The Northern Lights: How we built a robust monitoring and response plan

Phase 1 monitoring plan

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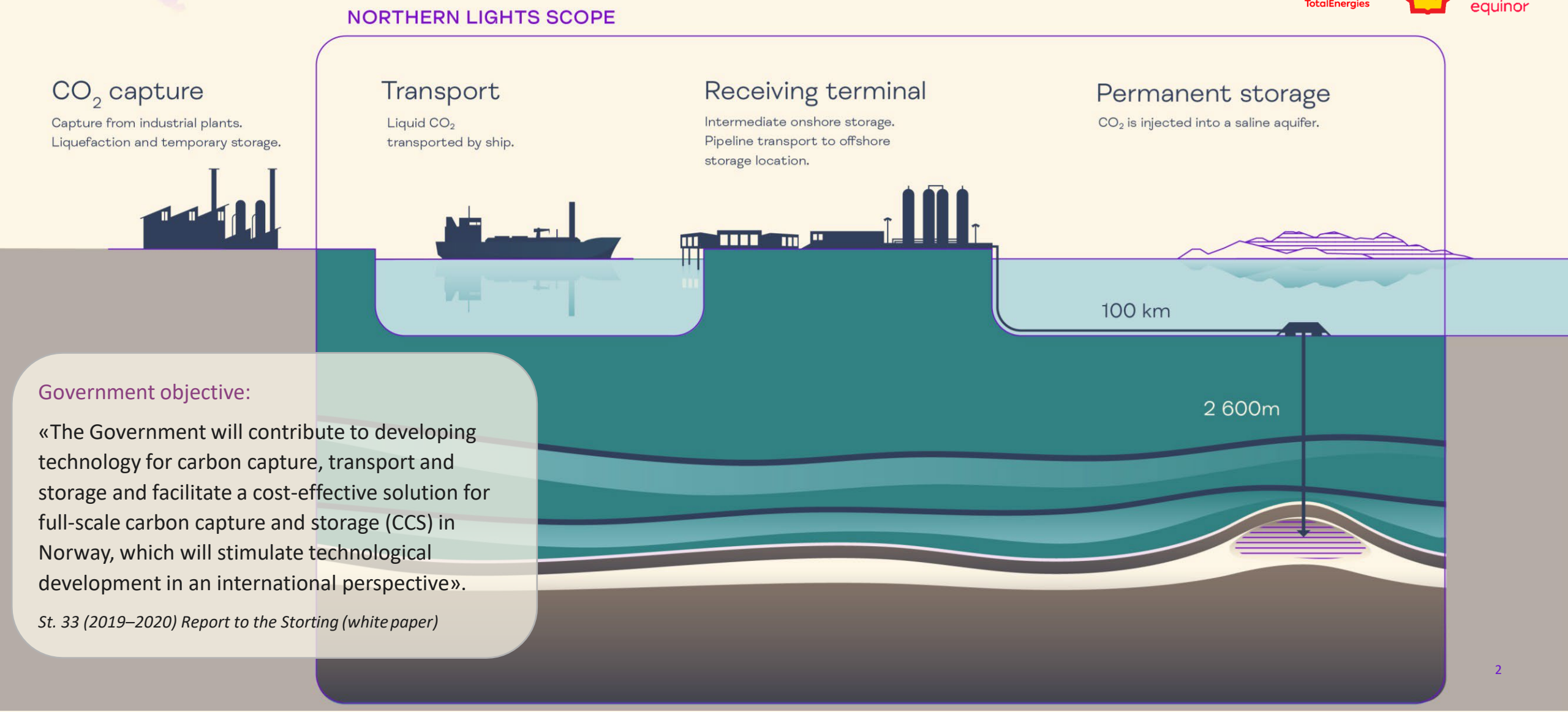
Northern Lights JV: A CO_2 transport and storage company

Northern Lights

TotalEnergies equinor



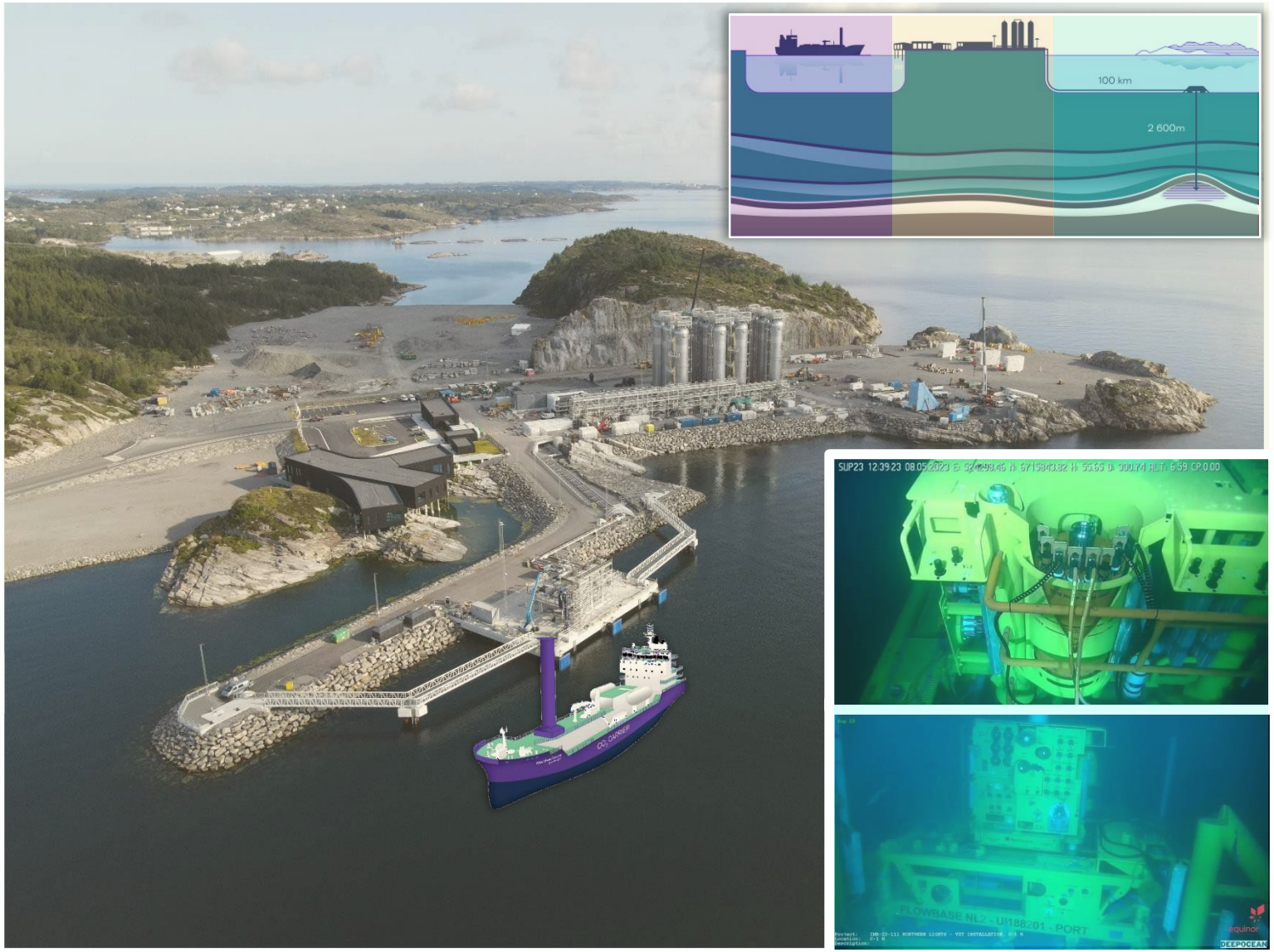
Government objective:

«The Government will contribute to developing technology for carbon capture, transport and storage and facilitate a cost-effective solution for full-scale carbon capture and storage (CCS) in Norway, which will stimulate technological development in an international perspective».

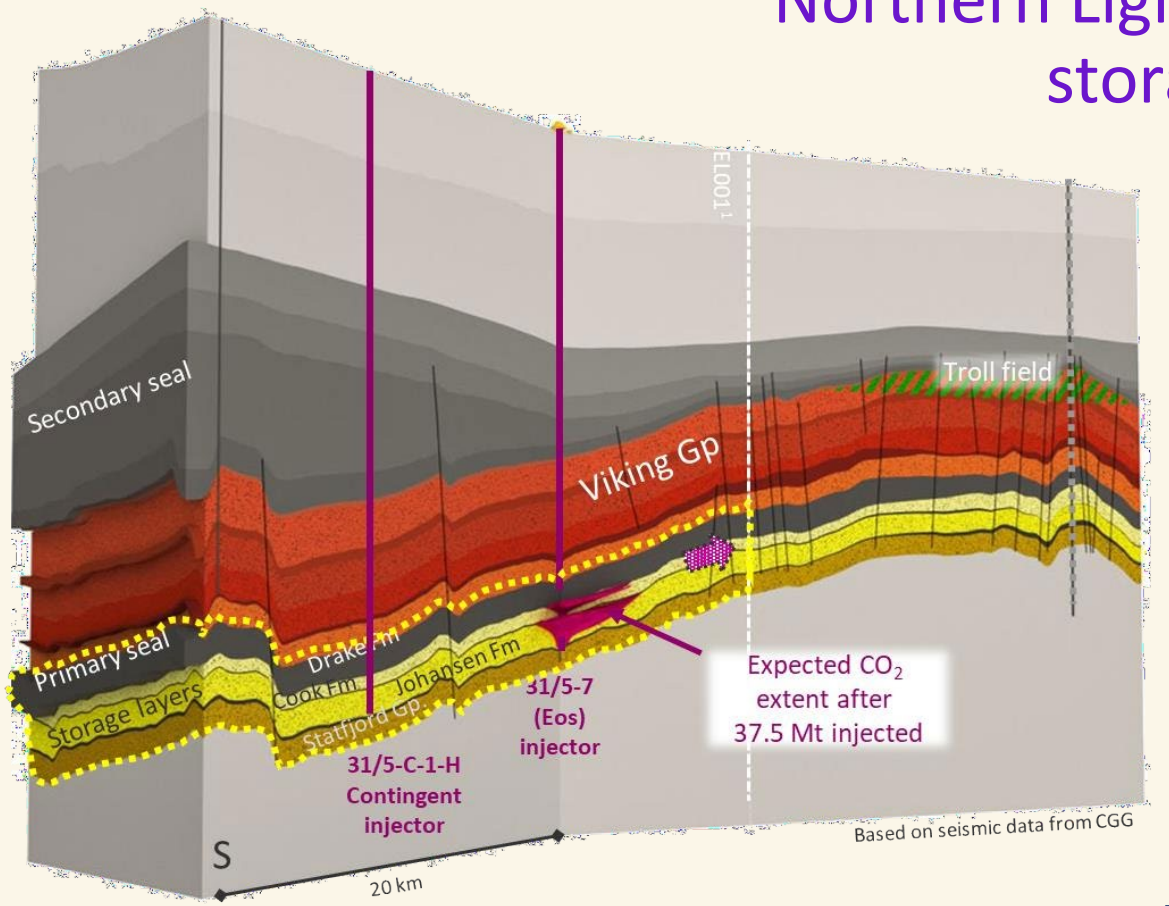
St. 33 (2019–2020) Report to the Storting (white paper)

An offshore CO_2 storage project becoming reality

Northern Lights

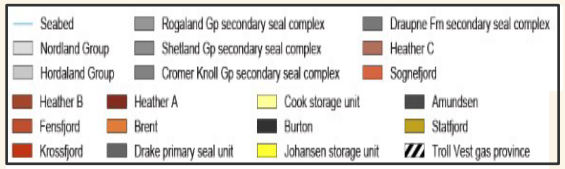


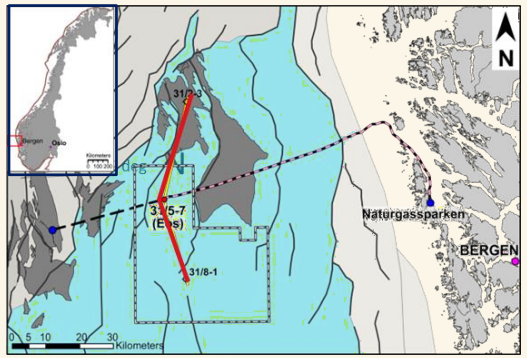
Northern Lights storage complex & storage site: Aurora



Aurora in a nutshell

- → 100 km offshore, 2 700 m deep
- → Semi-open (saline) aquifer
- → Primary "storage units": Cook & Johansen Fms.- Shallow marine Jurassic sands, pre-rift.
- → Secondary "storage unit": Statfjord Fm- Fluvial Triassic sands
- → Primary seal: Thick package of deepwater, organic rich, shales
- → Secondary seal: Base of Cretaceous Unconformity (BCU) (Troll field seal)





Aurora storage (Phase 1):

- → Storage Capacity: 37.5 Mt CO_2 (injection capacity)
- → Injection rates: 1.5 Mt/y
- → 25 years

Northern Lights: Why do we monitor?

Risk Mitigation

CCS Directive of the European Parliament specify these as reasons for monitoring

- Safe injection, no leakages
- Detecting migration of CO_2
- Detecting irregularities
- Compare actual and modelled behavior
- See the effect of corrective measures
- Prepare for hand-over criteria

European Commission

Climate Action

Monitoring is required by authorities

Monitoring mitigates NL Risk profile

- CO_2 out of the storage complex is defined as "leakage"
- The storage complex is bounded by the NL license border
- Troll Field lies North of the NL license
- **Troll Field EoFL = 2054:** No significant amounts of CO_2 injected can cross license boundary before 2054

→ **Risks have been identified and studied through the work program both pre, and post, FID/PDO**

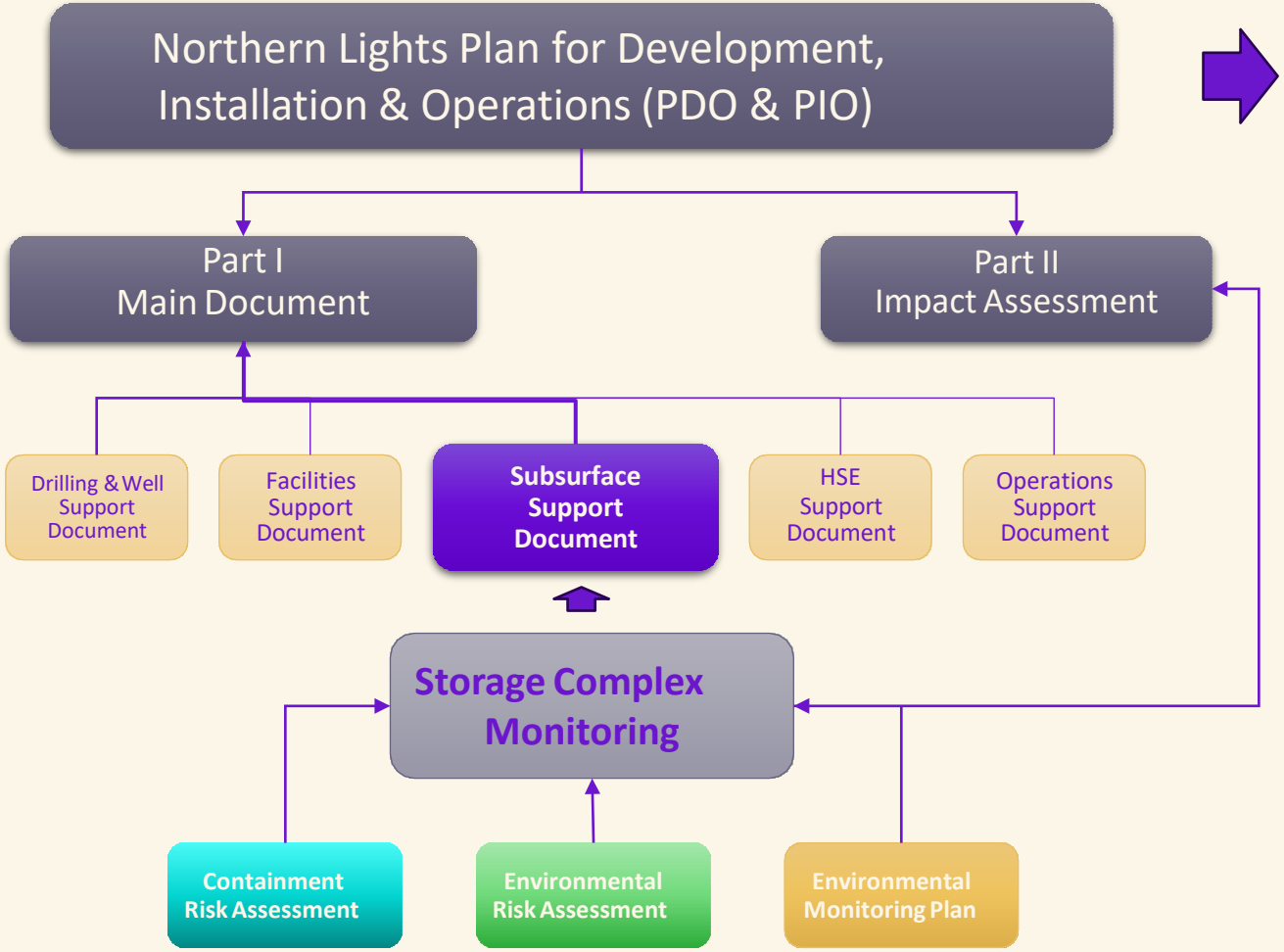
- → Containment risks
- → Storage capacity
- → Operational risks

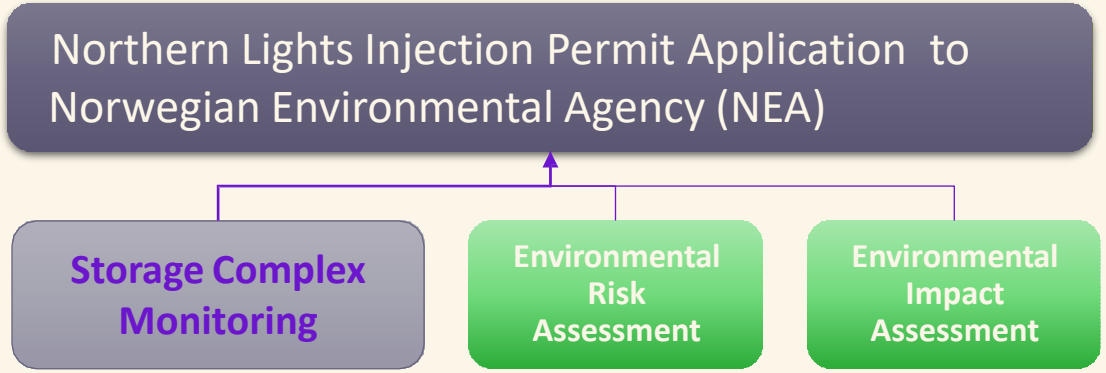
→ **Remaining risks must be handled through a robust monitoring program and response plan**

- → Operational procedures, constraints
- → In-well monitoring
- → Seismic monitoring program

Northern Lights: Why do we monitor?

Norway's regulatory framework





→ **Even though a project is approved for developments, it still needs:**

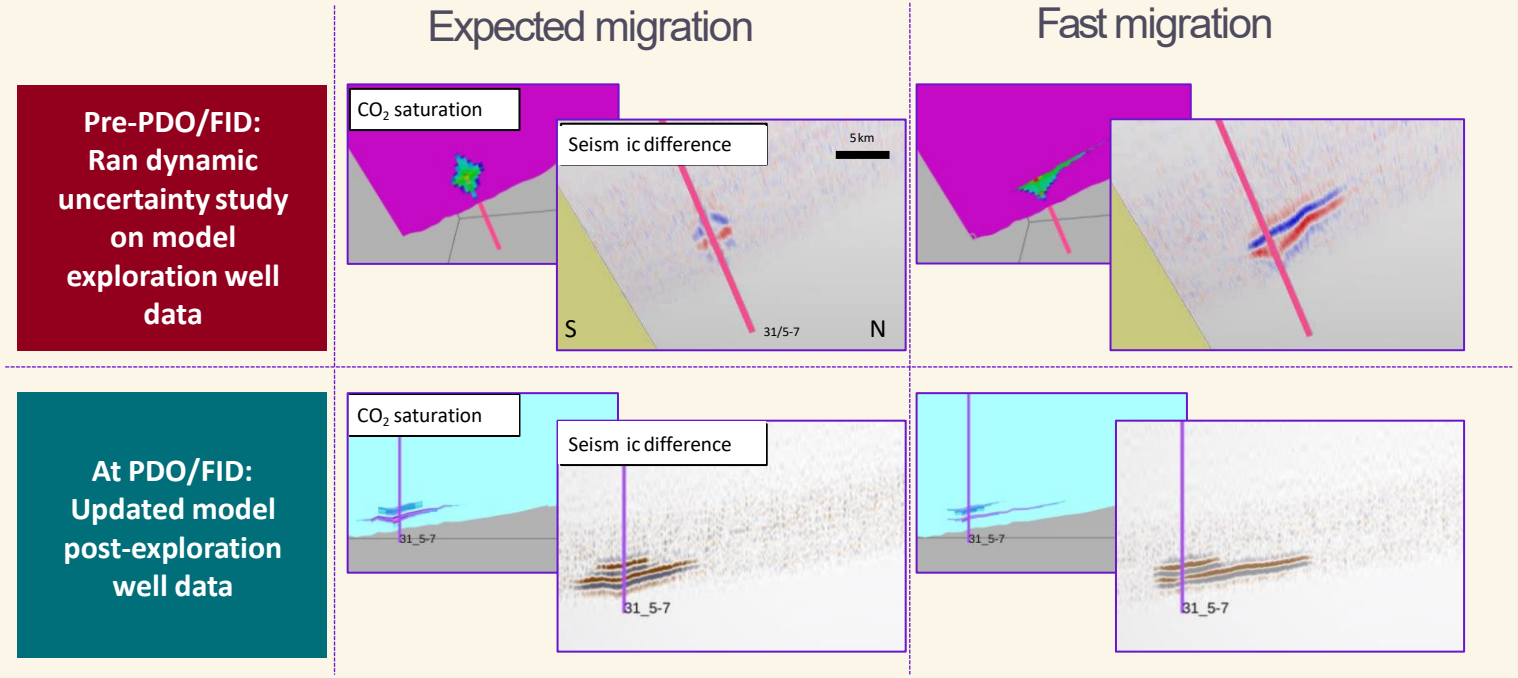
- Storage permit
- Injection permit

…which requires national approval processes

→ **Monitoring is vital in achieving the license to operate and the permit to inject**

Building the seismic monitoring plan:

Before FID* & PDO** submission to authorities



Pre-injection scenario testing

→ **Forward seismic simulations based on a selection of dynamic modelling scenarios outlining the variety of potential migration cases**

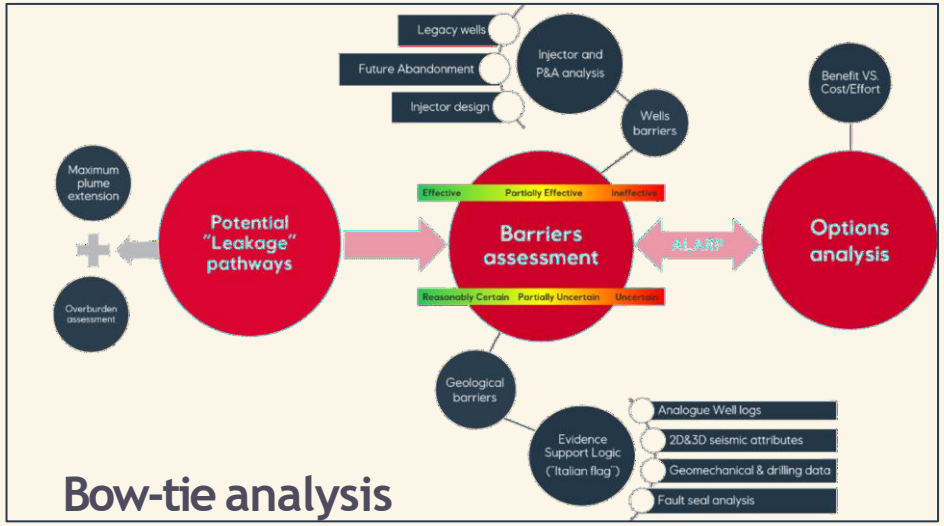
→ **Carefully selected scenarios used for:**

- Estimates of detectability (CO_2 layer thickness) and undetected volumes
- Incorporating expected noise level in repeated seismic data
- Seismic baseline survey planning (extent, acquisition parameters)

(*) Final Investment Decision
(**) Plan for Development & Operations

Building the seismic monitoring plan:

Before FID* & PDO** submission to authorities – CRA = Key input

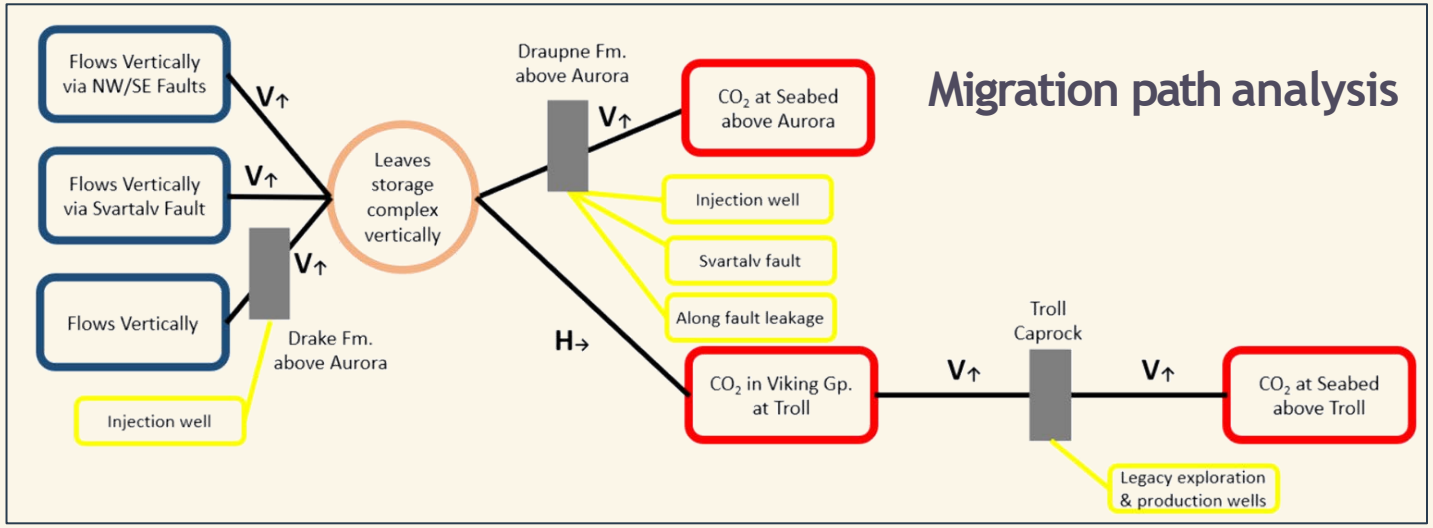


Containment Risk Assessment (CRA):
based on Bowtie diagrams that summarize the barriers

→ Along the pathways

→ In place to prevent leakage of CO2

→ In place to reduce or mitigate an event from leading to any unwanted consequence



The monitoring plan

→ Based on the identified pathways/bowties

→ Seeks to address the leakage paths as outlined in the CRA

Building the seismic monitoring plan:

Towards start-up of operations & NEA* Injection Permit application

Northern Lights

→ **Updated seismic modelling based on updated dynamic modelling**

- Modeling focus on plume speed

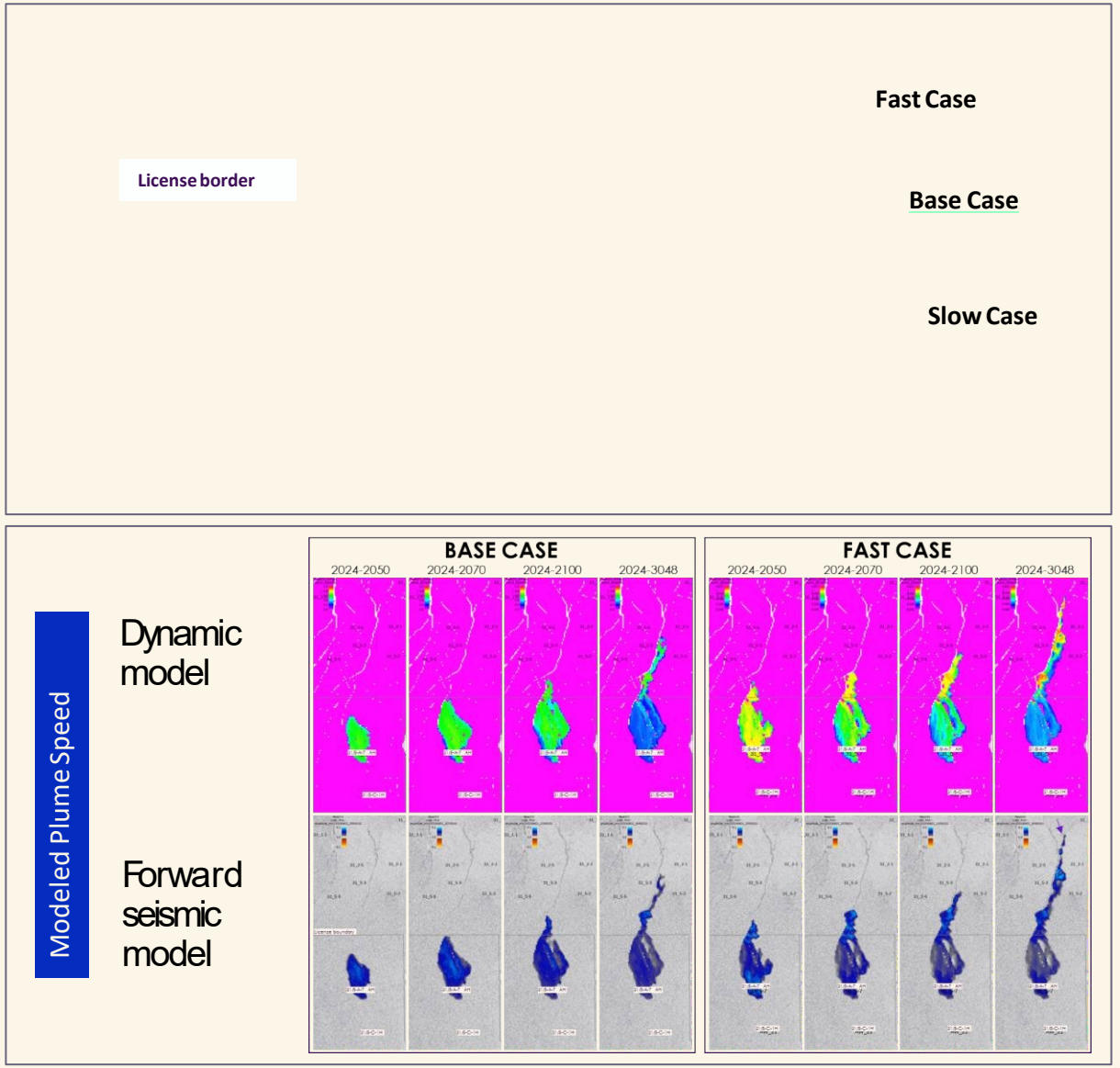
→ **New model used to update seismic repeat survey planning (timing, extent)**

- This planning was the cornerstone of the monitoring plan submitted in the injection permit application to the Norwegian Environmental Agency

→ **The 4D seismic baseline was acquired and processed**

- This activity gave us important insight into the timing for seismic activities, which in turn helped building a robust seismic repeat planning

(*) Norwegian Environmental Agency



Monitoring Plan during injection - Primary monitoring: Seismic

In-well Monitoring

PRESSURE
TEMPERATURE

Continuous

+

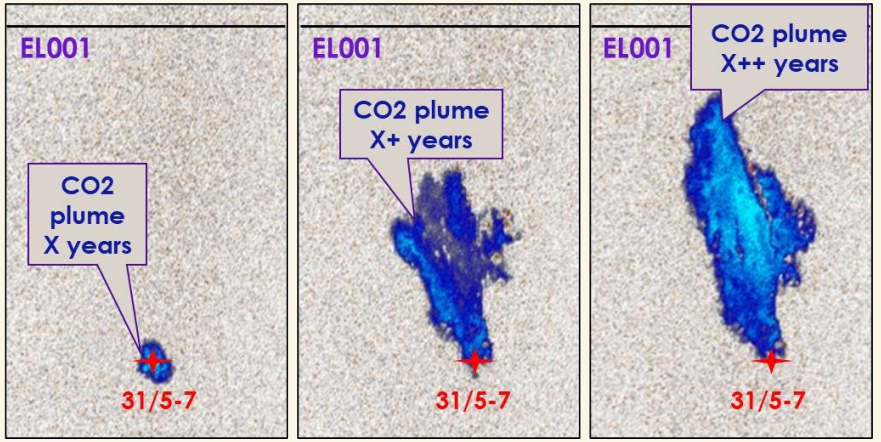
Seismic Monitoring

CO_2 SATURATIONS
CO_2 PLUME MIGRATION

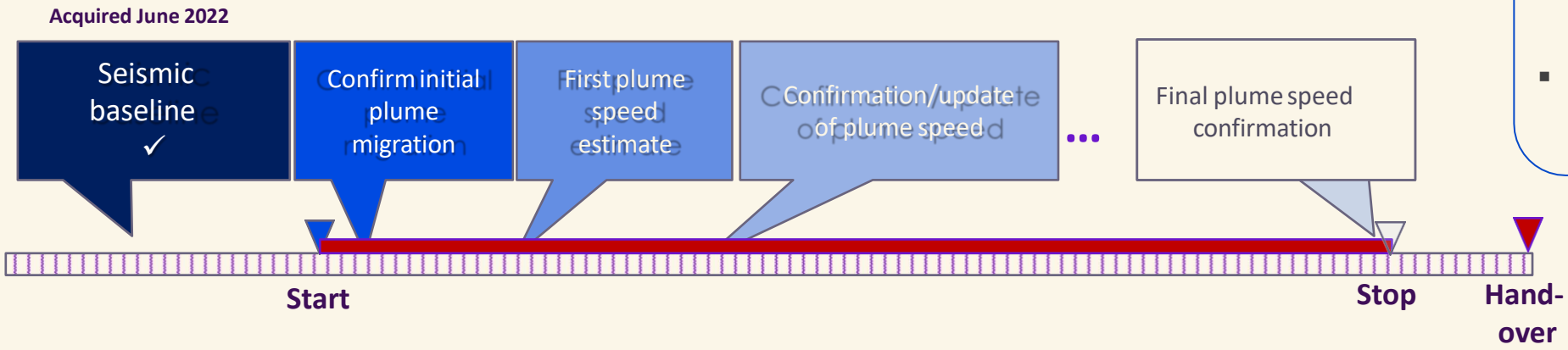
At specific times

- ACTIVE
- PASSIVE

Continuous



Primary (active) Seismic Monitoring Strategy

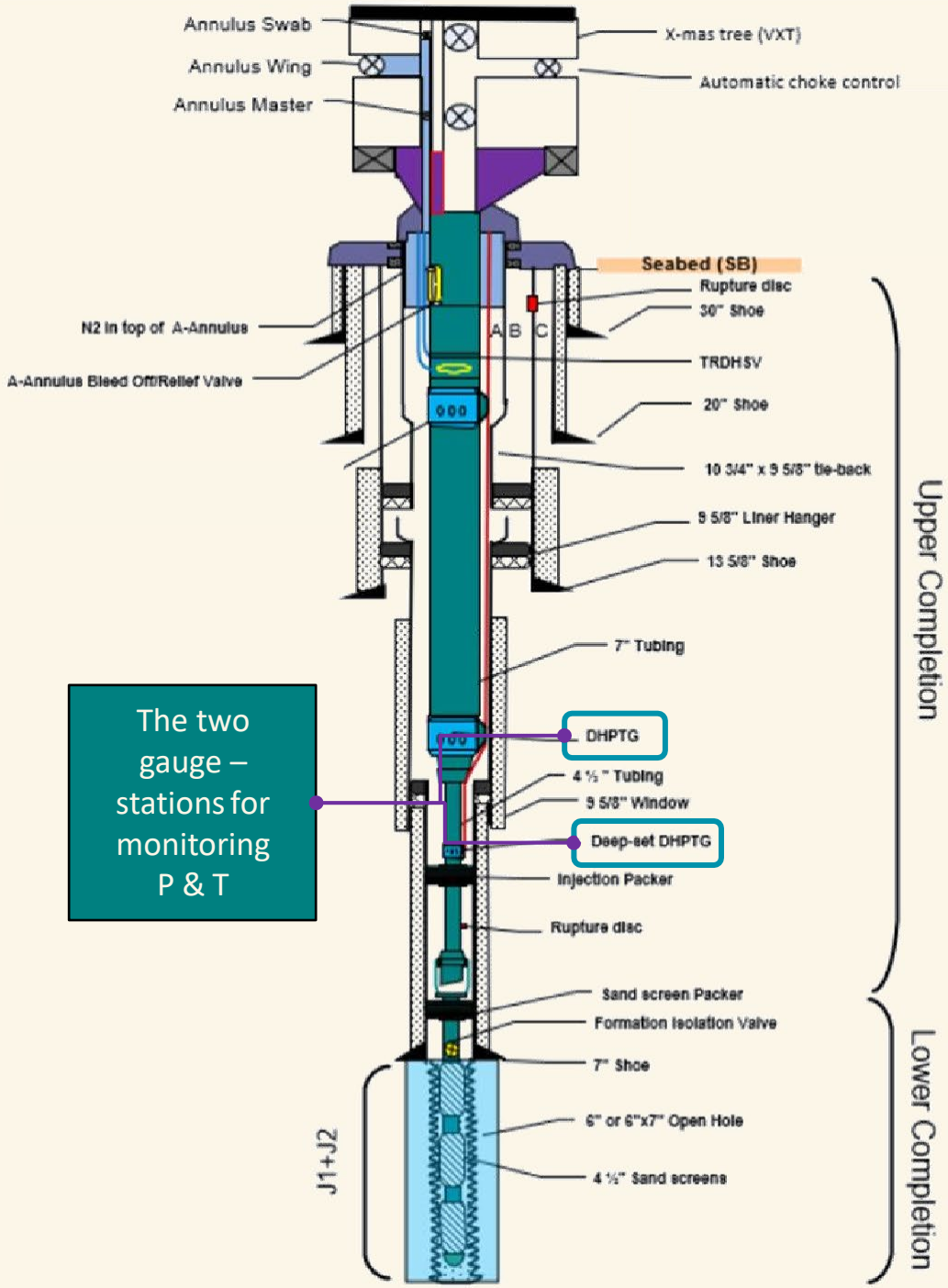


Primary Seismic Monitoring: chosen techniques

- ACTIVE: Repeat tow-streamer seismic surveys. 3D data acquired in 2022 provides the baseline
- PASSIVE: NNSN array to monitor for seismicity

Monitoring Plan during injection - Primary monitoring: In-well

- **Instrumentation**
  - Wellhead pressure, temperature + Venturi flow meter
  - Two down hole pressure/temperature gauges
    - Tubing + annular
- **Planned monitoring**
  - Injection pressure – Continuous
  - Reservoir pressure – Planned/regular fall-off testing
    - More frequent in early injection phase, reduced as experience gained
    - Also planned step-rate testing upon start-up, monitor injection performance parameters
    - Consistent procedures for all planned testing for better trend quantification
- **Triggered monitoring**
  - In case of non-conformance or non-containment a secondary monitoring may be "triggered". Example: decreased injection pressure indicative of fracture development, responses can include:
    - Reduce injection
    - Perform: Fall off test and/or PLT,and/or step-rate test
    - Seismic monitoring, i.e. additional seismic survey (2D hi-res or 3D)



Monitoring Plan during injection - Secondary monitoring & Modus Operandi

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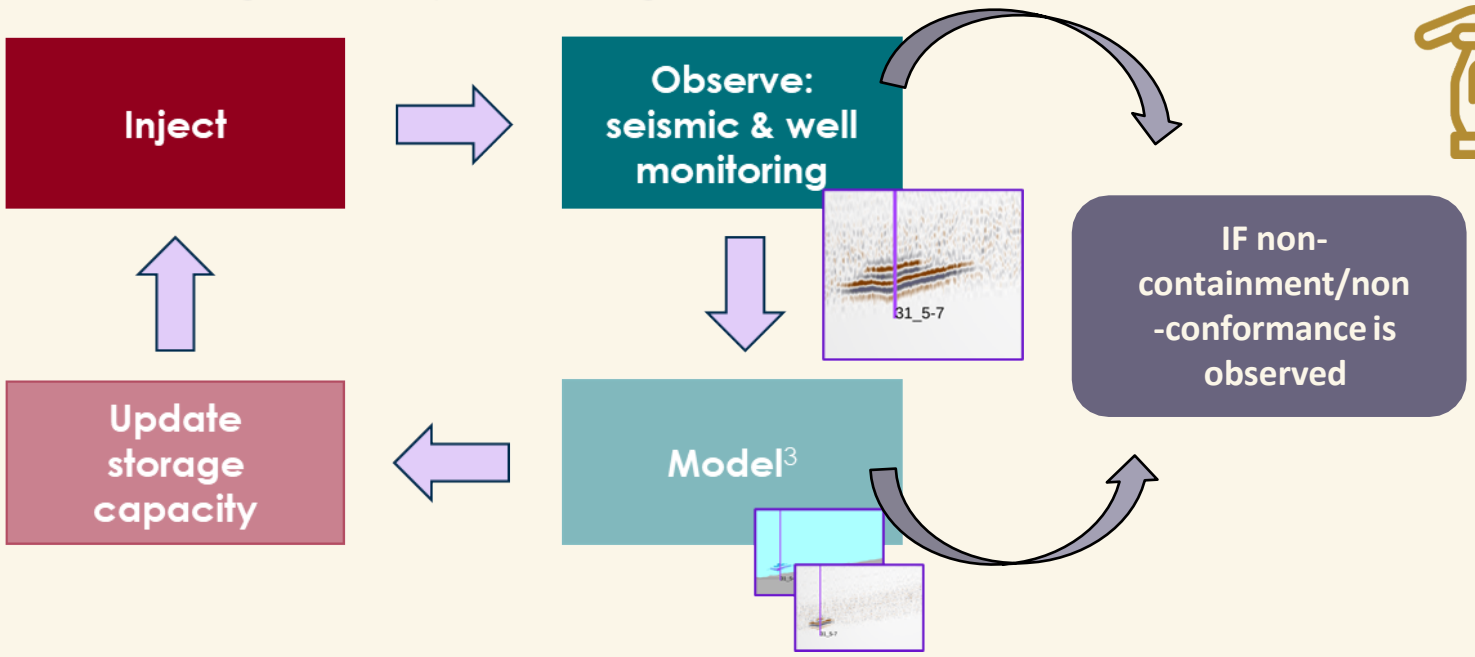
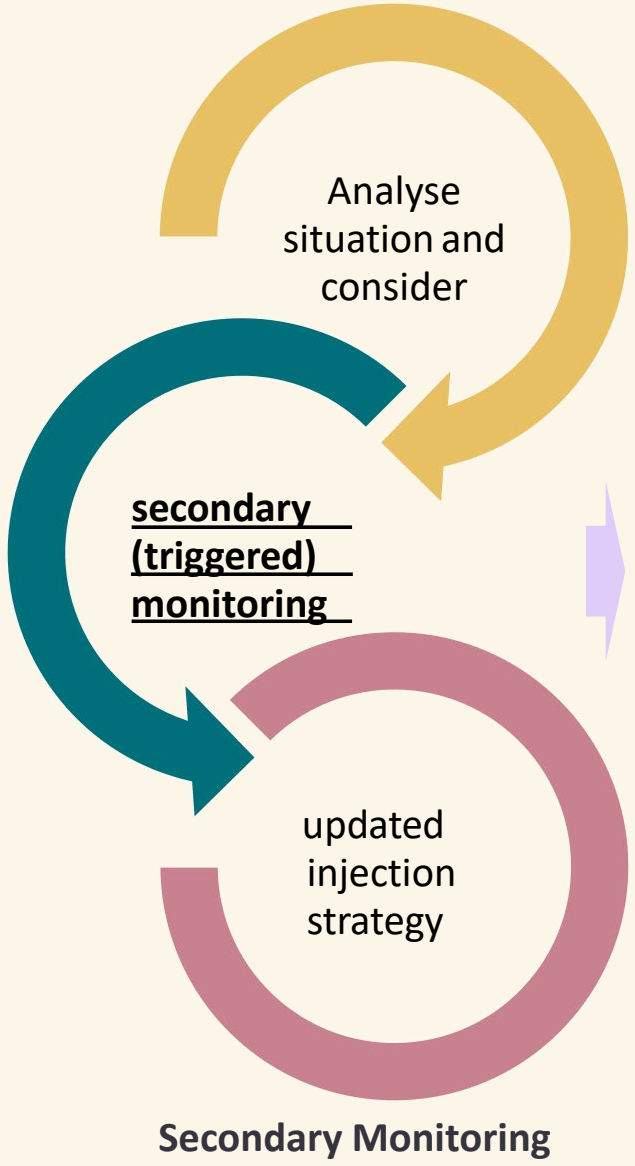
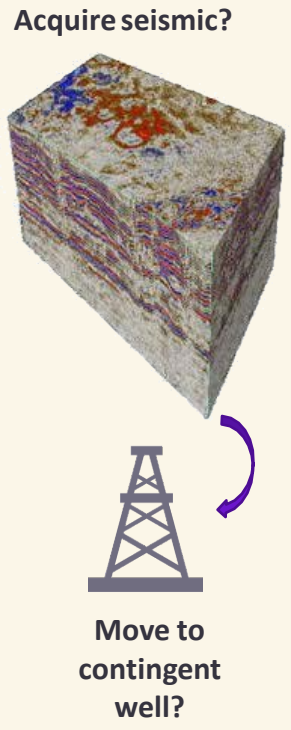
Modus operandi during injection

Monitoring & History matching ensemble

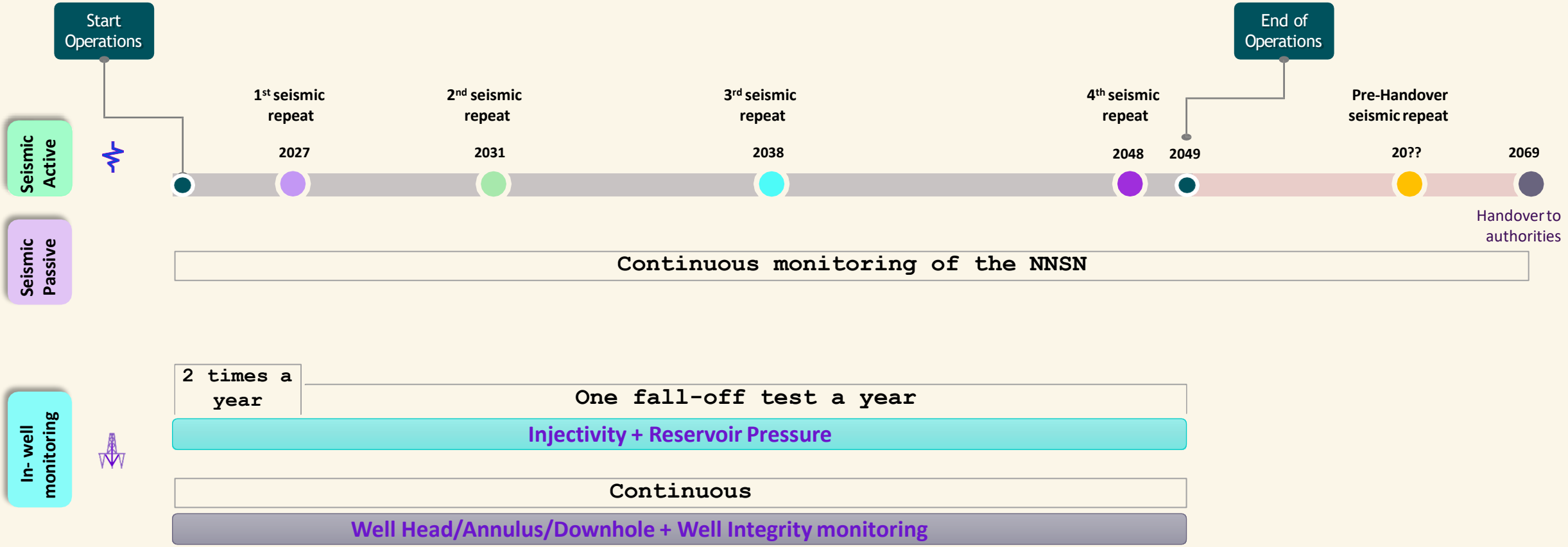






Northern Lights Final (base case) monitoring plan

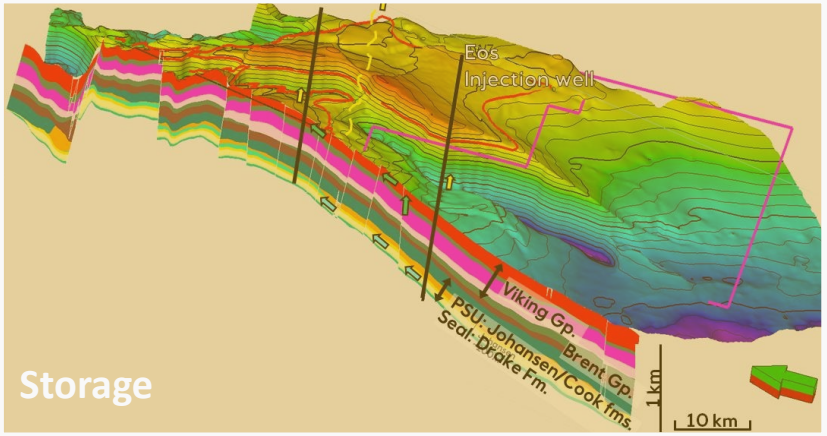
As described in the Injection Permit application to NEA*



(*) Norwegian Environmental Agency

Key messages & Summary

- Northern Lights is a leading CO_2 transport and storage company, its experience can be an example for others to follow
- A robust monitoring plan for Phase 1 is a core element of the CO_2 storage regulations in Norway and Europe
- The monitoring plan consists of in-well continuous monitoring and active & passive seismic monitoring. It spans throughout all the project stages: before, during and after injection operations, up until handover to authorities
- The plan for seismic monitoring consistsof four 3D-seismic repeat surveys during operations and one seismic survey after operations and before handover
- The plan for in-well monitoring consists of continuous monitoring and regular fall-off/step-rate testing every 6 months minimum
- This plan is not static, it's flexible and willbe updated accordingly based on observations



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