LIABILITIES;
CASE STUDY JOHANSEN STORAGE SITE

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Hallvard Høydalsvik, Senior Advisor Storage Development, Gassnova SF

JOHANSEN STORAGE SITE LIABILITIES

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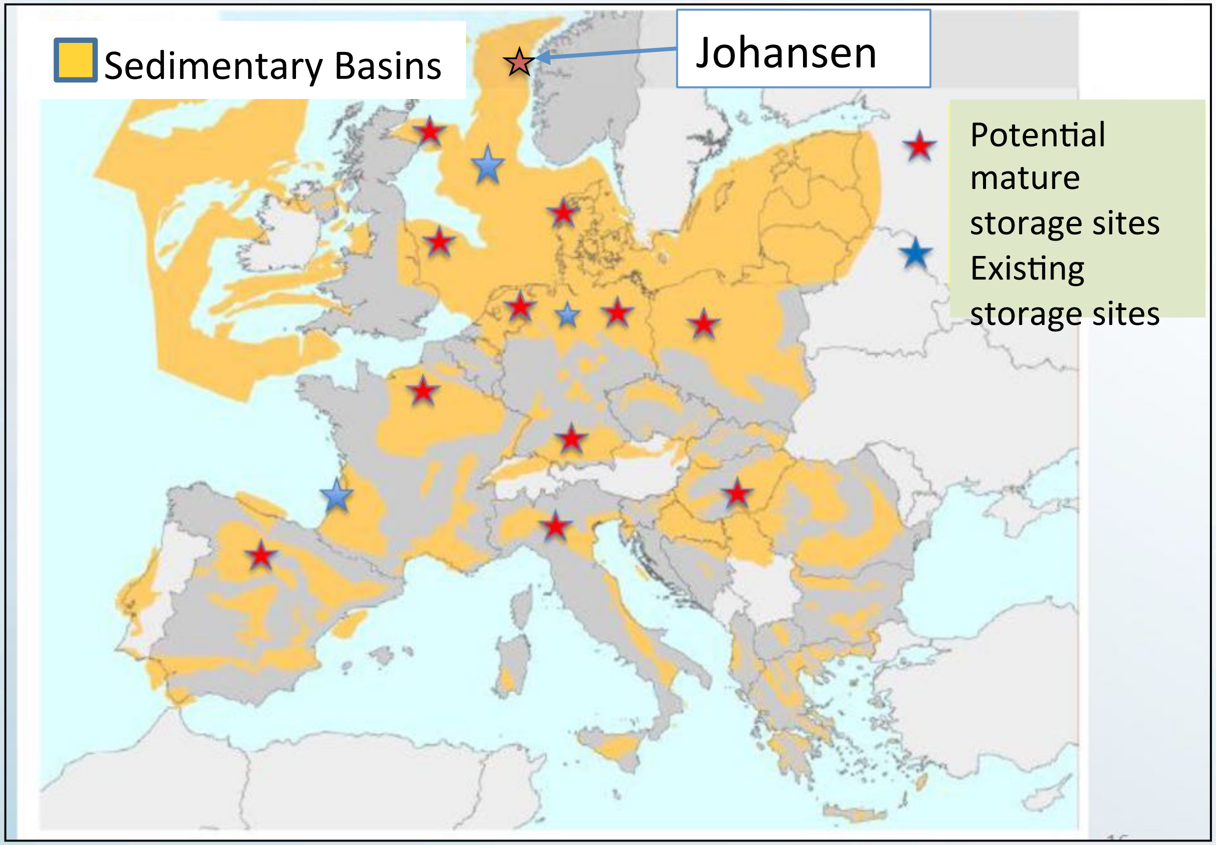
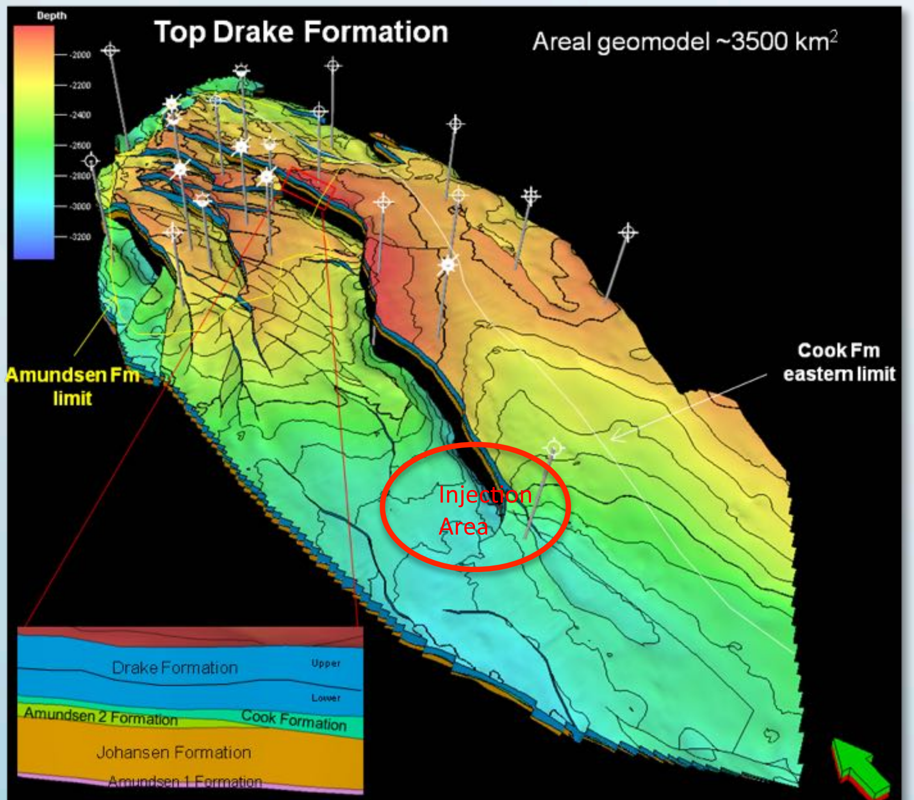
Objective of presentation;

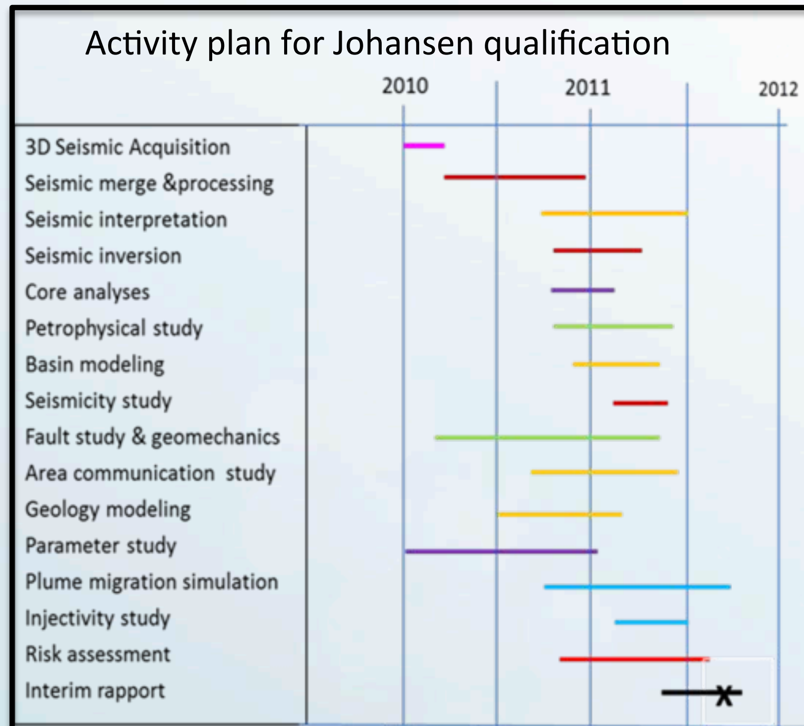
- **Example of real case**
- **Method for assessment**
- **Level of liability**



Johansen Storage Complex

- The Johansen Storage Complex has been thoroughly evaluated
- 3D seismic, Neighbouring wells, FEED-studies etc
- Matured past feasibility level
- Verification well in injection area required



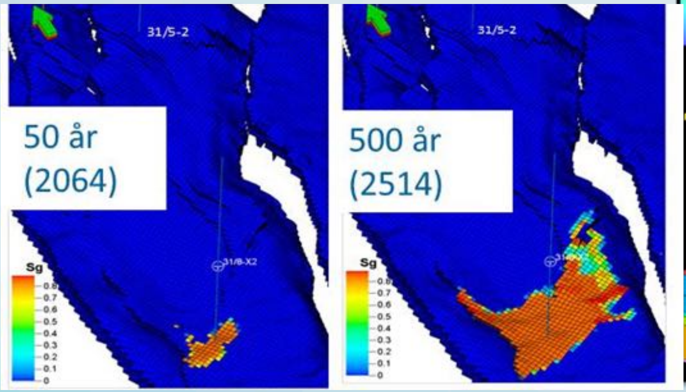


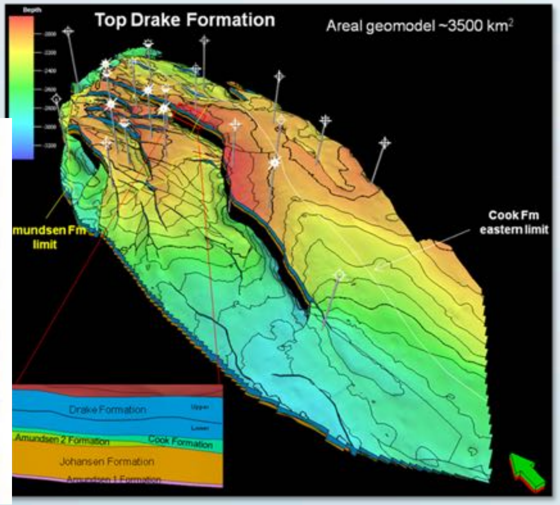
Full set of FEED-studies performed in 2009 and 2011

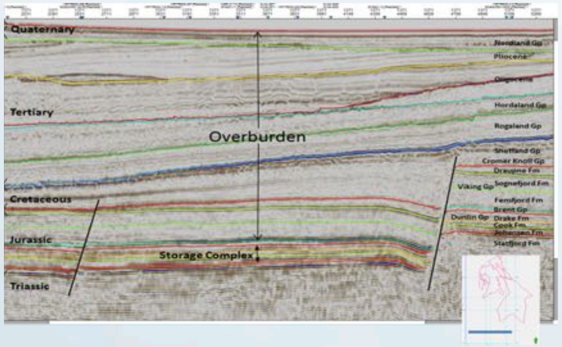
JOHANSEN STORAGE COMPLEX DESCRIPTION

- Aquifer Storage in Jurassic sandstones of Johansen and Cook Formations
- Laterally defined by major faults to the north and east and by pinch out to the west and south
- Primary sealed by 200m of Drake Shale supported by several thick shale layers above
- Good injectivity and sand quality
- Storage capacity of min 500 mill tonn CO_2 with additional upside
- God seal against leakage to the surface, minor risk for CO_2-migration towards Troll field
- Petroleum province, no residual hc

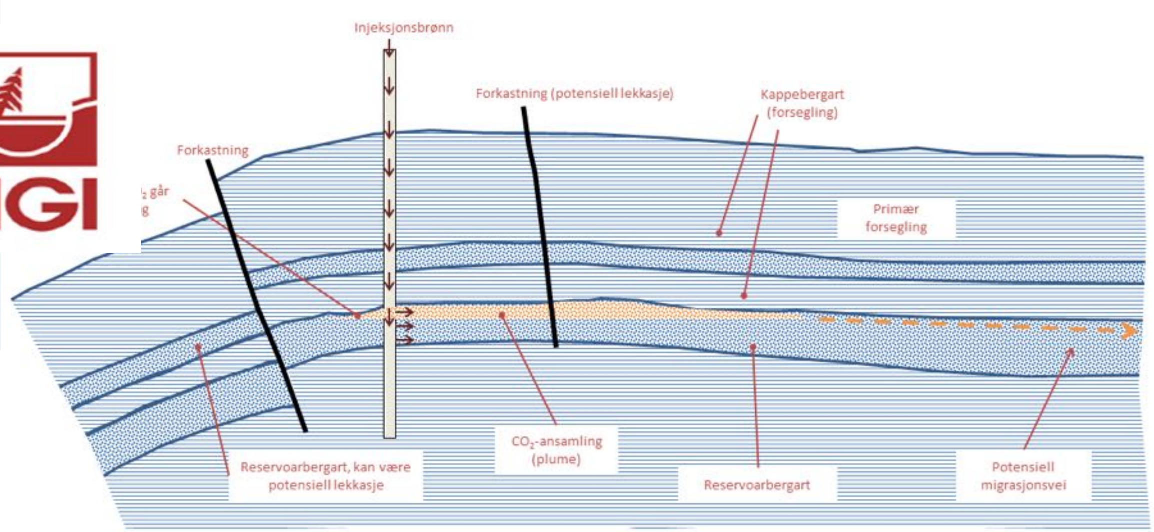
Kapasitet, injektivitet	
Sikker lagring	
Teknisk, kostnad	
Modning	







POTENTIAL LEAKAGES



- Faults:
  * Identified faults
  * Possible unidentified faults
  * Reactivation of faults
- Cracks/fractures in the cap rock:
  * Open/permeable fractures
  * Natural cementation- soluble in CO_2 brine?
  * Induced fractures
- Pressure build up and pressure communication
- Leakage through pores in the cap rock:
  * Capillary flow
- Injection well
- Abandoned wells
- Connecting sand bodies
- Chemical reaction between CO_2 and cap rock/overburden
- Catastrophic events
- Other heterogeneities in the cap rock/overburden, water/gas

Engaged experts to identify and assess potential leakages

Methodology

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DATA COLLECTION AND ASSESSMENT
Information and documentation provided by Ross Offshore and Gassnova

IDENTIFY RISK FACTORS
Hazard identification (based on HAZID for Utsira CO_2-storage)

ESTIMATE FREQUENCY OF OCCURRENCES FOR EVENTS
Using **event trees**, expert opinions and database with empirical data

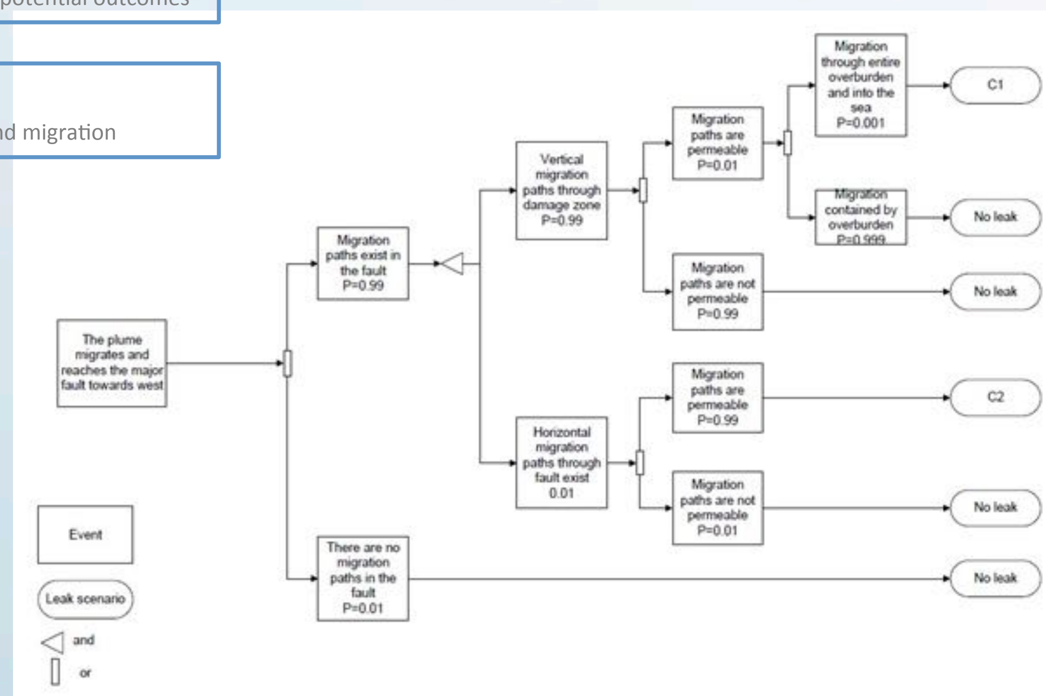
MODEL EVENTS AND ASSESS IMPACTS
Using **event trees** to evaluate potential outcomes

ESTIMATE IMPACTS
Calculation of leakage rates and migration

ESTIMATE RISK
In terms of **liability**. By combining probabilities (of leakage), leakage rates (given an unwanted occurrence) and estimated leaked CO_2 amounts

ADDRESS RISK MITIGATION AND VERIFICATION MEASURES
Monitoring and corrective measures

A GENERAL WORKFLOW FOR A PROBABILISTIC RISK ASSESSMENT (PRA) WAS
CO2 MIGRATION AND FLOW RATES CALCULATED AND SIMULATED



MAIN RESULTS OF LEAKAGE ASSESSMENT

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Leak Scenario	Expected % of total injected CO_2 leaked
A: Leakage through the Major Western Fault	1.26E-04
B: Leakage through the TWOP/TWGP Fault	3.68E-04
C: Leakage through induced fractures	4.47E-06
D: Leakage through sub-seismic faults and palaeo fractures	8.34E-03
E: Leakage through the injection well	1.23E-03
Total	**1.01E-02**

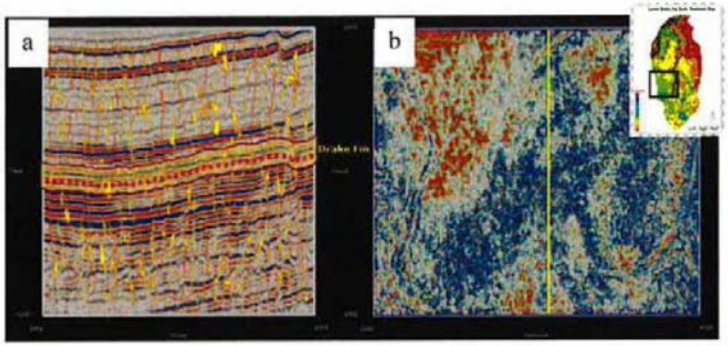

Figure 17: Fault In attribute from SVIPro; a) Seismic section shows the fracture/fault density, b) Map view of a time slice (~12 ms along the red dotted line on 'a') showing a polygonal fault system in the Lower Drake Formation (Ross Offshore report-2, 2011).

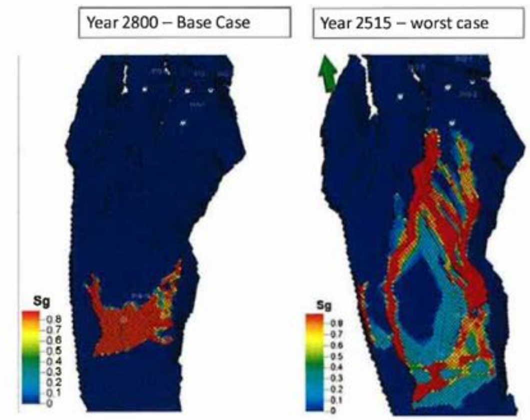

Figure 15: Plume migration top Cook. Comparison worst case and base case models (from Ross Offshore, 2011).

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REMEDIATION ACTIONS AND COSTS

Category	Potential cost drivers/remediation	Estimated timing of occurrence	Cost for remediation, mill €/probability
Blow out	Killing well, potential relief well New injection well (25%) or repair of original well Fatalities CO2 quota paid for lost volumes (63 days) Halt in operations	0-70 yrs (during operations and transfer	140/0,22%
Leak from installations	Repair of facilities Fatalities CO2 quota for lost volumes Halt in operations	0-70 yrs (during O&T) >70 yrs (through plugged wells	120/0,3%
Leak through faults or cap rocks	CO2 quota for lost volumes, several scenarios (maks. 50 mill ton, 100 years Termination of activities New CO_2-storage to be developed	After 20-2500 years	2300/0,001%
Impact on other commercial activities	CO_2 contamination of •freshwater resources •hydrocarbon resources •soil	After 150-300 years	12/2,5%

Assumptions

- Significant leakage to surface requires development of new site
- CO_2 quota paid by 50 Euro/ton for all leakages
- Time span of 1000 years
- For facilities and wells; Leakage and blow out frequencies, escaped volumes and mitigation periods are taken form North Sea Petroleum statistics.

RESULTS; LIABILITY COST DRIVERS

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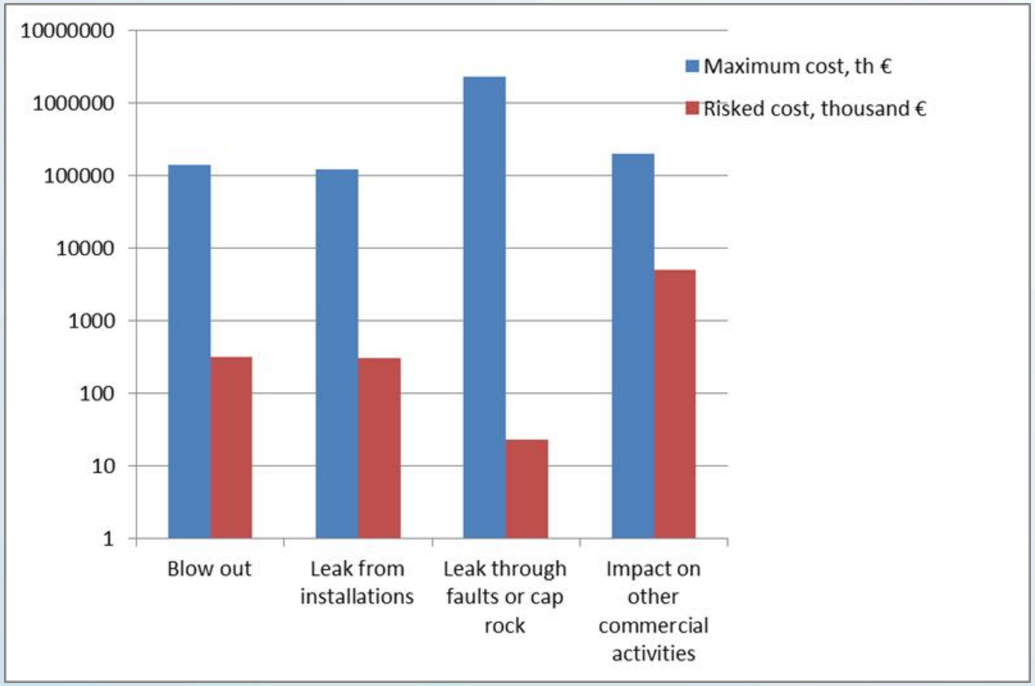
Liability cost for storing 3.2 Mt CO_2 a year over 50 years



Total technical liability;
1,5 mill € over 250 year period

	Fraction CO2 quota
Short term	20%
Long term	67%
Total	25%

10 000 €/yrs

4 000 €/yrs

Operation and transfer phase (0-70 years)

Post-closure phase (after 70 years)

Conclusion from our work

- For sites with good seal the liability in respect of leakage is limited
- Such sites are for example saline aquifers or abandoned fields in petroleum provinces, which have proved seal for millions of years
- In the unlikely occation that a leakage occur it will be costly
- CO2 quota makes 25%

- The numbers referred are approximations and must be understood as indications of levels with significant uncertainties