NORWEGIAN PETROLEUM DIRECTORATE

Overview of CO_2 storage capacity – CO_2 Atlas in NCS

The potential for CO_2 EOR offshore Norway

V. Pham 5.10.2015

CCS projects around the world

176 projects around the world on

Research- Testing- Pilot -Full scale

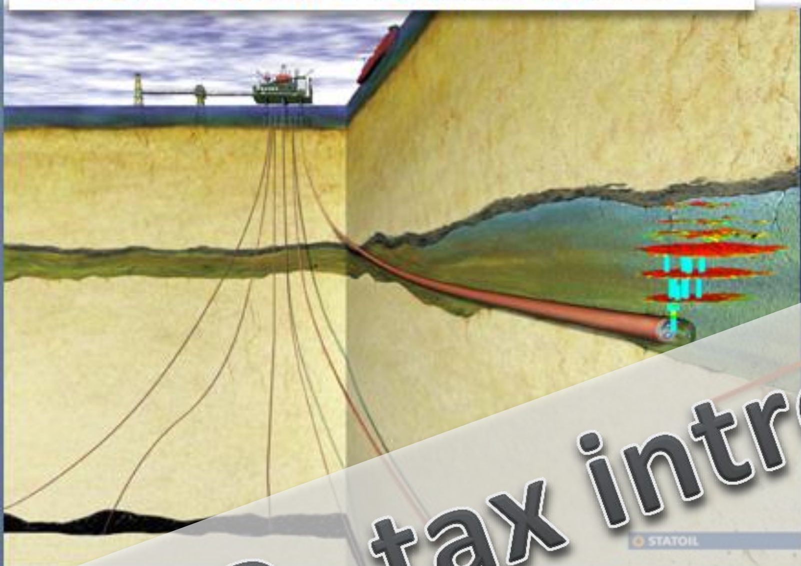
In Planning
Operational
Cancelled or Dormant
Finished
Pilot

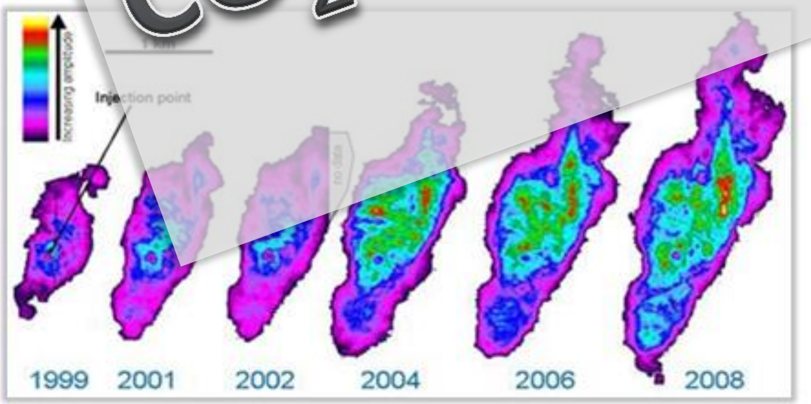
Norwegian CO_2 storage experiences

After CO_2 tax, injection and storage of CO_2 becomes benefit

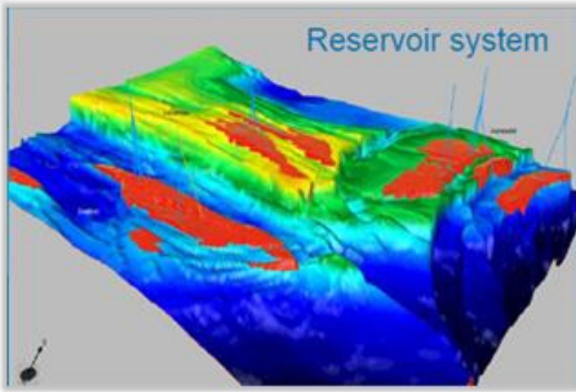
CO_2 tax introduced on NCS in 1991

Storage of CO_2 from the Sleipner Vest field

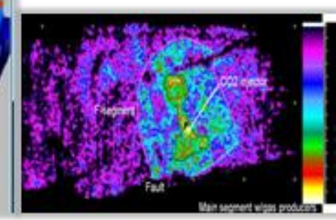




Storage of CO2 from the Snøhvit field



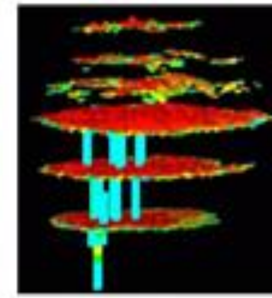
Start 2007



Norwegian CCS initiatives





Source

Capture

Transport

EOR

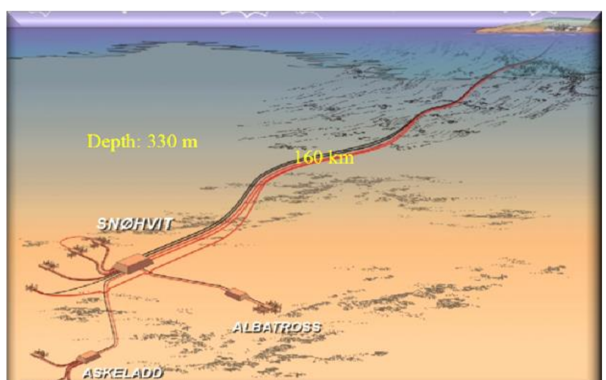
Injection

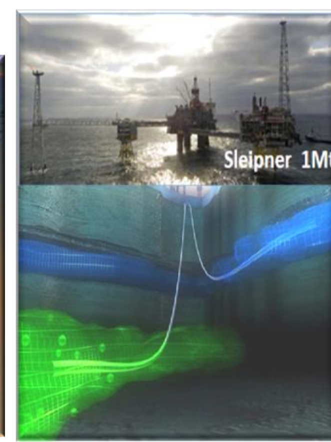
Storing & Monitoring

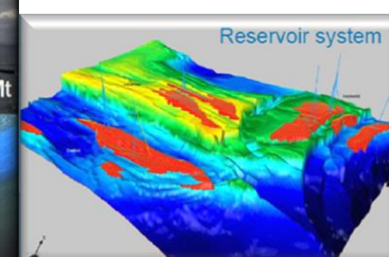
eg. Mongstad and Heidelberg Cement

Snøhvit CCS

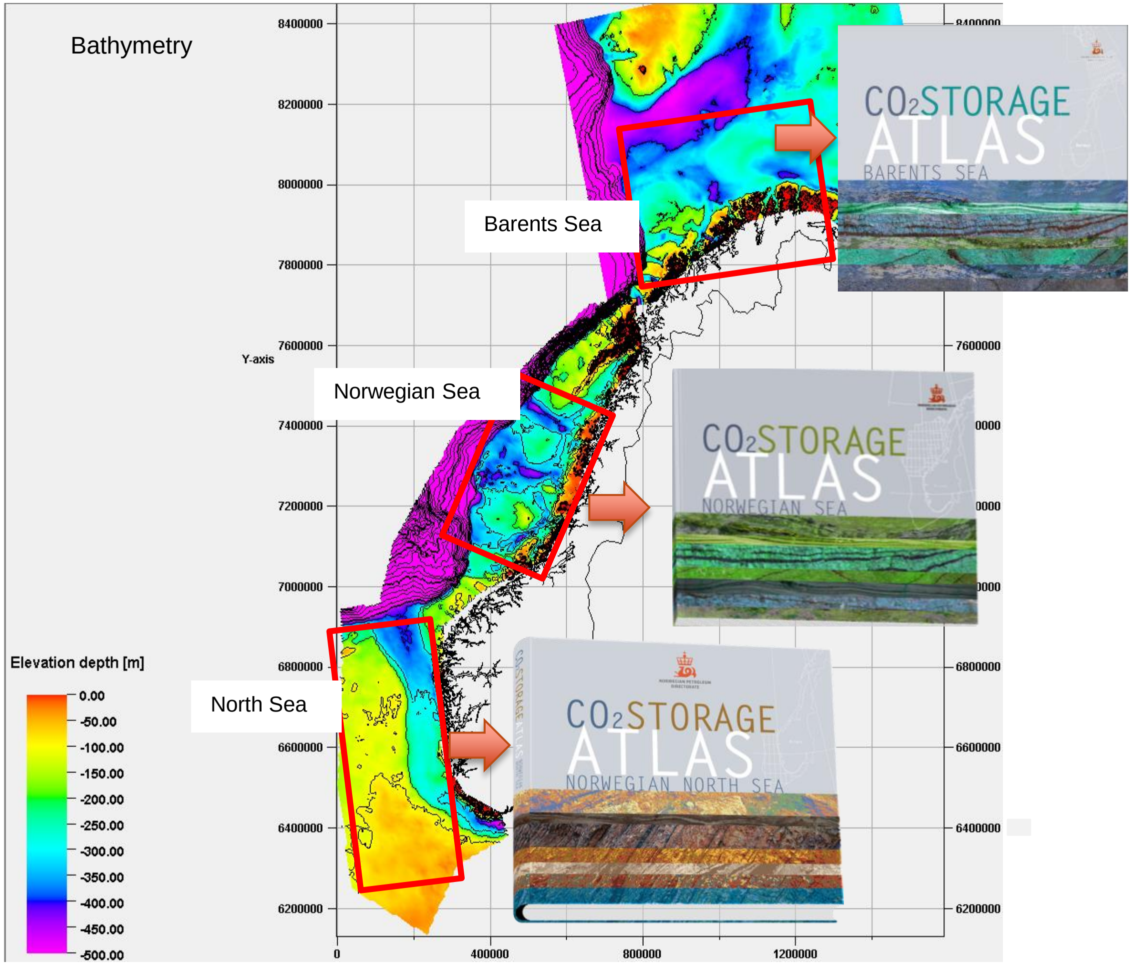
Sleipner West and Snøhvit

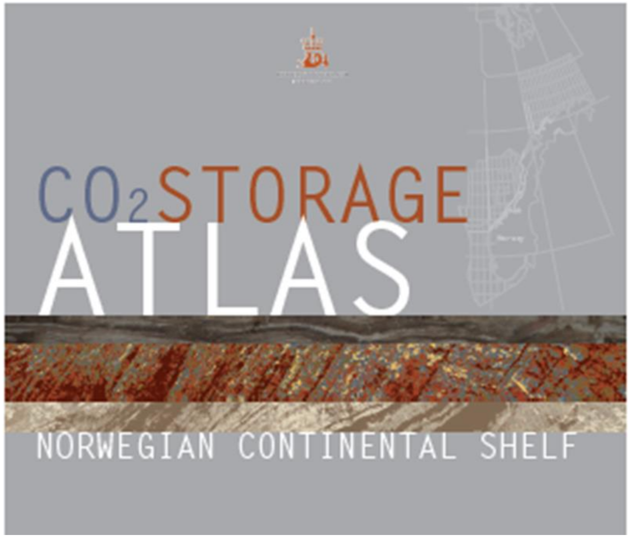






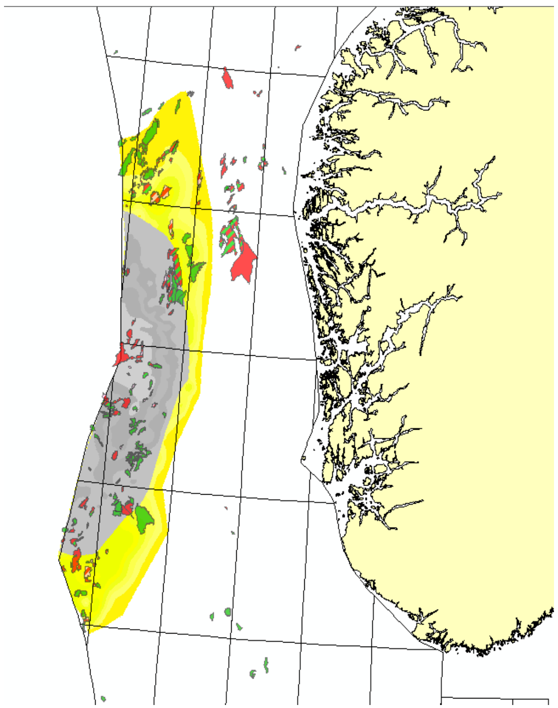
Overview of CO_2 Storage capacity in NCS, CO_2 Atlas from basin- regional area scale



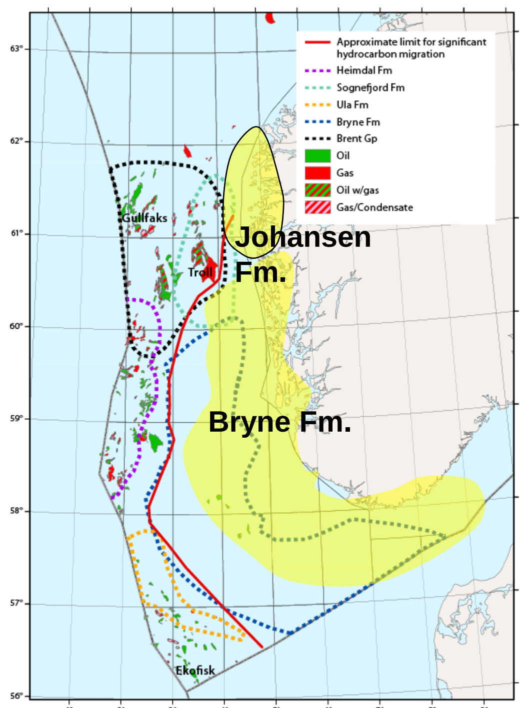


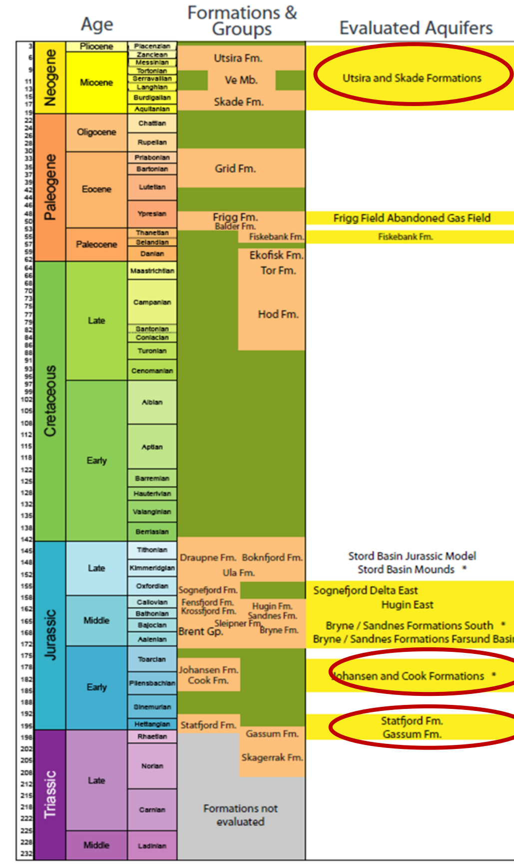
Mapping formations

- Selective criterions for all reservoir & seal pair to get overview of pore volum and overview of CO_2 storage capacity in the formations.

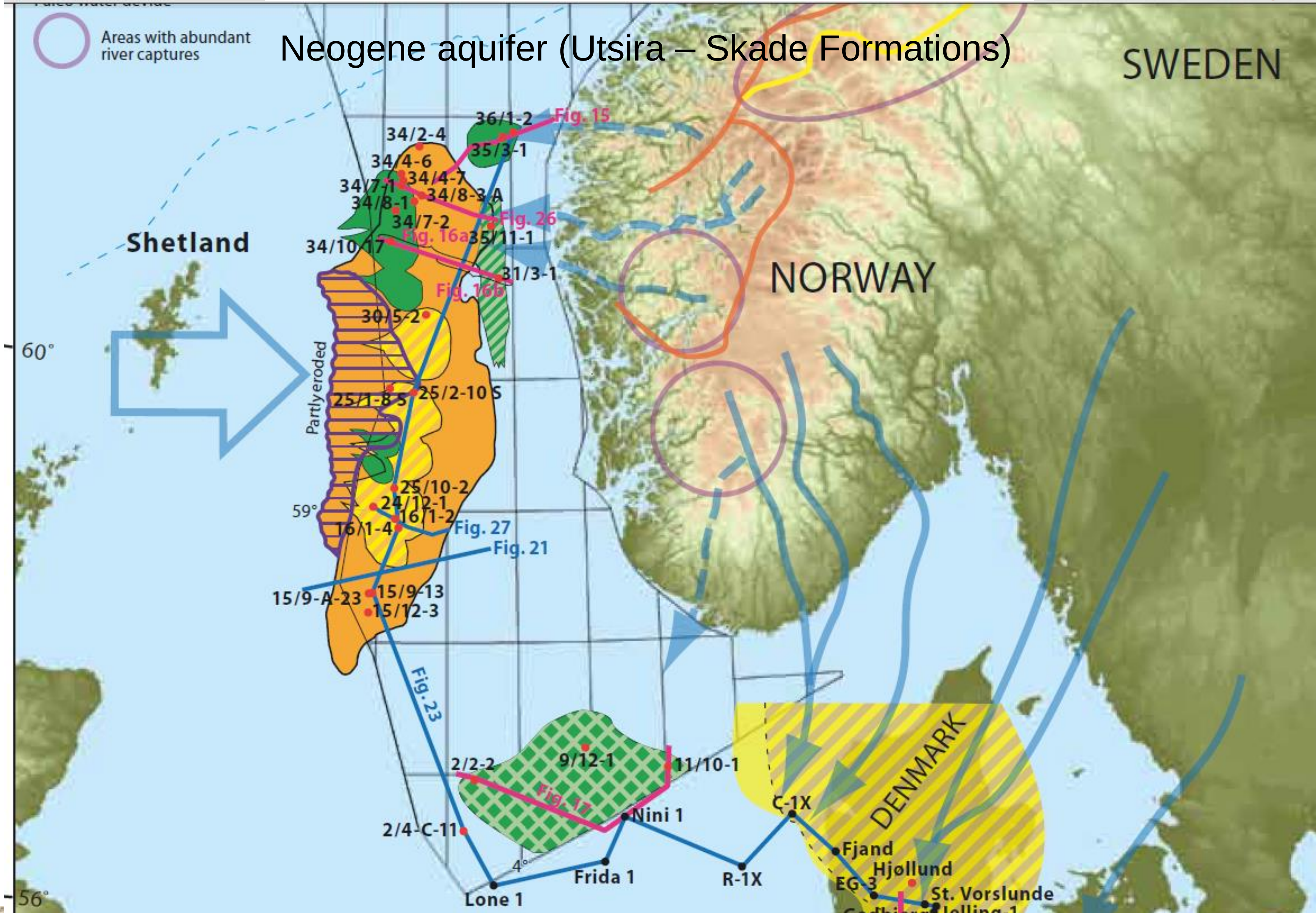


Utsira and Skade formation in Nowegian sector



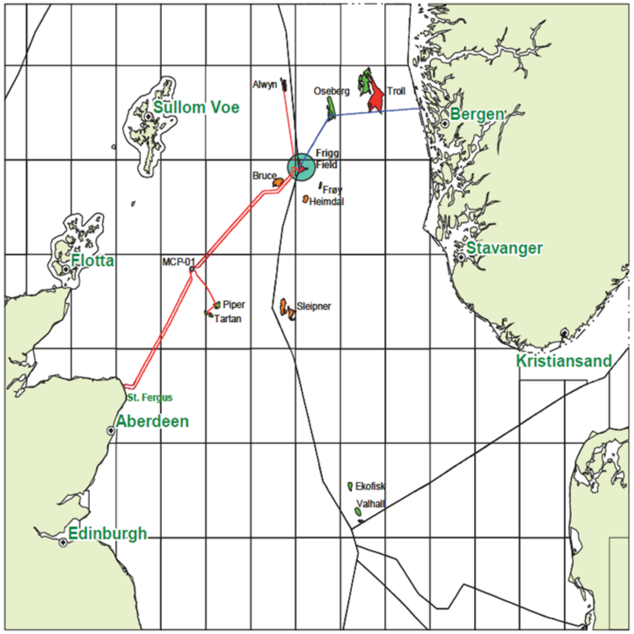


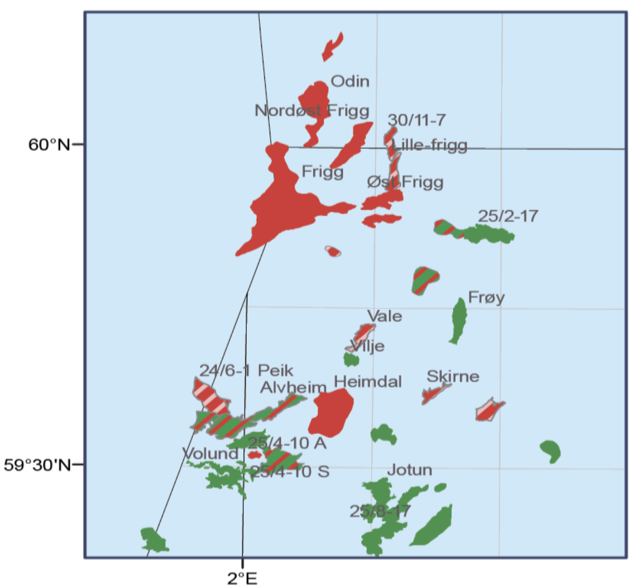
Neogene aquifer (Utsira – Skade Formations)

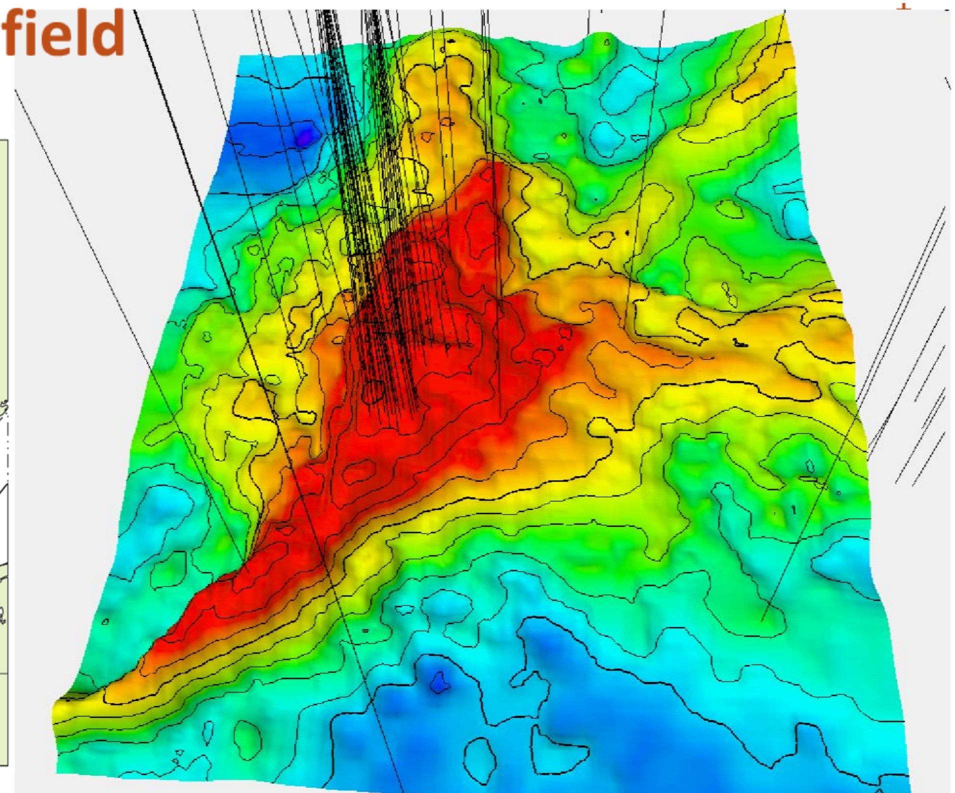


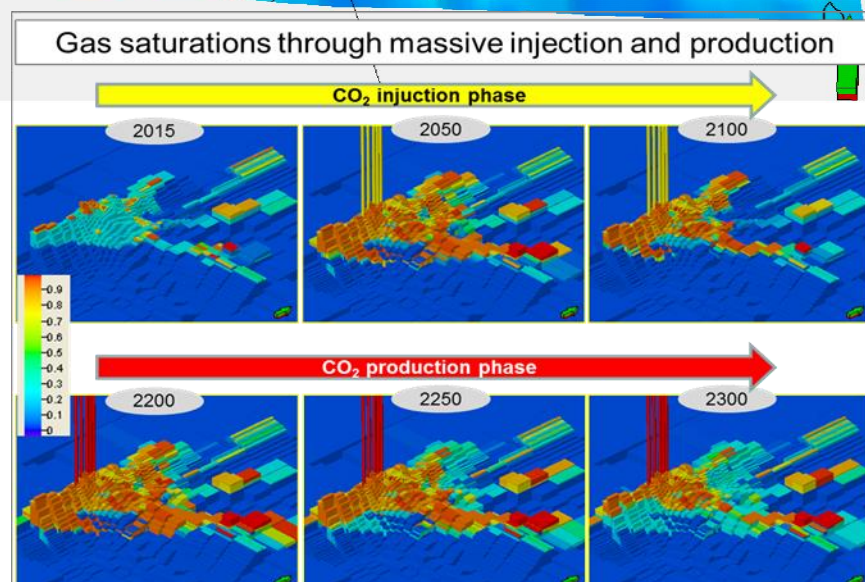
Neogene aquifer (Utsira – Skade Formations)

Frigg Field, abandoned gas field

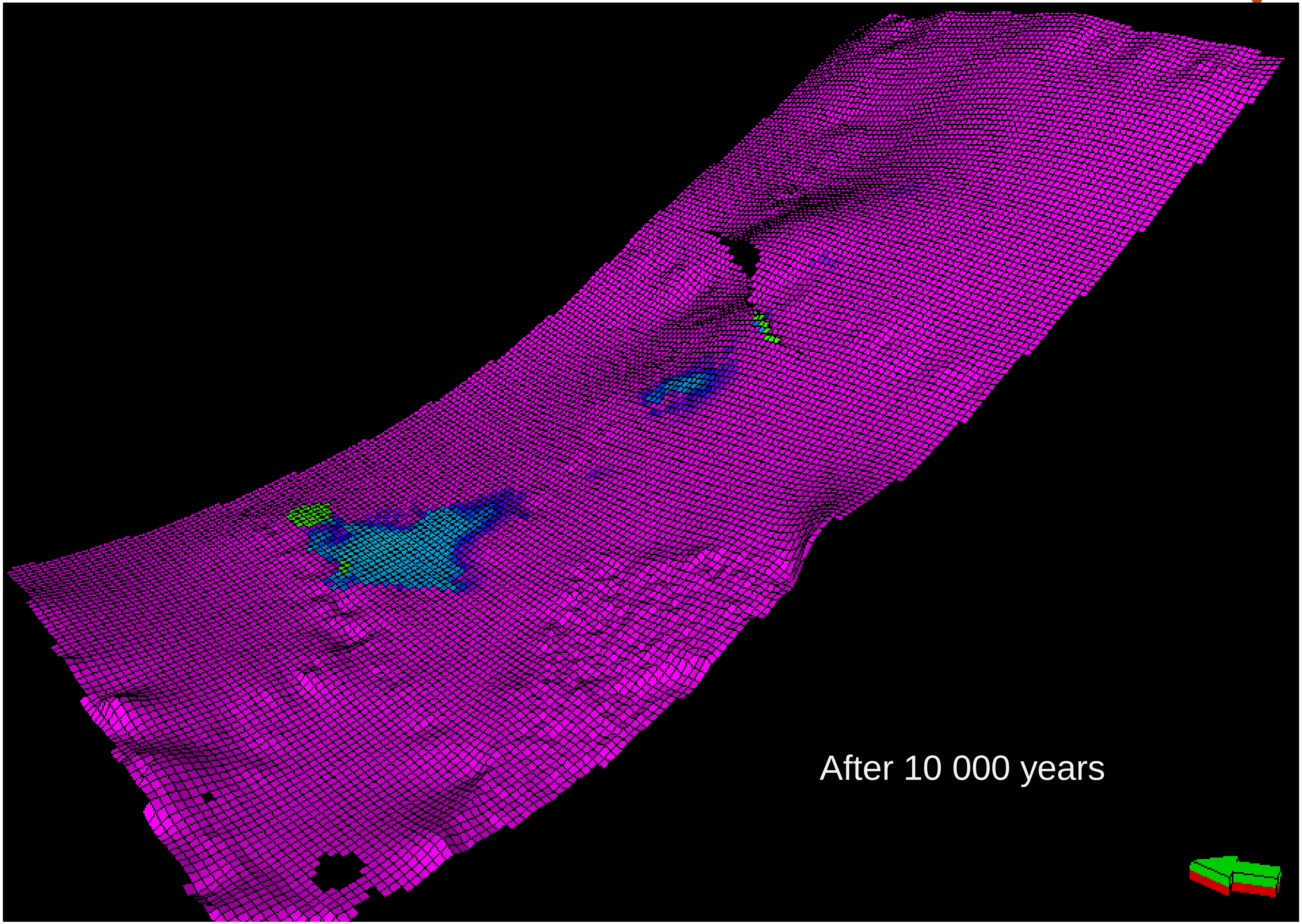




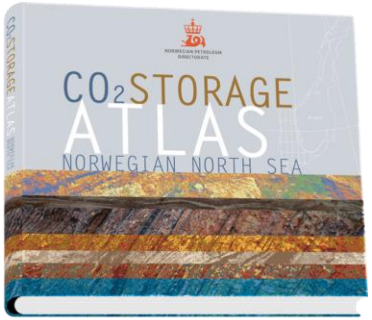




Froan Basin, storage possibility

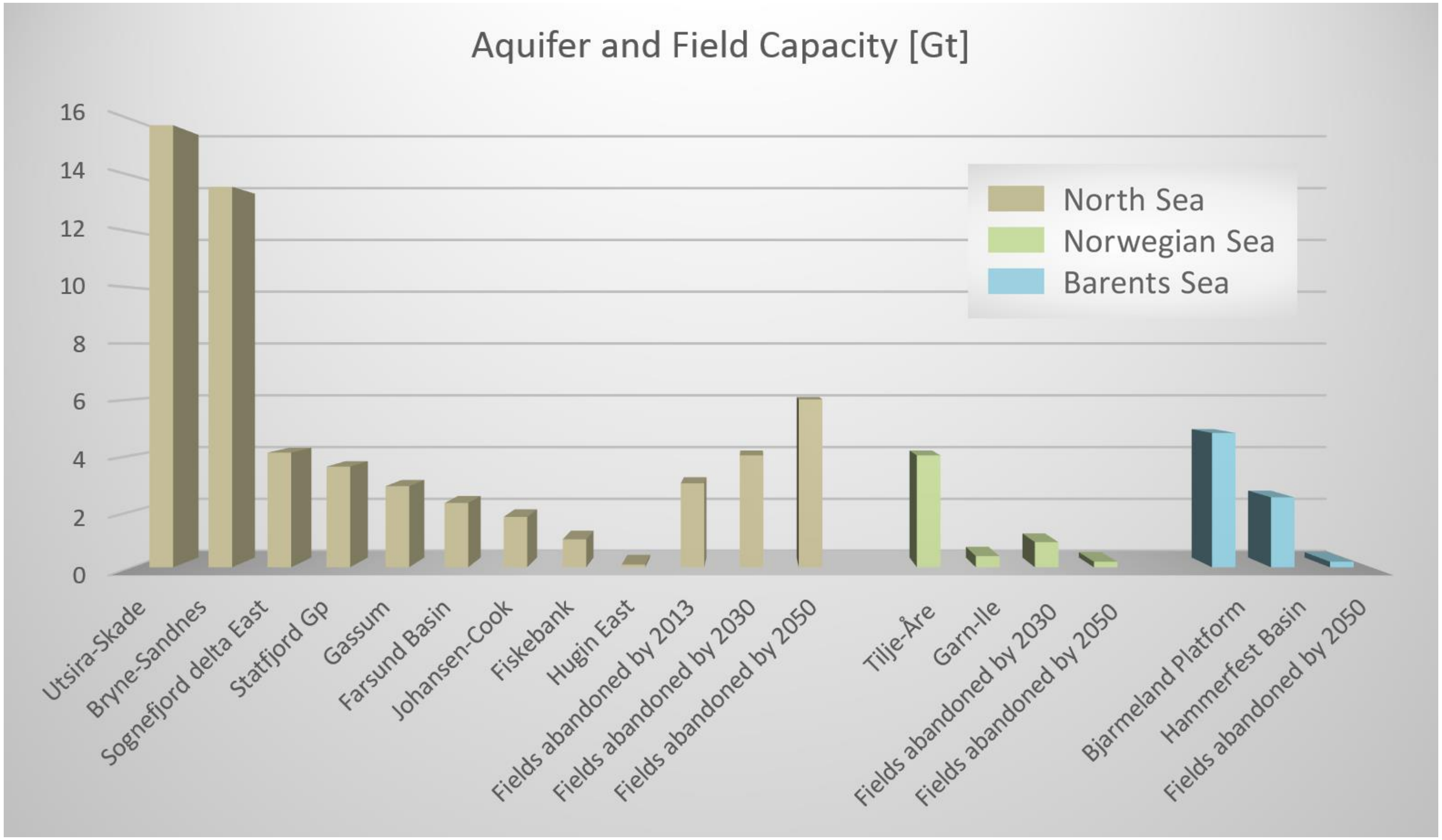


Results for The North Sea area



Aquifer	Capacity Gt	Injectivity	Seal	Maturity	Data quality
North Sea aquifers					
Utsira and Skade Formations	15,8	3	2		
Bryne and Sandnes Formations	13,6	2	2/3		
Sognefjord Delta East	4,1	3	2/3		
Statfjord Group East	3,6	2	3		
Gassum Formation	2,9	3	2/3		
Farsund Basin	2,3	2	2/3		
Johansen and Cook Formations	1,8	2	3		
Fiskebank Formation	1	3	3		

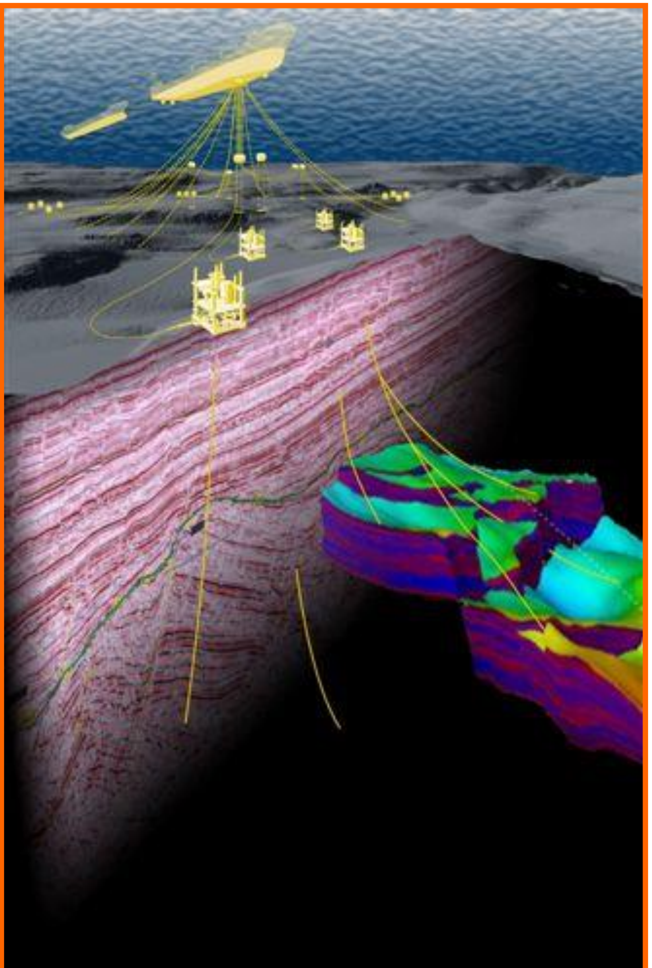
CO_2 storage capacity for The NCS.

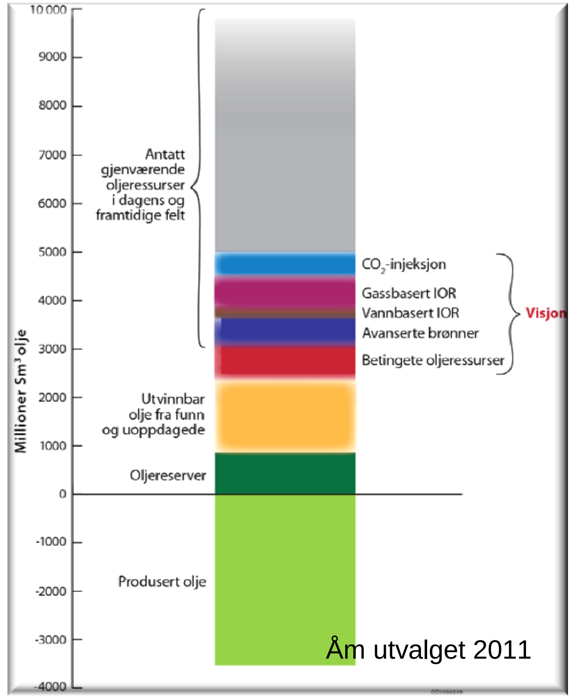


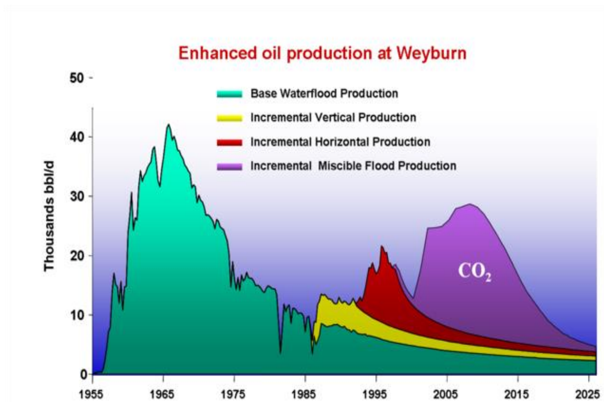
CO_2 for EOR in the Norwegian shelf – requires additional storage volumes

NPD

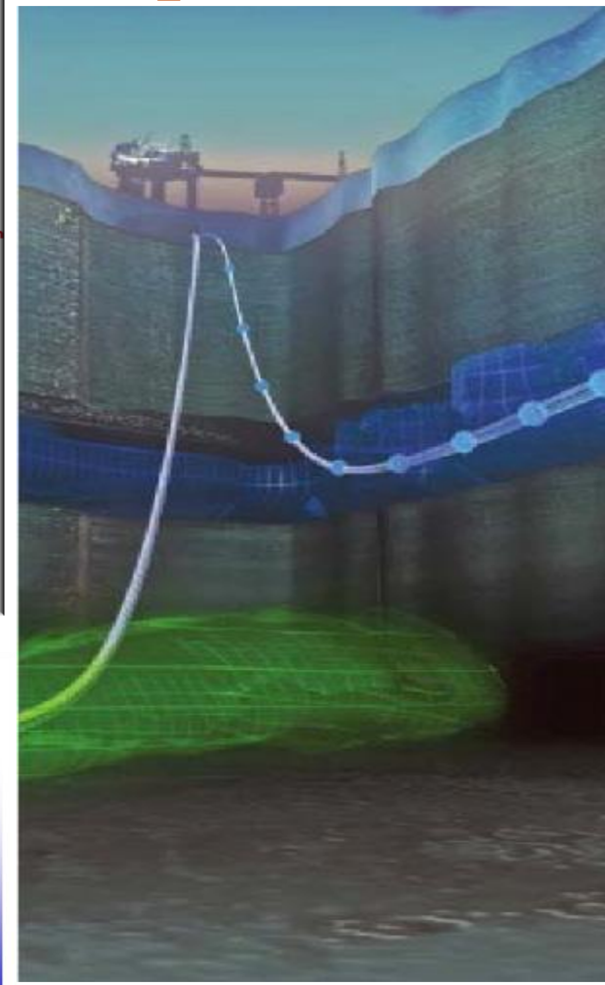
CO_2 for EOR







CO_2 storage



Motivation for using CO_2 for EOR and storage : *Large remaining oil resources and safe storage capacity*

NPD

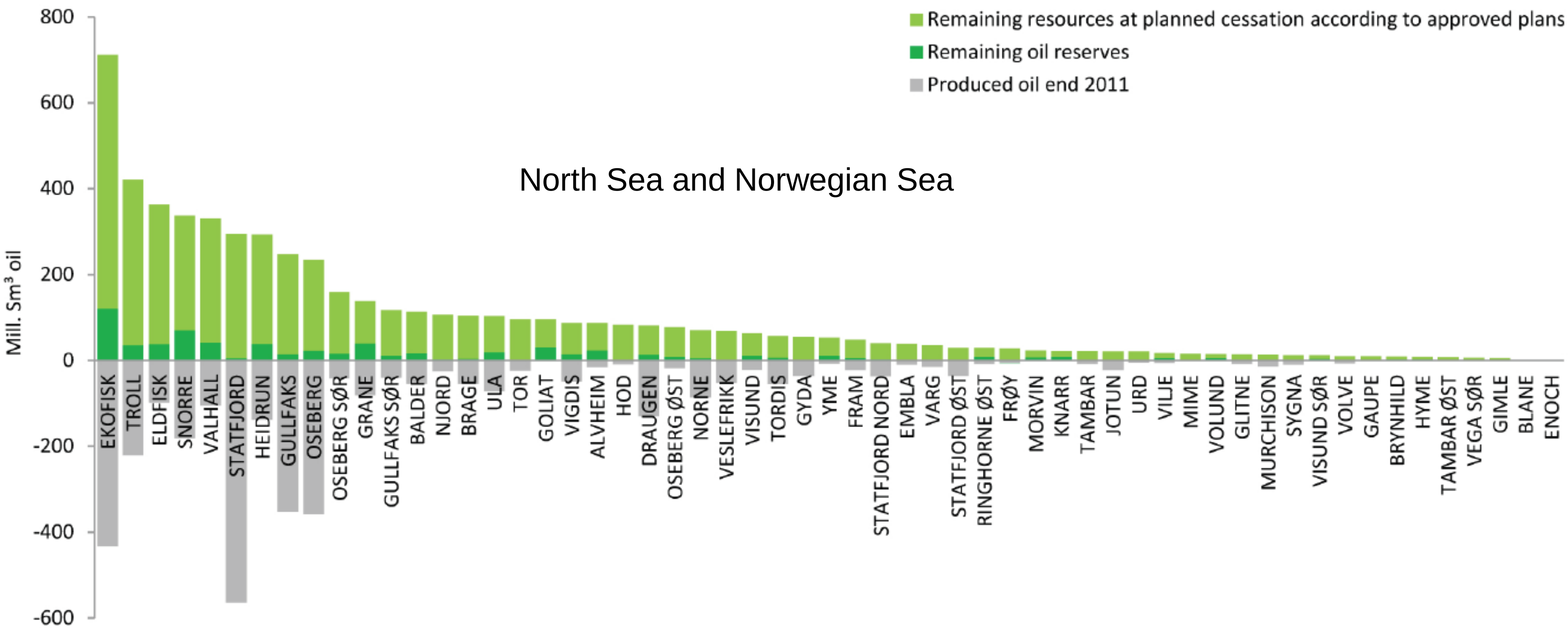


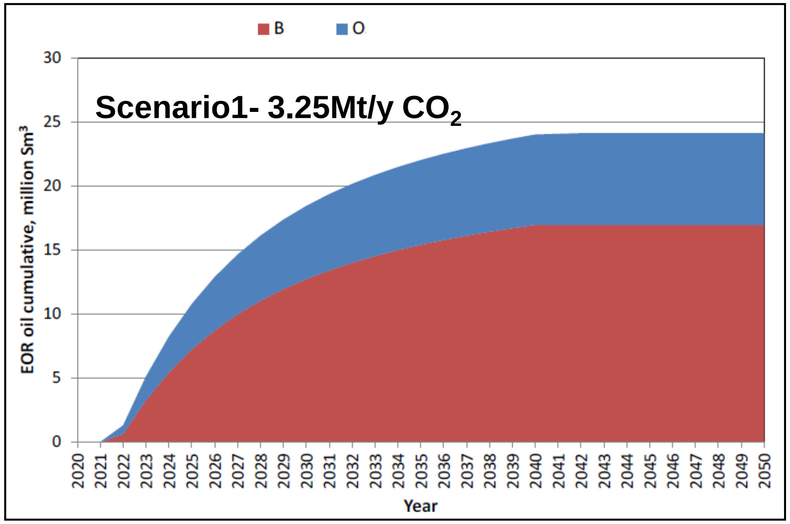
Figure 6.2 Distribution of oil resources and oil reserves in fields *(Source: Norwegian Petroleum Directorate)*

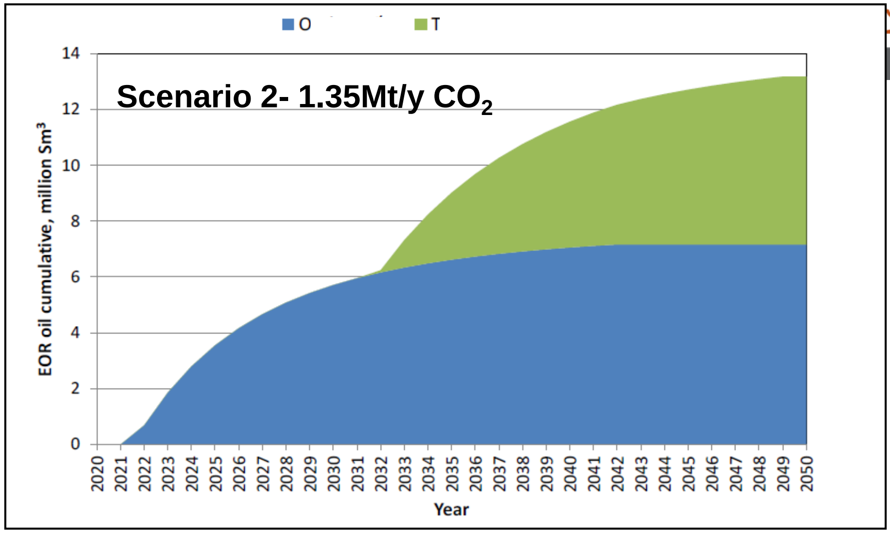
- 40 oil fields on production in the Norwegian North Sea selected for screening
- 23 fields chosen

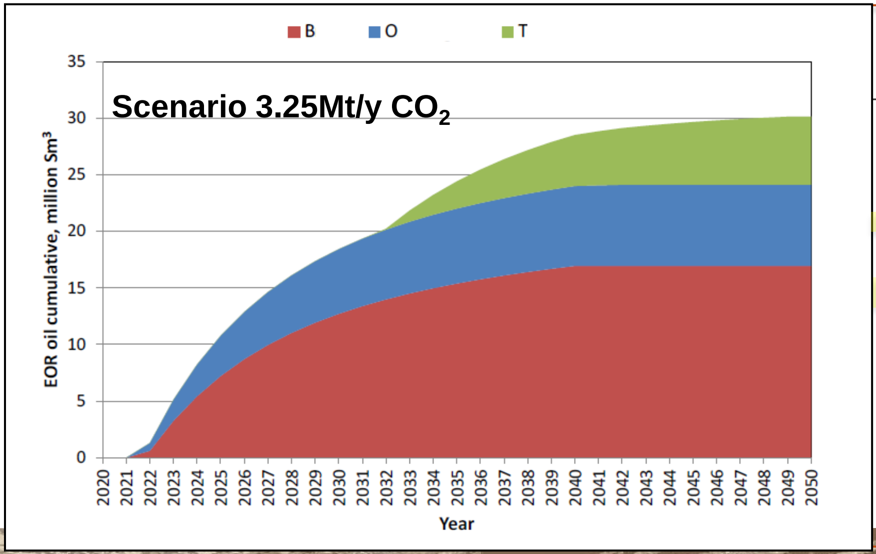
Theoretical potential for this study

- Total EOR oil - 322 mill Sm^3
- Total EOR recovery - 6.9%
- Total stored CO2 in oil fields - 1.3 bill. tonnes
- Total stored CO2 in aquifers   - 1.7 bill. tonnes

CO_2 for EOR with CO_2 available amount of 1-3Mt/y



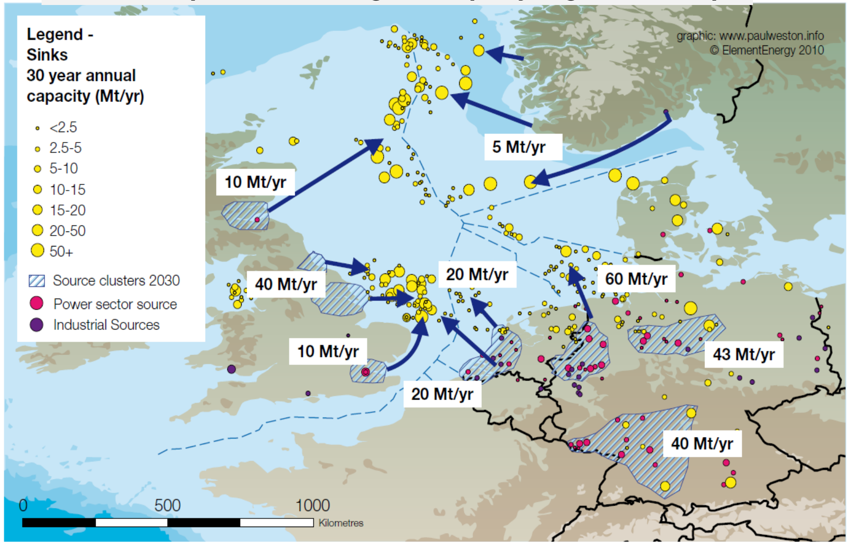


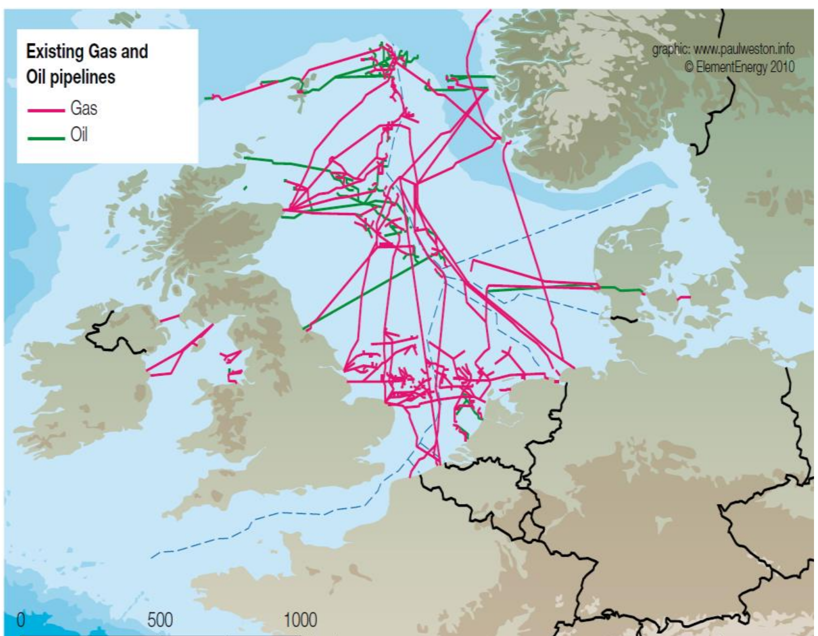


Economical results

	Scenario 1	Scenario 2	Scenario 3
Annual amount of CO_2 imported, million tonnes	3.25	1.35	3.25
Total well costs, billion USD	1.1	1.1	1.7
Total investment costs, billion USD	1.8	1.8	2.9
Total NPV, billion USD	5.3	2.9	6.9
Total oil production, % of OOIP	54.1	45.5	51.0
Total EOR oil, million Sm^3	24.1	13.2	30.1
Total EOR oil, % of OOIP	10.9	8.8	10.3
Total stored CO_2 in oil fields, million tonnes	28	25	43
Total stored CO_2 in aquifers, million tonnes	69	15	55

CCS transport and storage2030 (Very high scenario)





Source: "One North Sea" 2010

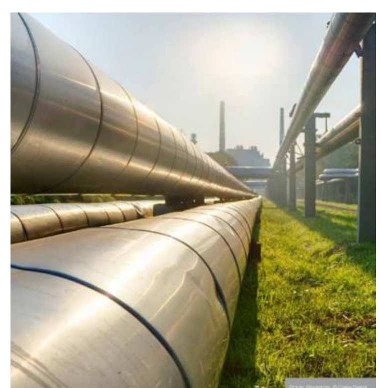
Transportation

International and National regulations

- **The London Protocol**
- **The OSPAR Convention**

Cross-border challenges

- Legal rights to transport CO_2 across borders
- Regulation of cross-border transport of captured CO_2
- Storage complex spanning national boundaries
- Cross border impacts from storage operation
- Emissions accounting



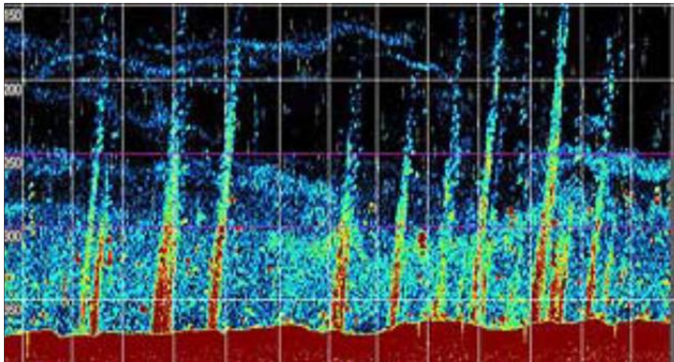
ABOUT CO_2 STORAGE

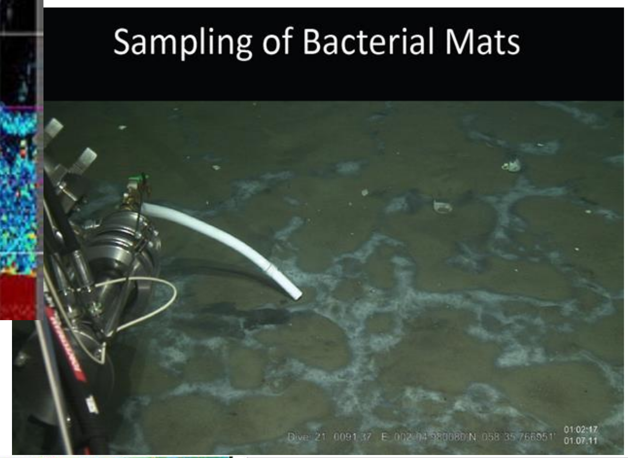
- **Shutdown of a storage site:** The operator is still responsible for monitoring, reporting and implementation of corrective action and responsible for sealing the storage site and removing the injection facilities.
  - **All available information indicates that the stored CO_2 will remain completely and permanently contained. The operator must document that the actual behavior of the injected CO_2 are consistent with the modeled behavior, that it can not be detected leakage and the storage locality develops toward a state of permanent stability.**

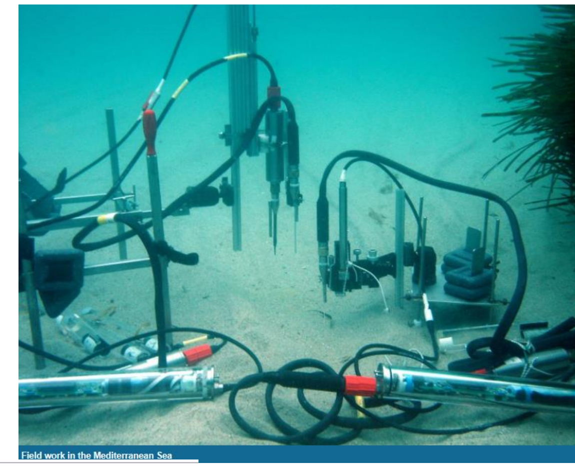
- A minimum period shall not be less than 20 years unless the Department or the attorney is convinced that the requirement are met before the end of this period,

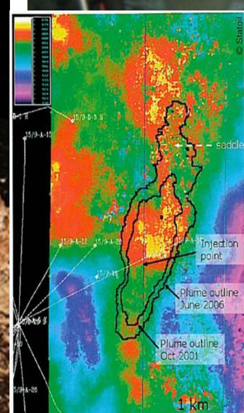
Tools for monitoring injected CO_2

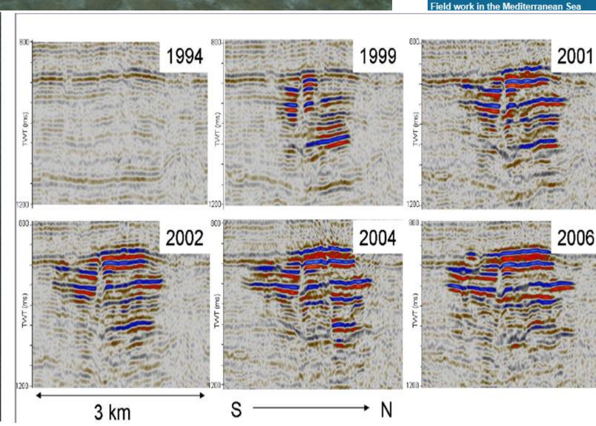
Effective and credible monitoring tools must be available

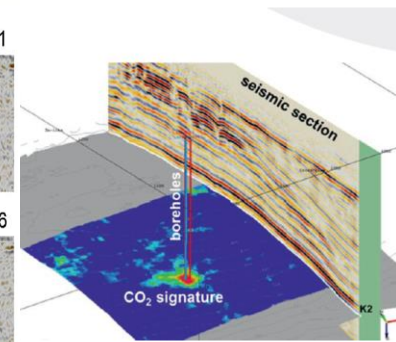












Summary

- The evaluation of geological volumes suitable for injecting and storing CO_2 in Norwegian continental shelf is summarized for the North Sea, Norwegian Sea and Barents Sea, total ~ 86.23 Gt.

- The total storage capacity of the North Sea aquifer much larger compared to the Norwegian and the Barents Sea. In the North Sea there are important aquifers at several stratigraphic levels, while in the Norwegian Sea and Barents Sea, only the Jurassic formations will be the main target for CO_2 injection.

- NPD's evaluation shows that Norwegian continental shelf has a substantial potential regarding CO_2 storage. In addition, using CO_2 for EOR/IOR purpose has a big potential.

Thank you!

Back up

QUIZ

1. If you burn 1 kg of methane, how much CO2 will be produced?

2. How much pore space will it occupy at 1000 m depth compared with the methane?

3. How much does the pressure increase in a closed aquifer after injecting CO_2 corresponding to 0.5 % of the pore water volume?

1. Approximately 3 kg (atomic weights of O, C and H)
2. Approximately 40 % (density 0,7 compared to 0,1)
3. A few tens of bars (water, rock and gas compressibility)

Results for Utsira-Skade aquifer

Utsira and Skade Fm		Summary
Storage system	half open to fully open	
Rock volume, m^3		2,5 E+12
Pore volume, m^3		5,26 E+11
Average depth		900 m
Average permeability		>1000 mD
Storage efficiency		4
Storage capacity aquifer		16 Gigatons
Storage capacity prospectivity		0,5-1,5 Gigatons
Reservoir quality		
	capacity	3
	injectivity	3
Seal quality		
	seal	2
	fractured seal	3
	wells	2
Data quality		
Maturation		level 2-4

$$M_{CO_2e} = V_r \times N/G \times \phi \times \rho_{CO_2r} \times S_{eff}$$

- V_r: rock volume
- N/G: sand fraction
- ϕ: average reservoir porosity
- ρ_{CO_2r}: CO_2 density at reservoir conditions
- S_{eff}: storage efficiency factor

Theoretical storage efficiency calculated from pore volume in a closed aquifer is typically 0.5 to 1 % because of pressure build-up.

Higher values for depleted aquifers or if formation water is produced.

In half-open aquifers a value of 4% is regarded as typical, but should be tested by reservoir simulation.

The Bryne Formation

CHECKLIST FOR RESERVOIR PROPERTIES

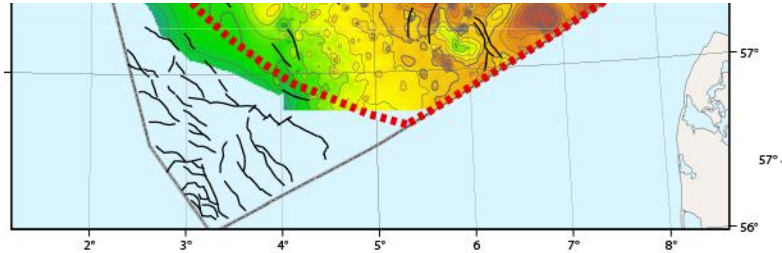
Typical high and low scores		
Reservoir Properties	High	Low
Aquifer Structuring		v /uncertain closures
Traps		nition of traps
Pore pressure		sure
Depth		or > 2500 m
Reservoir		neous
Net thickness		< 15 m
Average porosity in ne		< 15 %
Permeability		< 10 mD

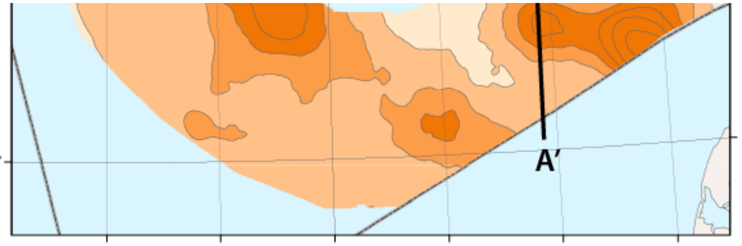
CHARACTERIZATION OF AQUIFERS AND STRUCTURES

Criteria		
Reservoir quality	Capacity, communicating volumes	3 2 1
	Injectivity	3 2 1

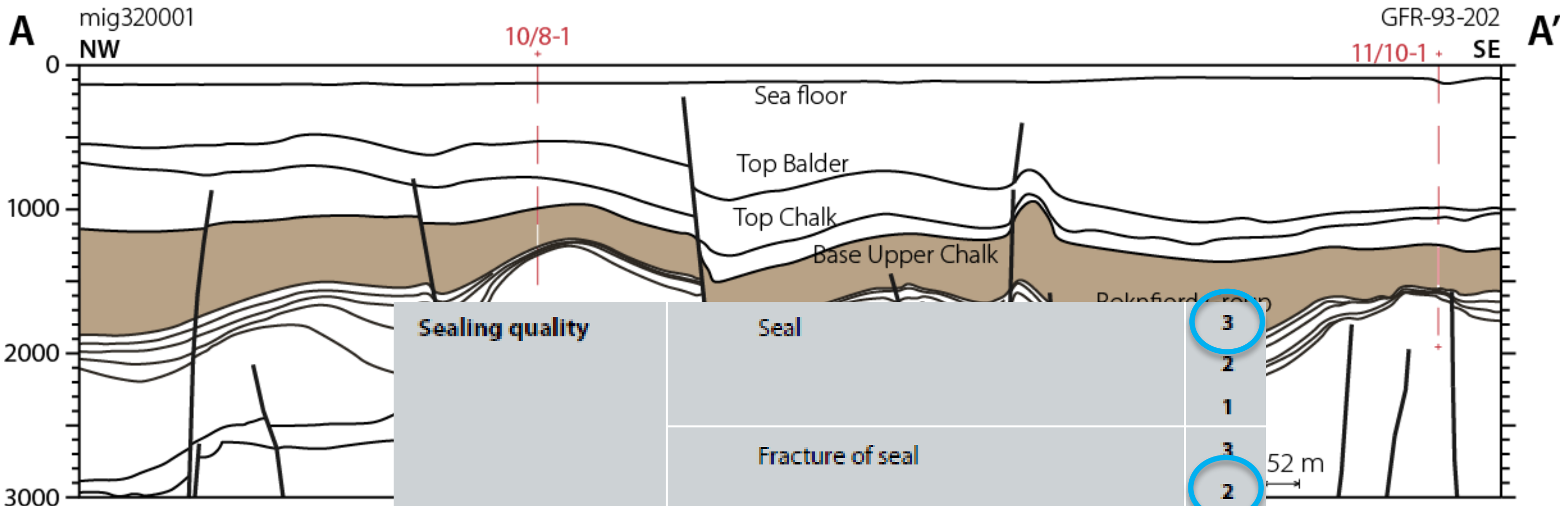
Data coverage

- Good : 3D seismic, wells through the actual aquifer/structure
- Limited : 2D seismic, 3D seismic in some areas, wells through equivalent geological formations
- Poor : 2D seismic or sparse data





The Boknfjord Group



Sealing quality	Seal	3 2 1
	Fracture of seal	3 2 1
Other leak risk	Wells	3 2 1

Data coverage
Good : 3D seismic, wells through the actual aquifer/structure
Limited : 2D seismic, 3D seismic in some areas, wells through equivalent geological formations
Poor : 2D seismic or sparse data

FOR SEALING PROPERTIES			
Sealing Properties	High	Low	Unacceptable values
Sealing layer			No known sealing layer over parts of the reservoir
Properties of seal			
Composition of seal			
Faults	No faulting of the seal	Big throw through seal	Tectonically active faults
Other breaks through seal	No fracture	sand injections, slumps	Active chimneys with gas leakage
Wells (exploration/ production)	No drilling through seal	High number of wells	