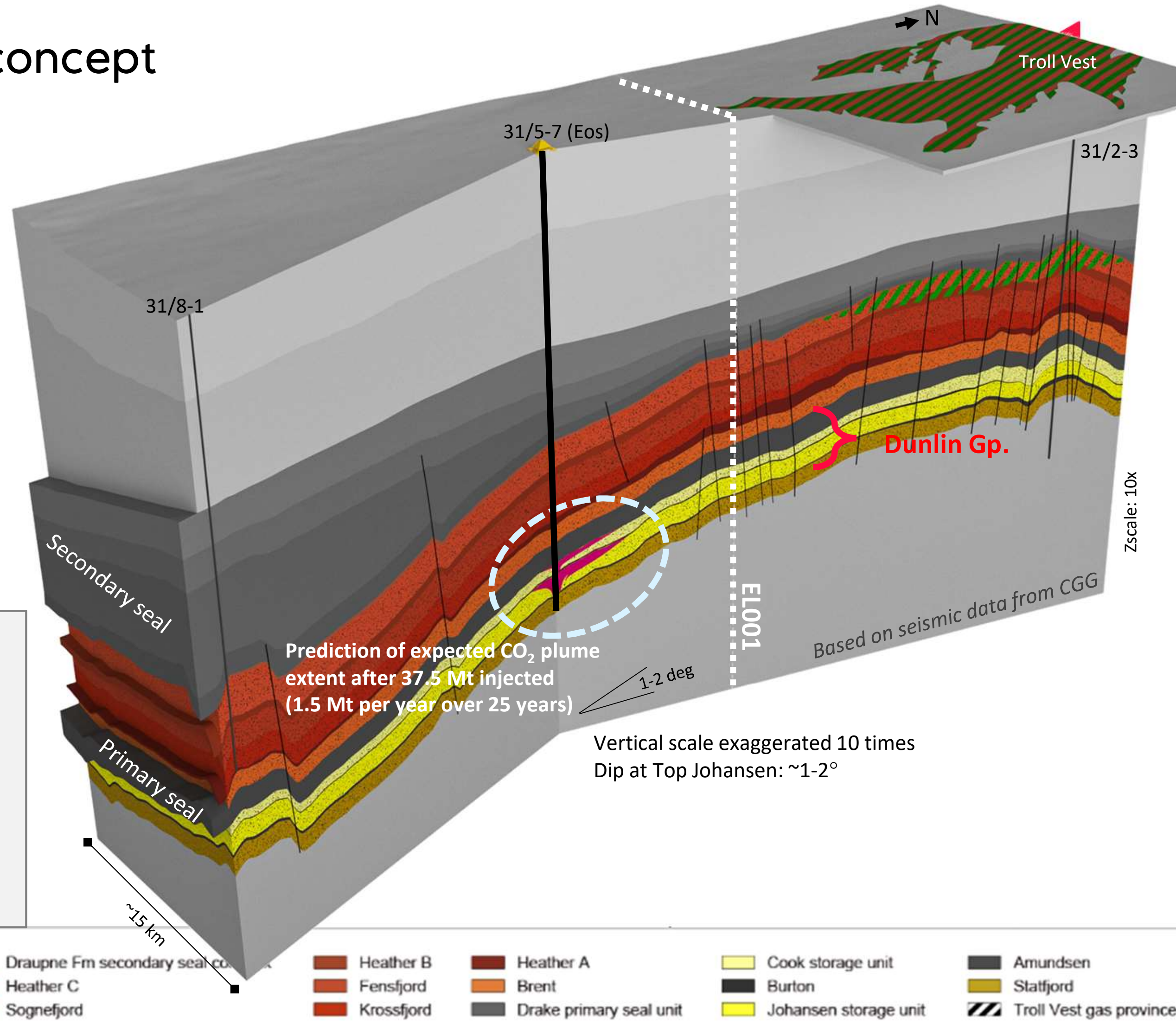
TOTAL

Northern Lights CO_2 storage concept



- CO_2 injection into dipping saline aquifer in the Lower Jurassic Dunlin Gp. sandstones in EL001
  → Drake Fm. is a primary seal
  → no stratigraphic trap within the EL001

- CO_2 will be trapped while migrating northwards (up-dip) within the Dunlin Gp.



Northern Lights – challenging project schedule

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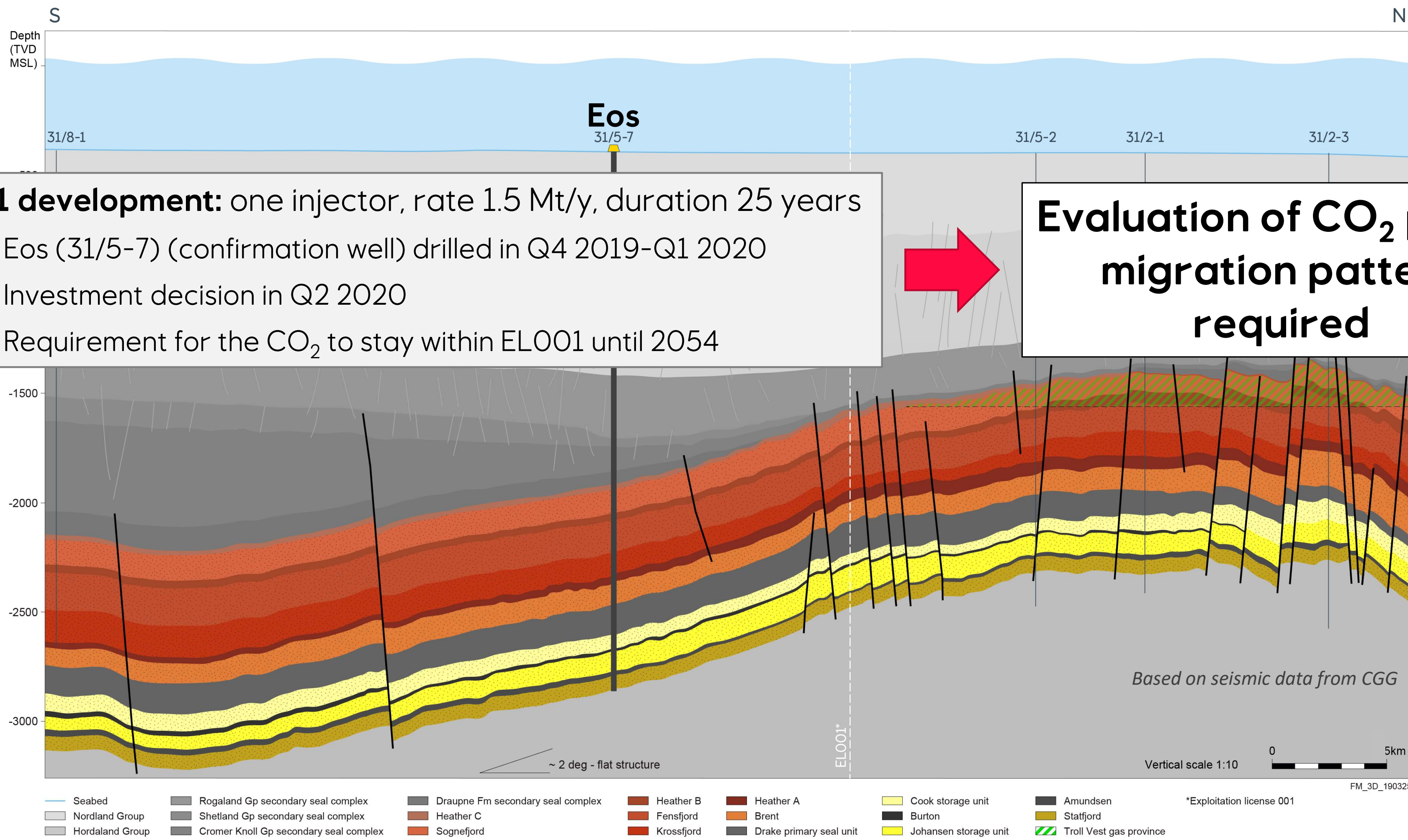
Phase 1 development: one injector, rate 1.5 Mt/y, duration 25 years

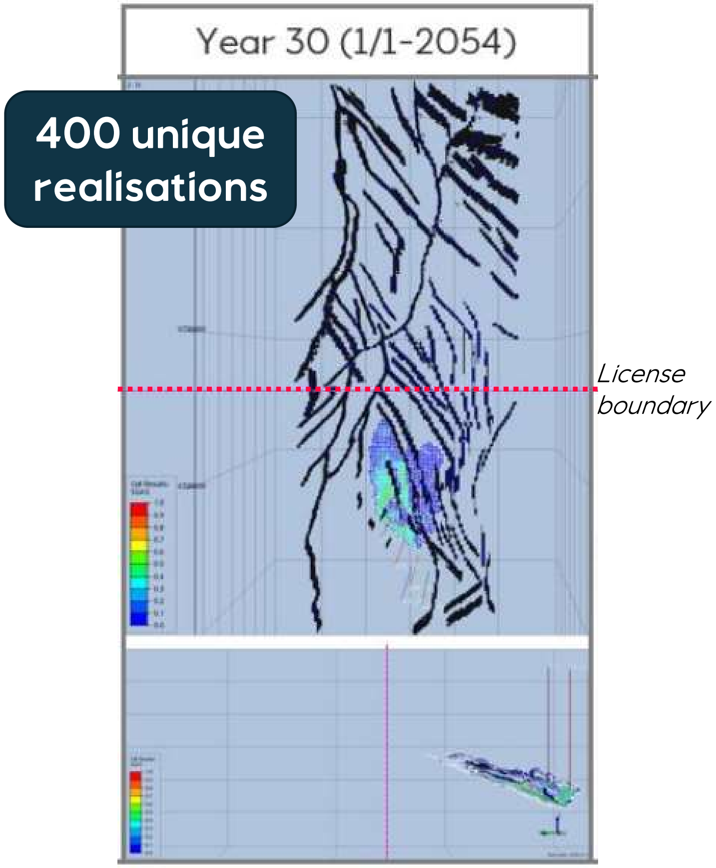
- Eos (31/5-7) (confirmation well) drilled in Q4 2019-Q1 2020
- Investment decision in Q2 2020
- Requirement for the CO_2 to stay within EL001 until 2054

Evaluation of CO_2 plume migration pattern required



Evaluation of the CO_2 migration and storage capacity

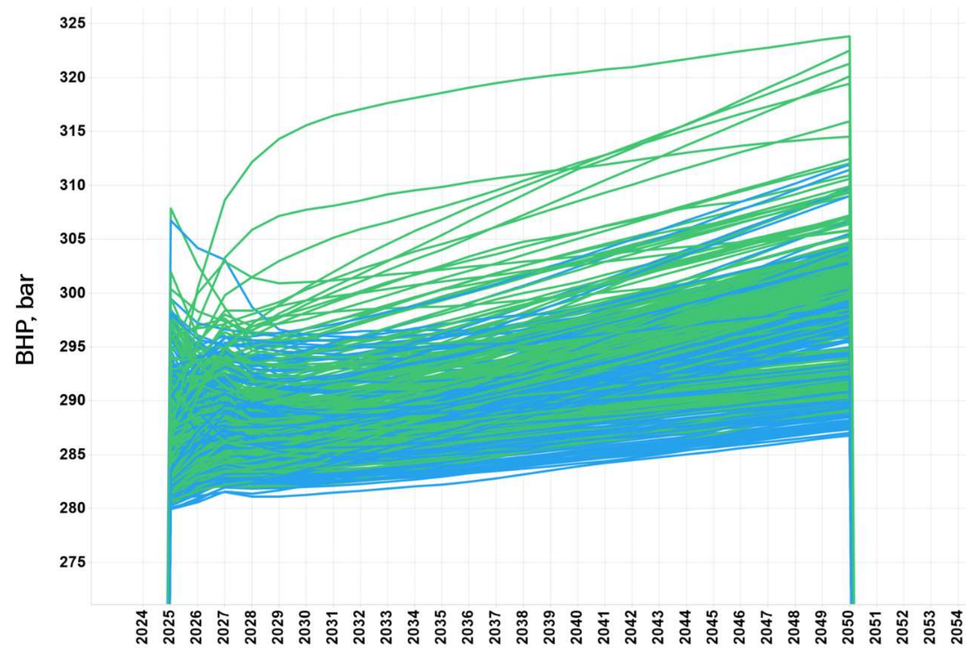
- Ensemble based approach that allows to perform the uncertainty study:
  - Static and dynamic uncertainty parameters included as input variables in the modelling workflow
    → a parameter could be a scalar, a vector, a map or a 3D grid property
  - Uncertainty parameters described by continuous or discrete probability distributions
  - Sampling from distributions using Monte Carlo method
    → generates an ensemble with multiple dynamic model realisations covering the uncertainty range
- Ensemble of 400 realisations run with Eclipse 300 software (CO2STORE module)



Example of CO_2 distribution in the reservoir in 2054; 1 of 400 realisations

Evaluation of the CO_2 migration and storage capacity

- Ensemble simulation output is used to calculate the statistics and to evaluate dynamic uncertainty study results with focus on:
  - CO_2 migration versus time
    → amount of CO_2 crossing the licence boundary after 30 years from start of injection
  - Total injected CO_2 volumes
    → storage and injection capacity vs. injection pressure



Example of results output from an ensemble of 400 realisations

Evaluation of the CO_2 migration risk and storage capacity

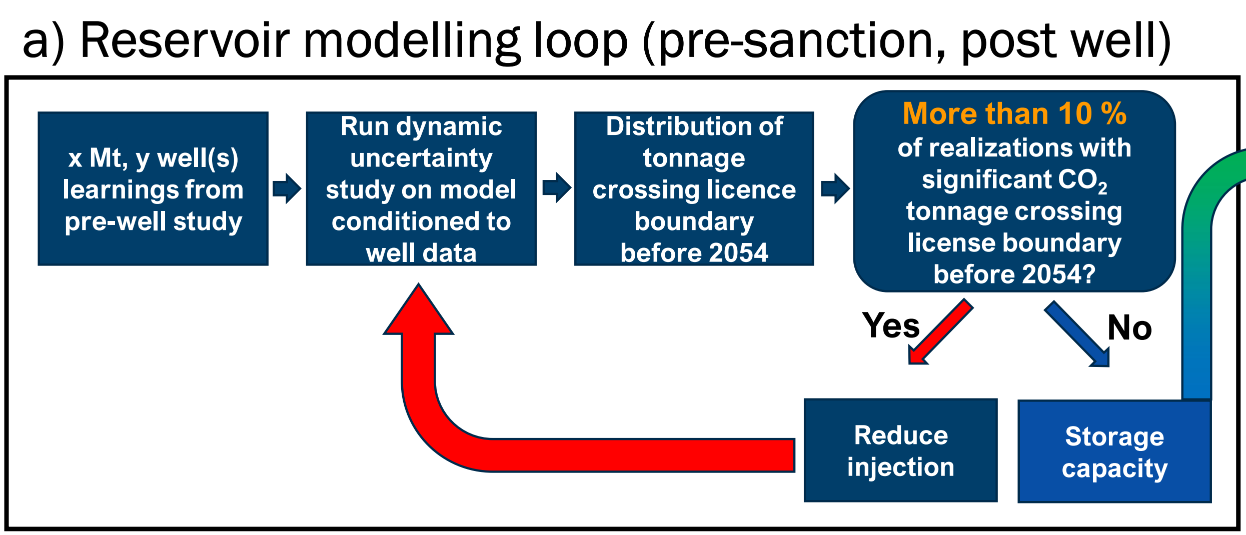
Storage capacity is an amount of CO_2 that can be stored within the planned development (no extra capex)

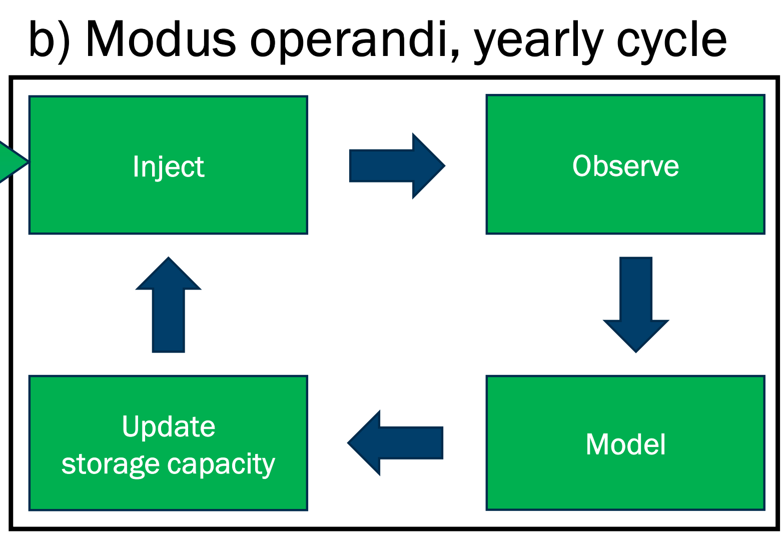
- ✓ Chance of crossing license boundary

  no 3rd party migration exposure ➔ CO_2 stays within defined storage complex

- ✓ Chance of reservoir pressurisation

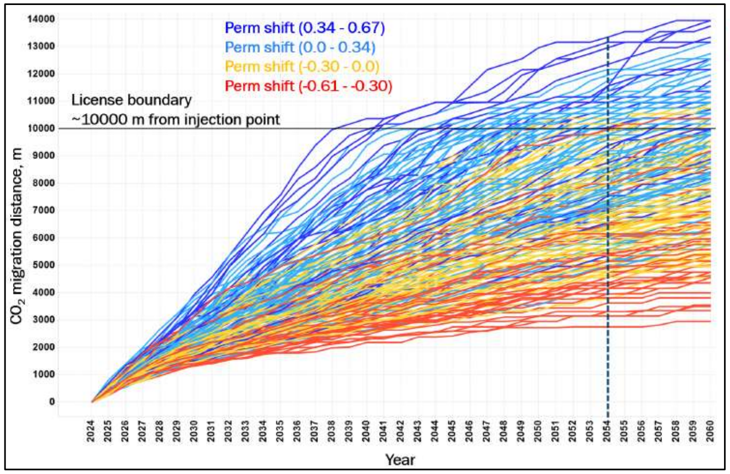
  integrity of the caprock cannot be compromised ➔ injection capacity restricted by maximal allowed reservoir pressure



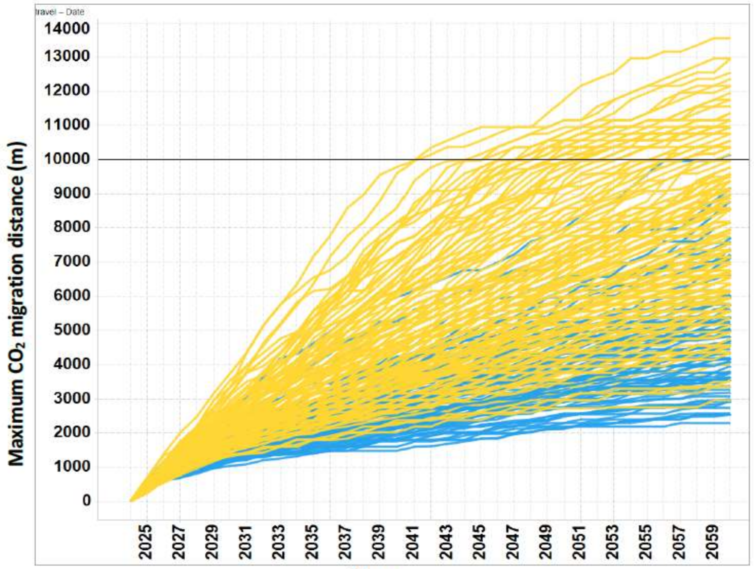


Results of the study

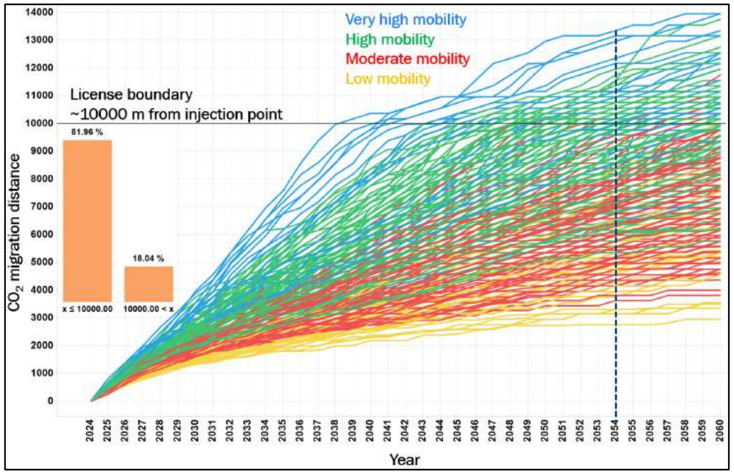
- Results from the reservoir modelling indicate impact of the following parameters on CO_2 plume migration:
  - ➢ reservoir permeability
  - ➢ relative permeability model (CO_2 mobility)
  - ➢ vertical barriers



Effect of reservoir permeability on CO_2 migration distance: high permeability (blue) vs. low permeability (yellow and red)



Effect of vertical barrier on CO_2 migration distance: limited barrier (yellow) vs. extended barrier (blue)



Effect of relative permeability on CO_2 migration distance: high mobility CO_2 (blue and green) vs. low mobility (red and yellow)

Results of the study

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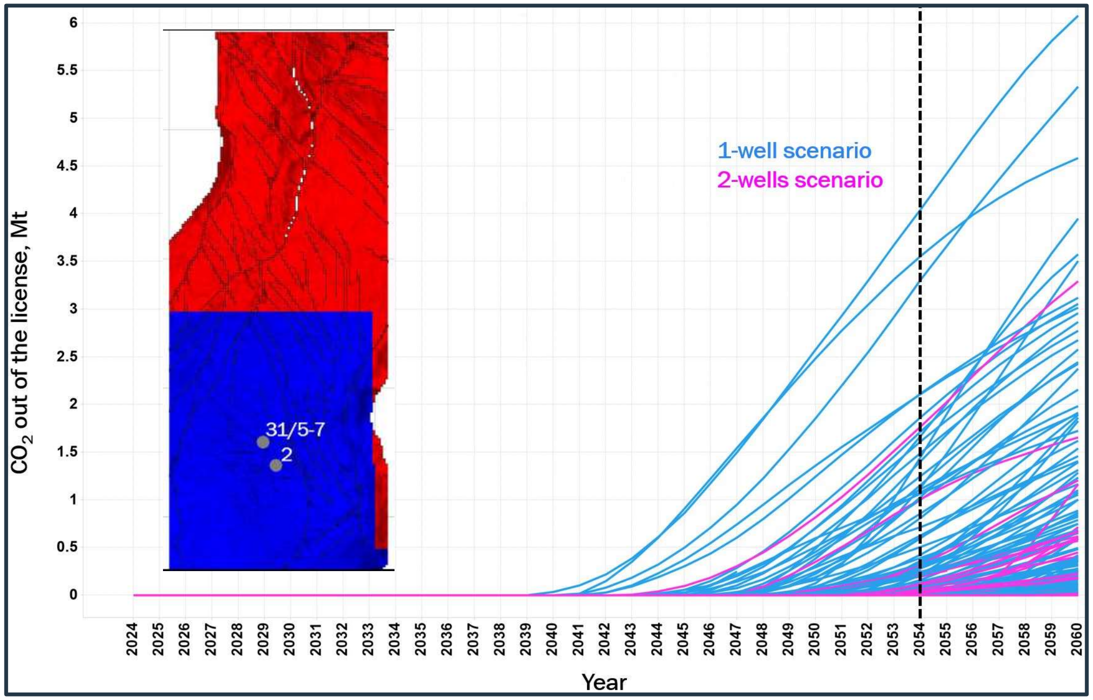
- Phase 1 development:
  - injection rate 1.5 Mt/y, duration 25 years

% of realisations fulfilling criteria (probabilistic approach, 400 realisations)		
Criteria / Scenario	0% of injected CO_2 outside licence by 2054	<1% of injected CO_2 outside licence by 2054
1 well	81 %	93 %
2 wells	94 %	99 %

- Mitigation strategy:
  - Containment and conformance monitoring
  - Contingent well → can mitigate both injectivity issues and migration



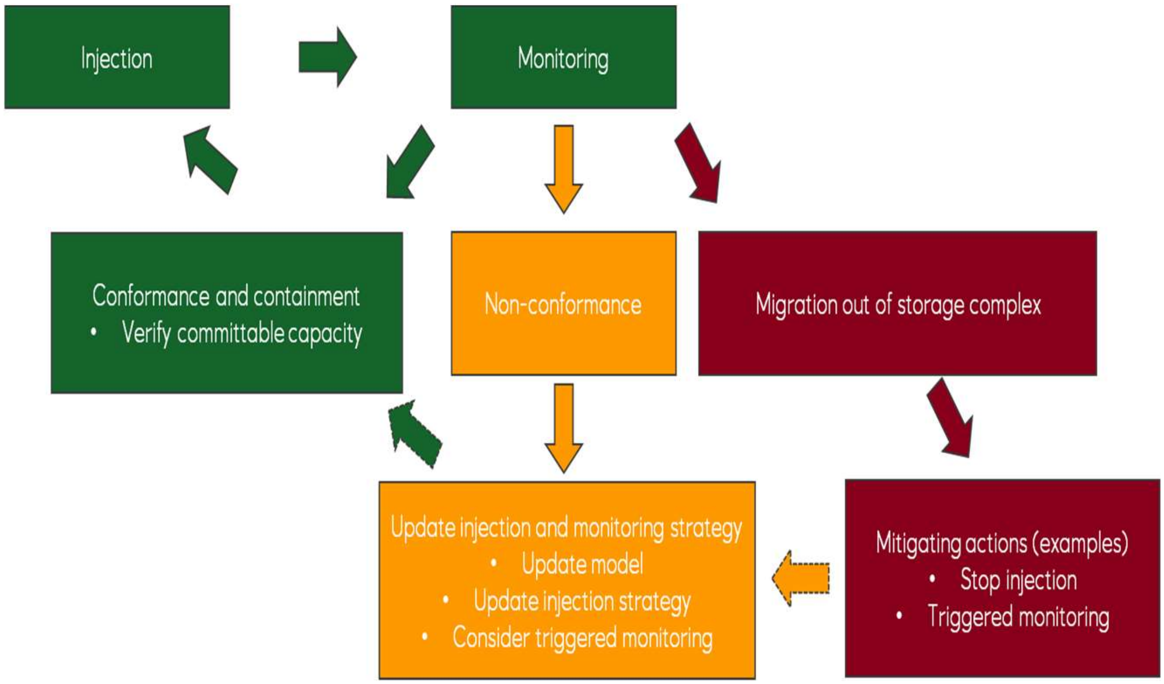
Mass (Mt) of CO_2 out of the license by 2054: one vs. two injection wells

Containment and conformance monitoring

- Monitoring plan
  → in-well monitoring of pore pressure and temperature, and seismic (active and passive) monitoring

- Repeated seismic surveys will be used for containment and conformance monitoring
  - Containment → retention of CO_2 within the storage complex
  - Conformance → CO_2 plume behaviour according to expectations/model prediction

- Non-conformance or non-containment might trigger modifications to the injection programme
  - updating well injection rates and/or injection intervals,
  - moving injection locations or
  - stopping injection in the present location



Summary and conclusions

- The Northern Lights project is expected to come on stream in 2024
- The very tip of the CO_2 plume will migrate northwards, across the current license boundary, and will be sequestered deep below the Troll field
- Current storage capacity is defined by the project as an amount of CO_2 that can be injected and will not migrate across the license boundary within minimum 30 years
- A reservoir modelling workflow allowed to evaluate reservoir uncertainties within a compressed timeframe between drilling the exploration well and the project investment decision
- Study results show that project's Phase 1 development ambition of injecting 1.5 Mt/y in 25 years and CO_2 not crossing the license boundary within 30 years is achievable
- Results indicate that reservoir permeability, relative permeability model and reservoir flow barriers have the strongest impact on CO_2 migration pattern
- The reservoir monitoring plan will allow the estimation of CO_2 migration velocity from 4D seismic surveys
- In line with regulatory requirements, a mitigation strategy has been developed to address the unlikely scenario of non-conformance or non-containment of CO_2

Northern Lights

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Open