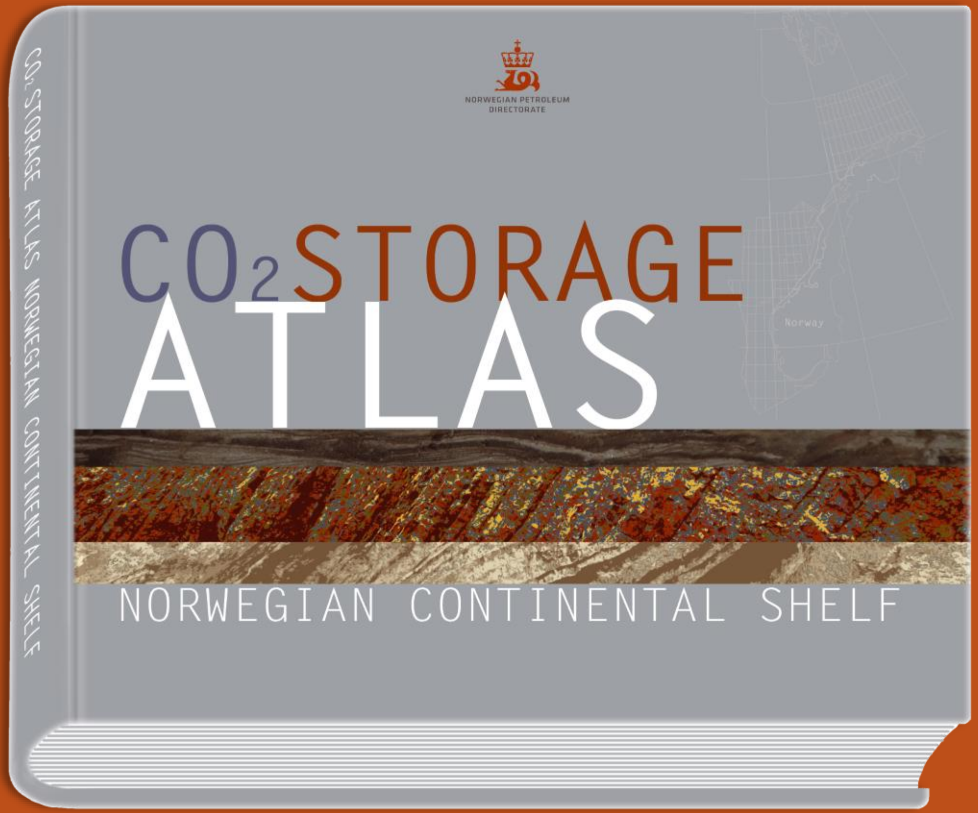
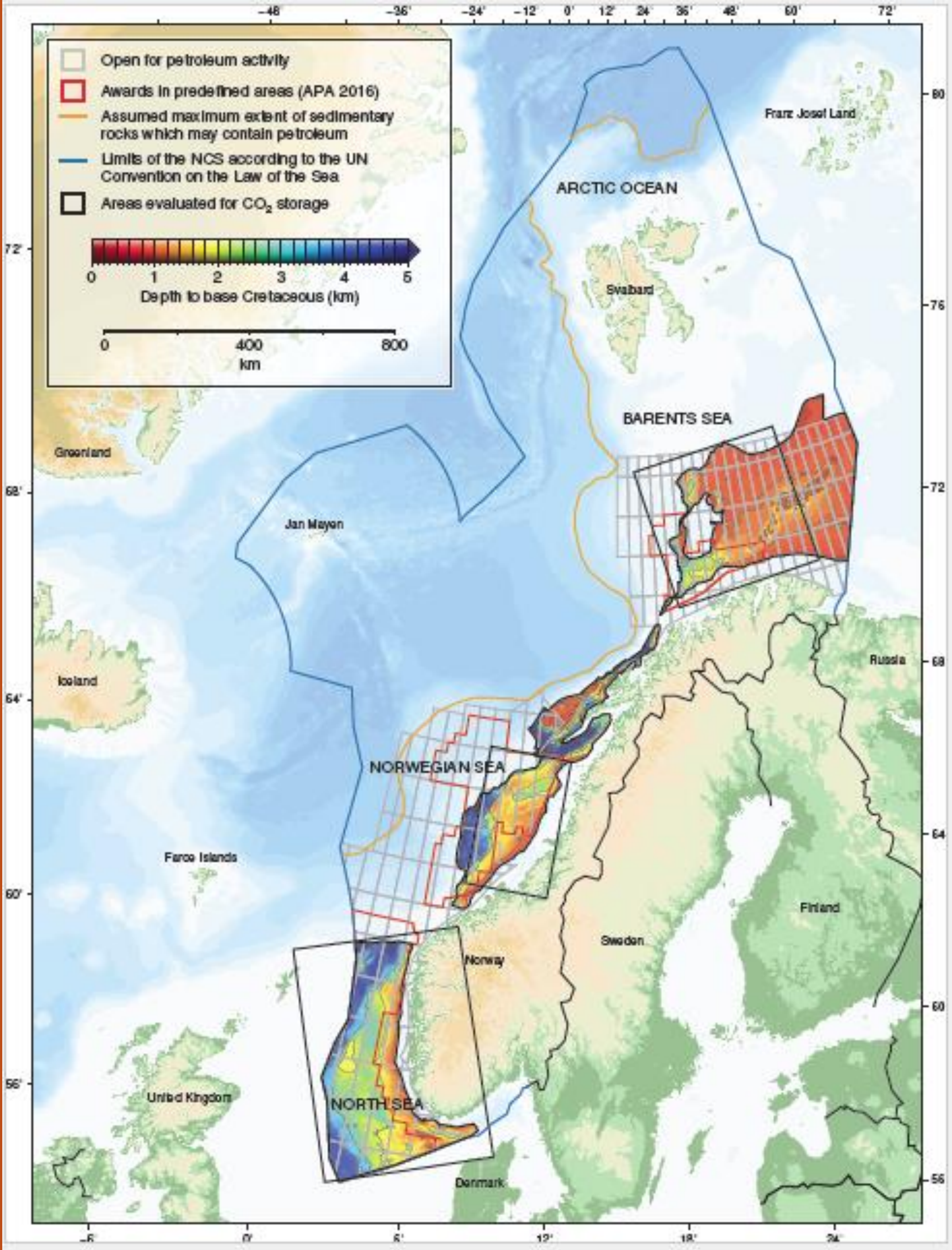


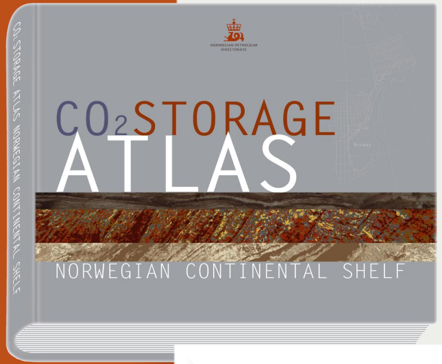
The Atlas was launched by the Norwegian Minister for Petroleum and Energy May 20th 2014

NORWEGIAN PETROLEUM DIRECTORATE

Outline

- About storage of CO2
- About utilization of CO2
- About CO2 intensive industries
- About CO2 transportation
- About regulation and incentives





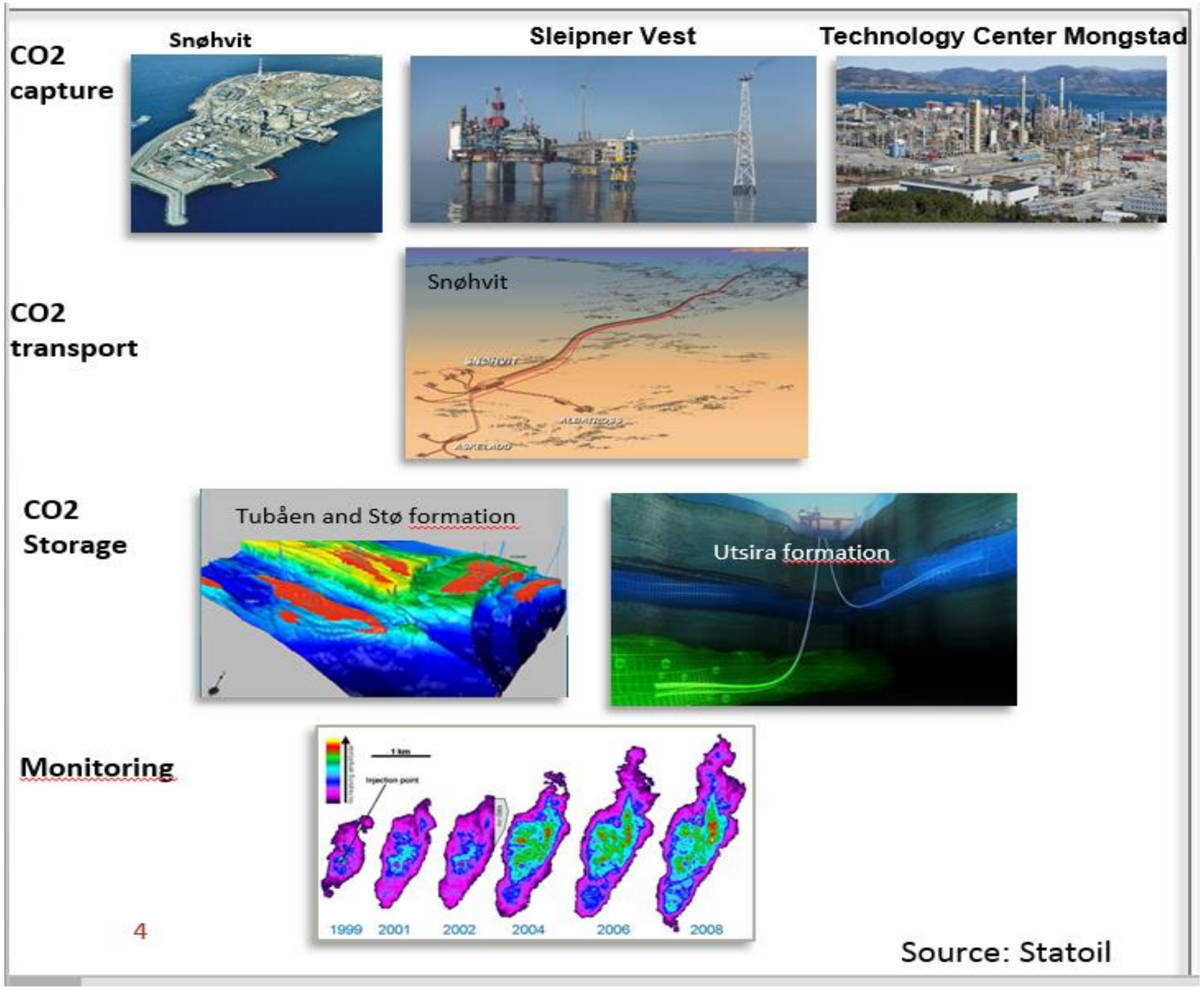
NORWEGIAN PETROLEUM DIRECTORATE

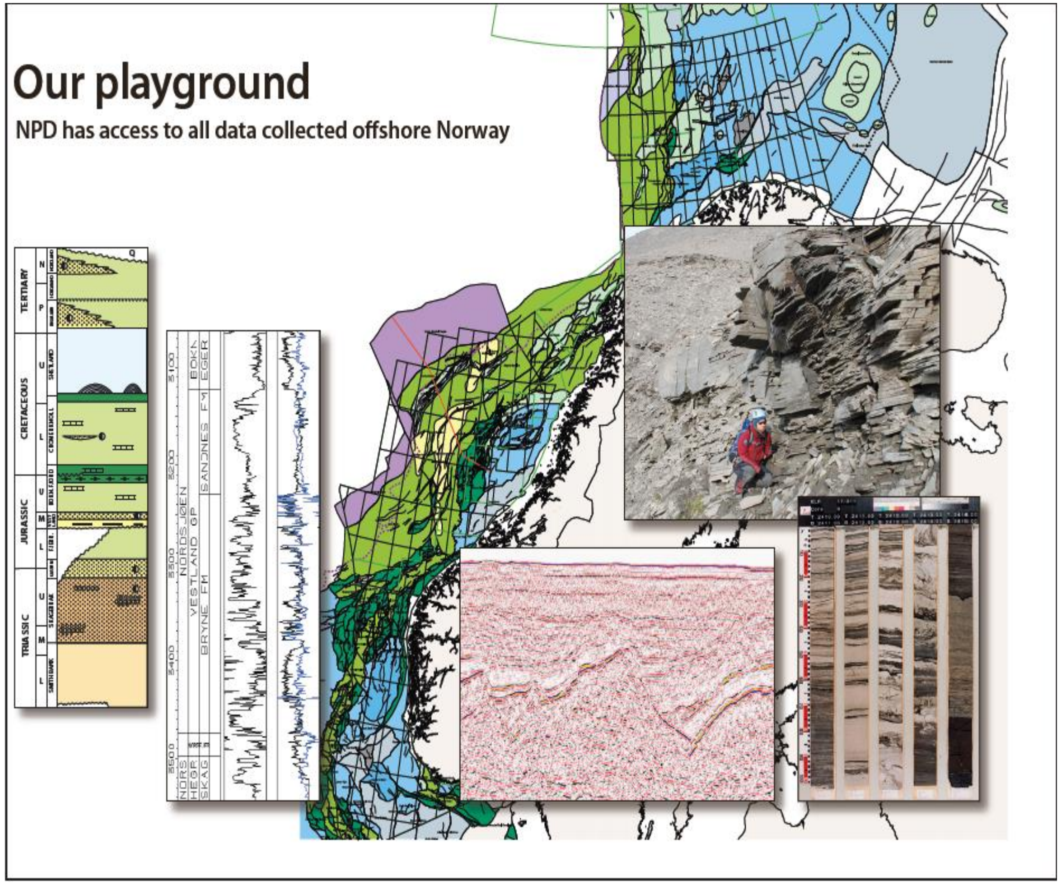
Objectives and requirements

- Find the safe and effective areas for storage of CO_2
- No interference with the petroleum activity
- Build on the accumulated knowledge from the Norwegian petroleum activity
- Build on the experience we have with CO_2 storage
- Mapping and volume calculations should be verifiable
- The work will define relevant storage areas and estimated storage capacities
- The evaluation will form the basis for any terms and conditions set for a development of a storage site offshore Norway

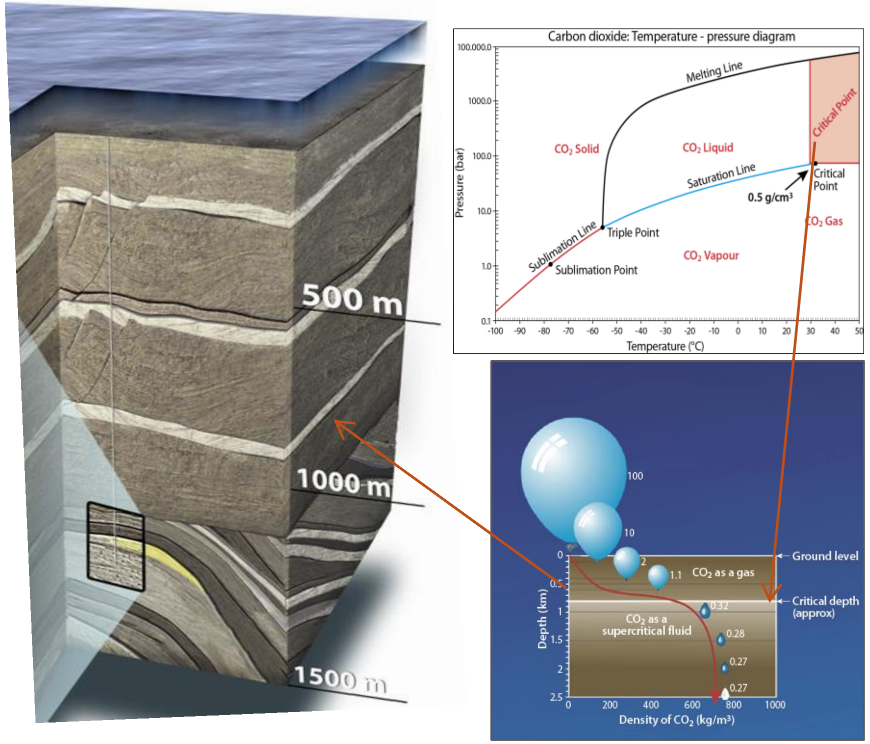
Norwegian CCS experience

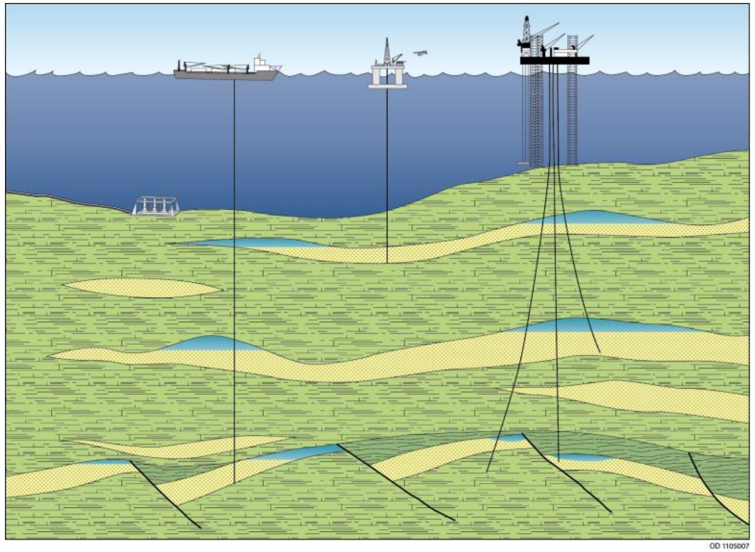
20 years with offshore CO_2 storage





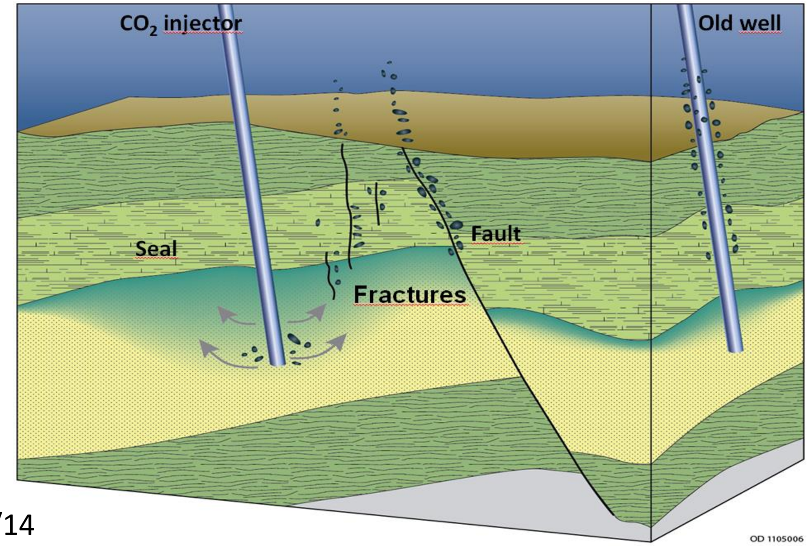
Conditions, sites and leakage points for storage of CO_2





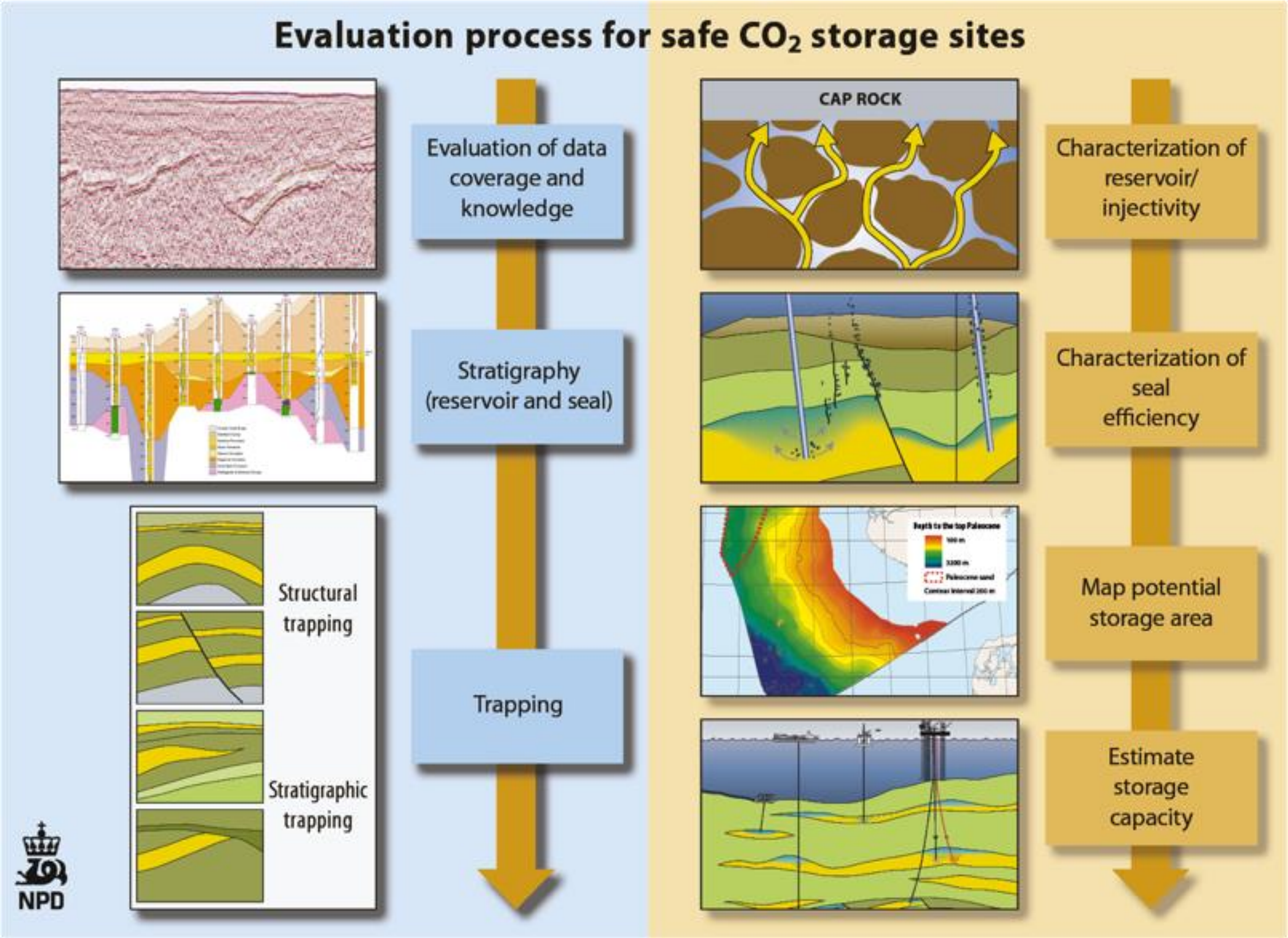
Type of storage sites

- Saline aquiferes
- Water- filled structures (dry-drilled)
- Abandoned hydrocarbon fields
- Producing fields (EOR)



Potential leakage risks

- Faults
- Seal
- Old wells
- Injection wells


Evaluation process for safe CO_2 storage sites
Evaluation of data coverage and knowledge
Stratigraphy (reservoir and seal)
Trapping
Structural trapping
Stratigraphic trapping
CAP ROCK
Characterization of reservoir/ injectivity
Characterization of seal efficiency
Map potential storage area
Estimate storage capacity
NPD

Characterization and Maturation of potential CO_2 storage sites

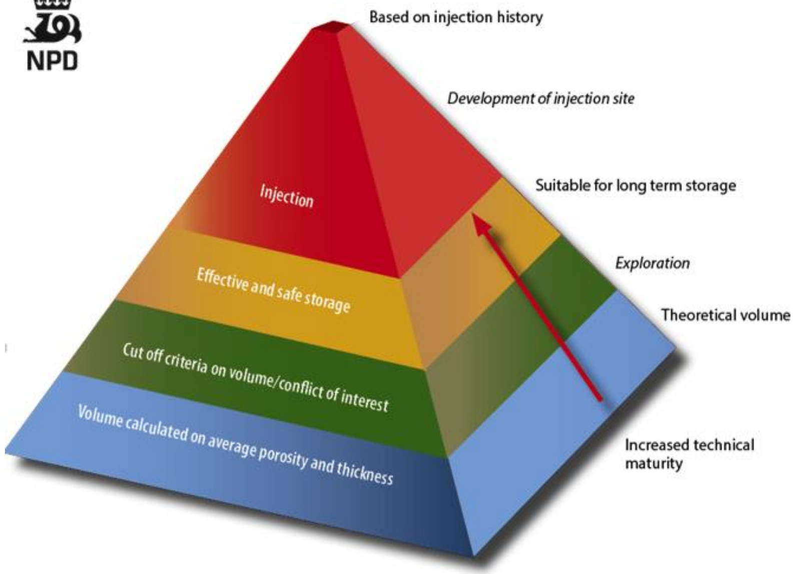
CHARACTERIZATION OF AQUIFERS AND STRUCTURES

	Criteria	Definitions, comments	
Reservoir quality	Capacity, communicating volumes	3	Large calculated volume, dominant high scores in checklist
		2	Medium - low estimated volume, or low score in some factors
		1	Dominant low values, or at least one score close to unacceptable
	Injectivity	3	High value for permeability * thickness (k*h)
		2	Medium k*h
		1	Low k*h
Sealing quality	Seal	3	Good sealing shale, dominant high scores in checklist
		2	At least one sealing layer with acceptable properties
		1	Sealing layer with uncertain properties, low scores in checklist
	Fracture of seal	3	Dominant high scores in checklist
		2	Insignificant fractures (natural / wells)
		1	Low scores in checklist
Other leak risk	Wells	3	No previous drilling in the reservoir / safe plugging of wells
		2	Wells penetrating seal, no leakage documented
		1	Possible leaking wells / needs evaluation
Data coverage	Good data coverage	Limited data coverage	Poor data coverage

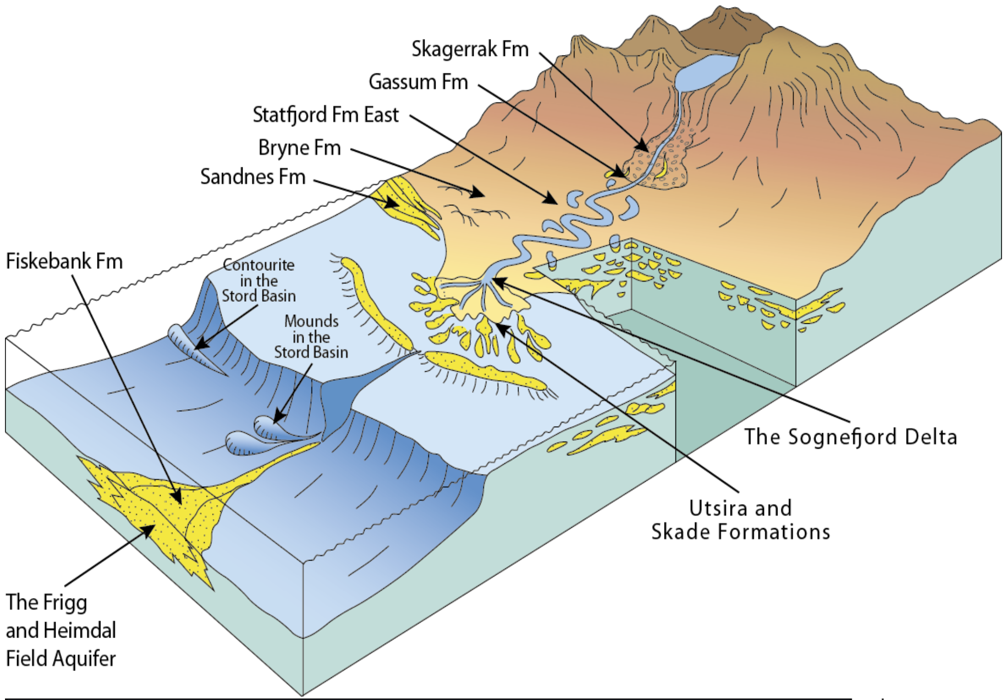
Other factors:
How easy / difficult to prepare for monitoring and intervention. The need for pressure relief. Possible support for EOR projects. Potential for conflicts with future petroleum activity.

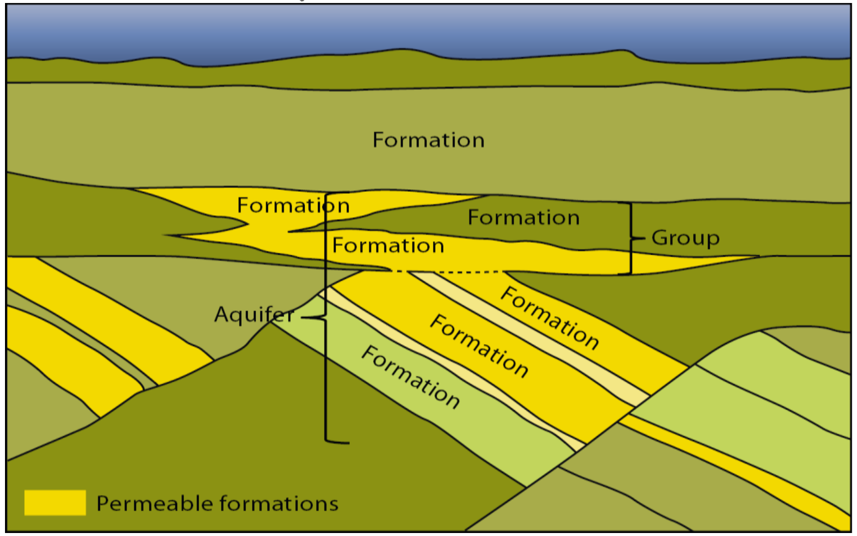
Data coverage
Good : 3D seismic, wells through the actual aquifer/structure
Limited : 2D seismic, 3D seismic in some areas, wells through equivalent geological formations
Poor : 2D seismic or sparse data

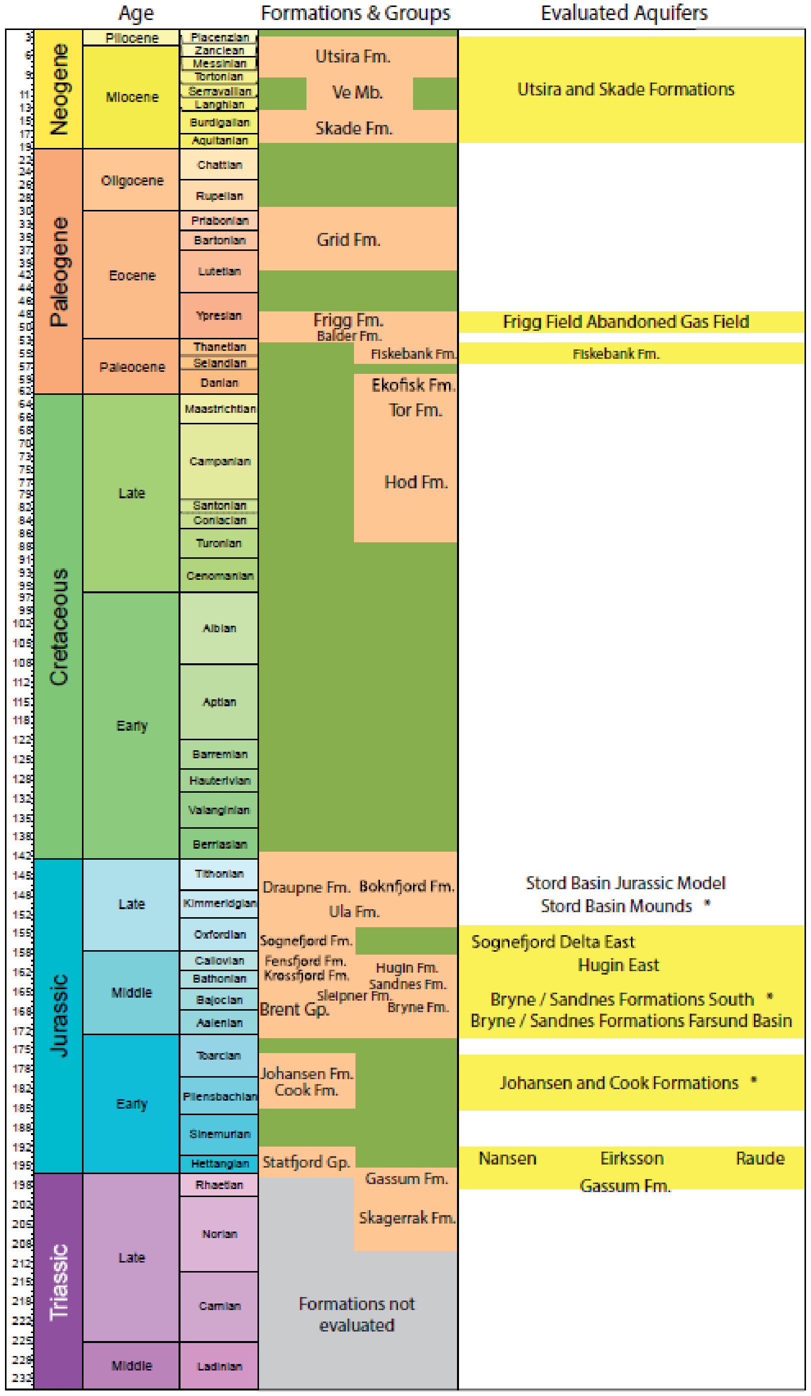
NPD



Geological formations and saline aquifers



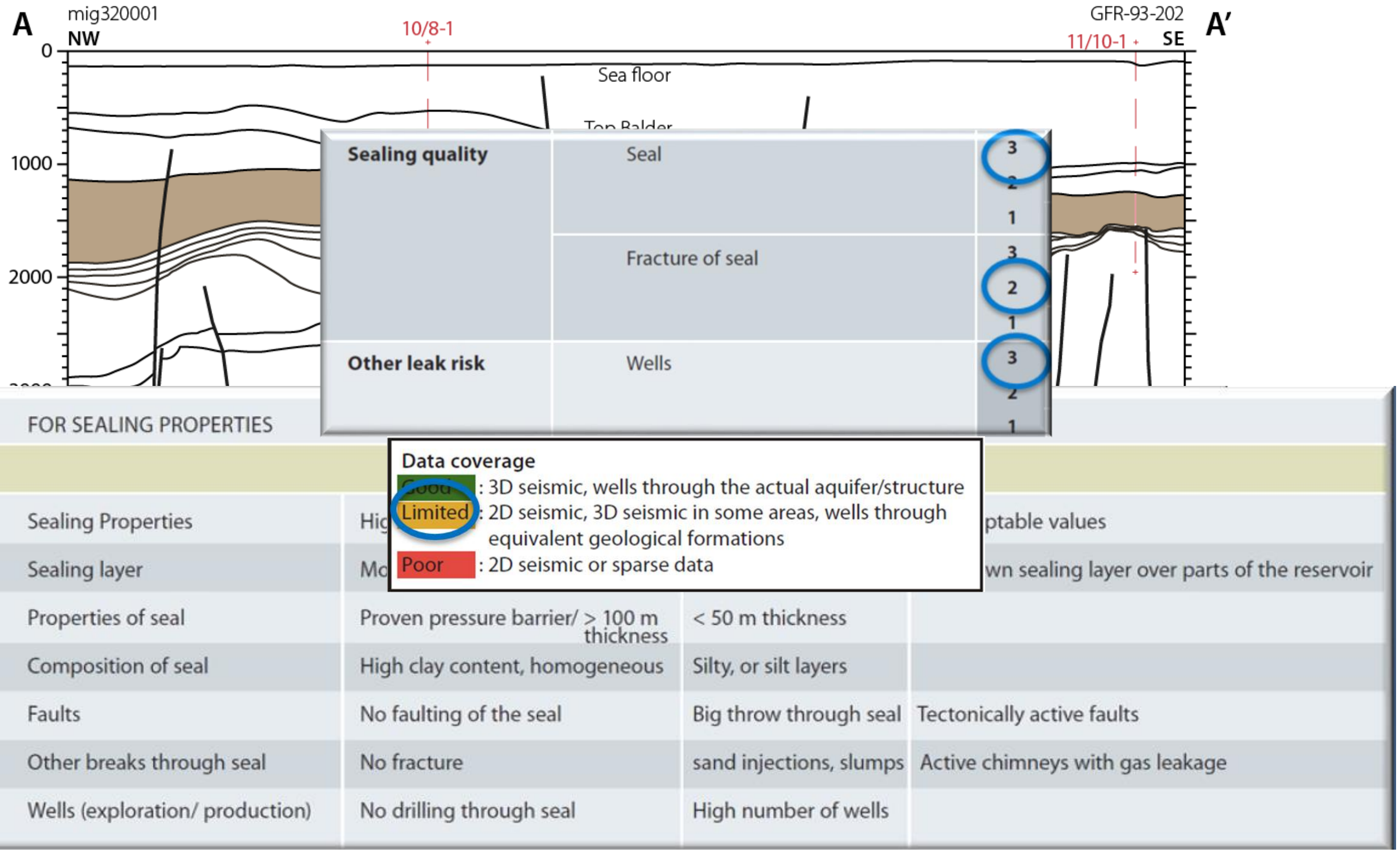




* Evaluated prospects

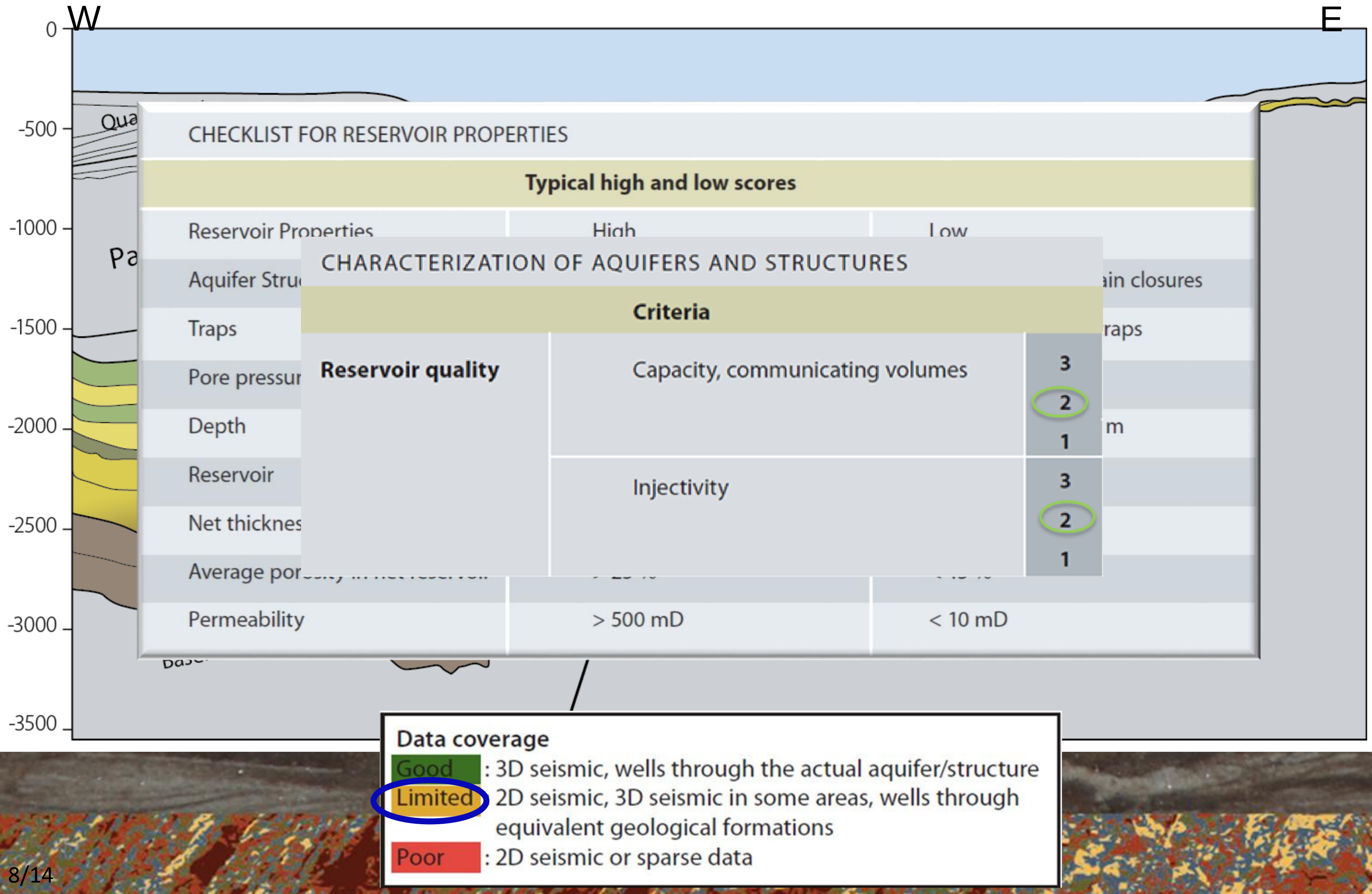
The Boknfjord Group, North Sea

(an example of how to evaluate a seal for a CO_2 storage site)

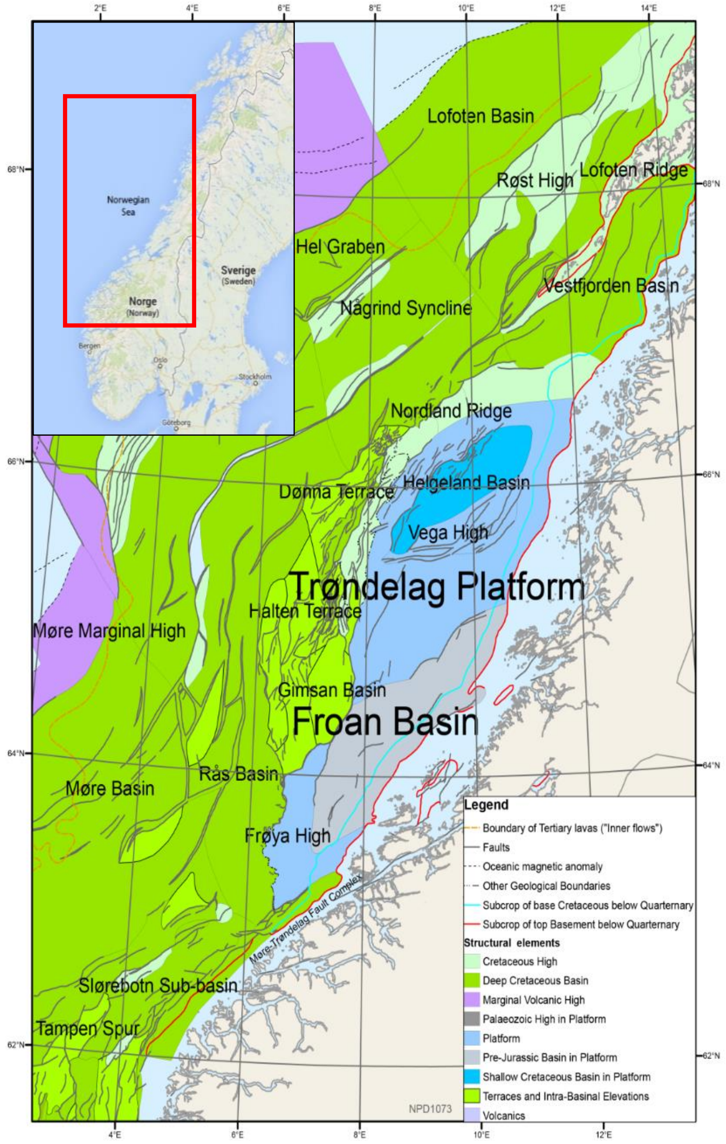


Froan Basin, Norwegian Sea

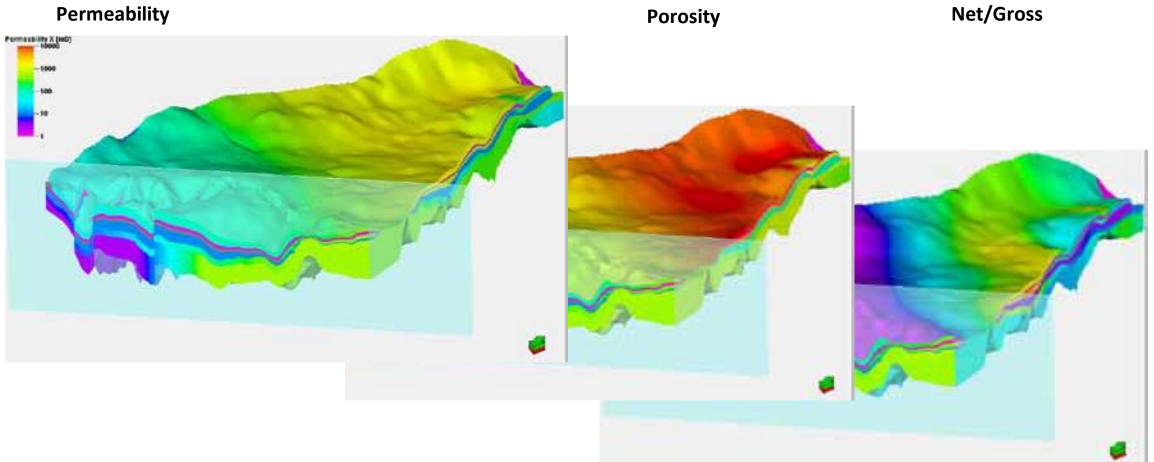
(an example of how to evaluate a saline aquifer as a CO_2 storage site)

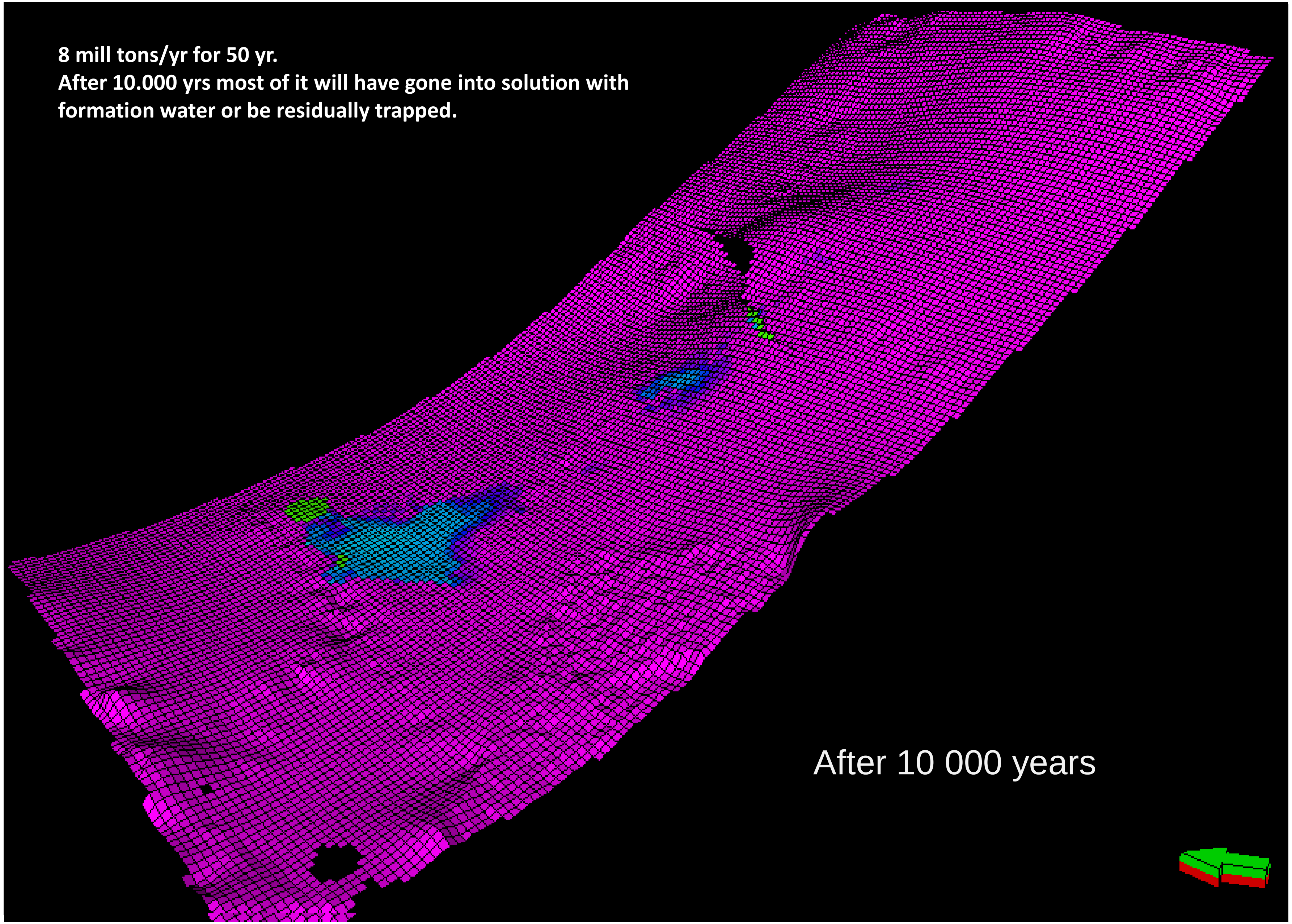


Example from the Froan Basin



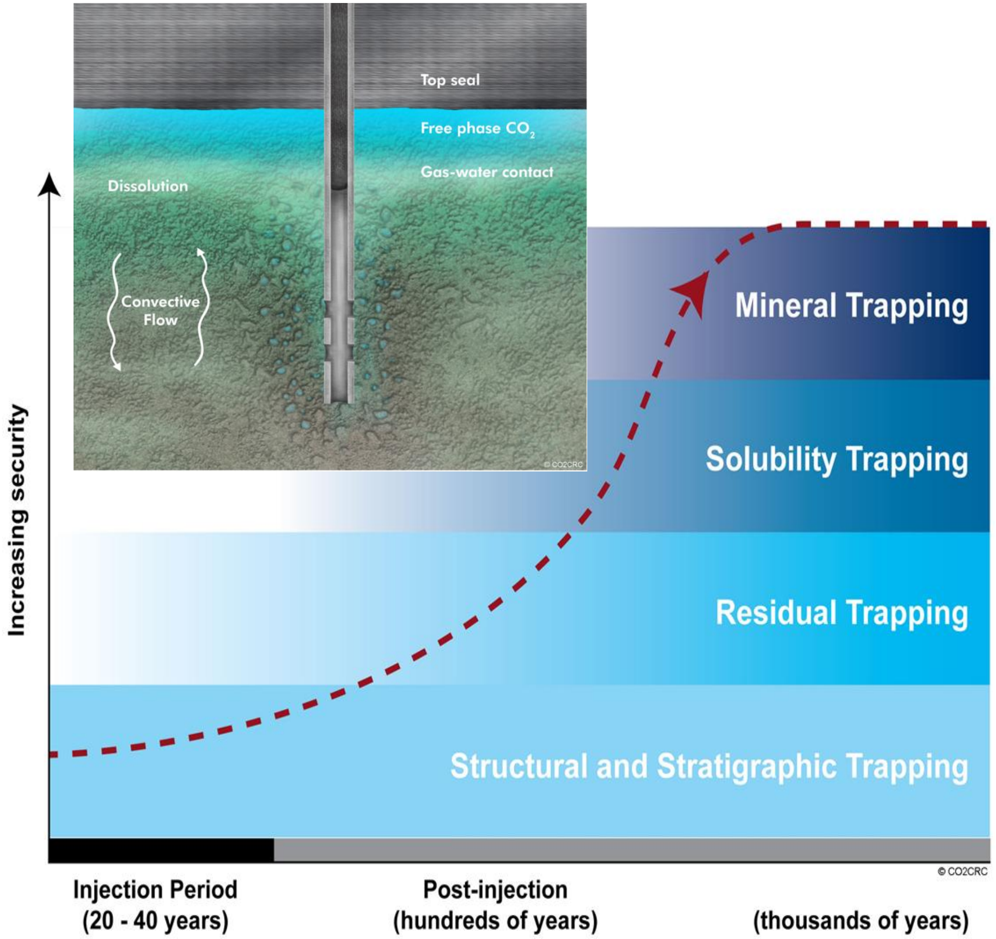
The Garn/Ile aquifer		Summary	Summary
Storage system		half open	closed
Rock volume		4400 Gm^3	4400 Gm^3
Net volume		1100 Gm^3	1100 Gm^3
Pore volume		300 Gm^3	300 Gm^3
Average depth Garn Fm		1675 m	1675 m
Average depth Ile Fm		1825 m	1825 m
Average net/gross		0.25	0.25
Average porosity		0.27	0.27
Average permeability		580 mD	580 mD
Storage effieciency		4 %	0.2 %
Storage capacity aquifer		8 Gt	0.4 Gt
Reservoir quality			
	capacity	2	2
	injectivity	3	3
Seal quality			
	seal	3	3
	fractured seal	3	3
	wells	3	3
Data quality			
Maturation			

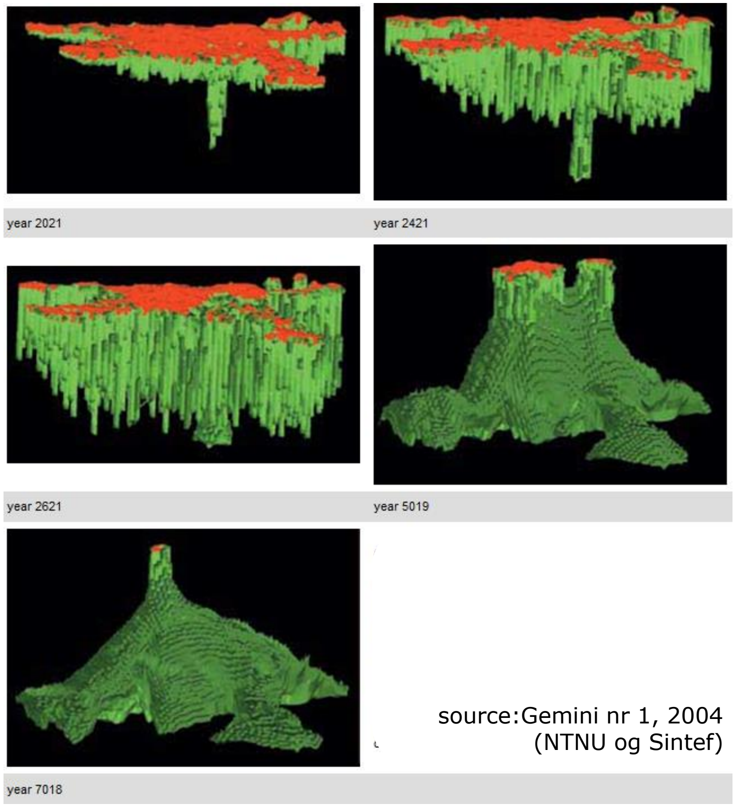



8 mill tons/yr for 50 yr.
After 10.000 yrs most of it will have gone into solution with formation water or be residually trapped.
After 10 000 years

CO_2 after termination of injection

CO_2 dissolves in water and become heavier than water





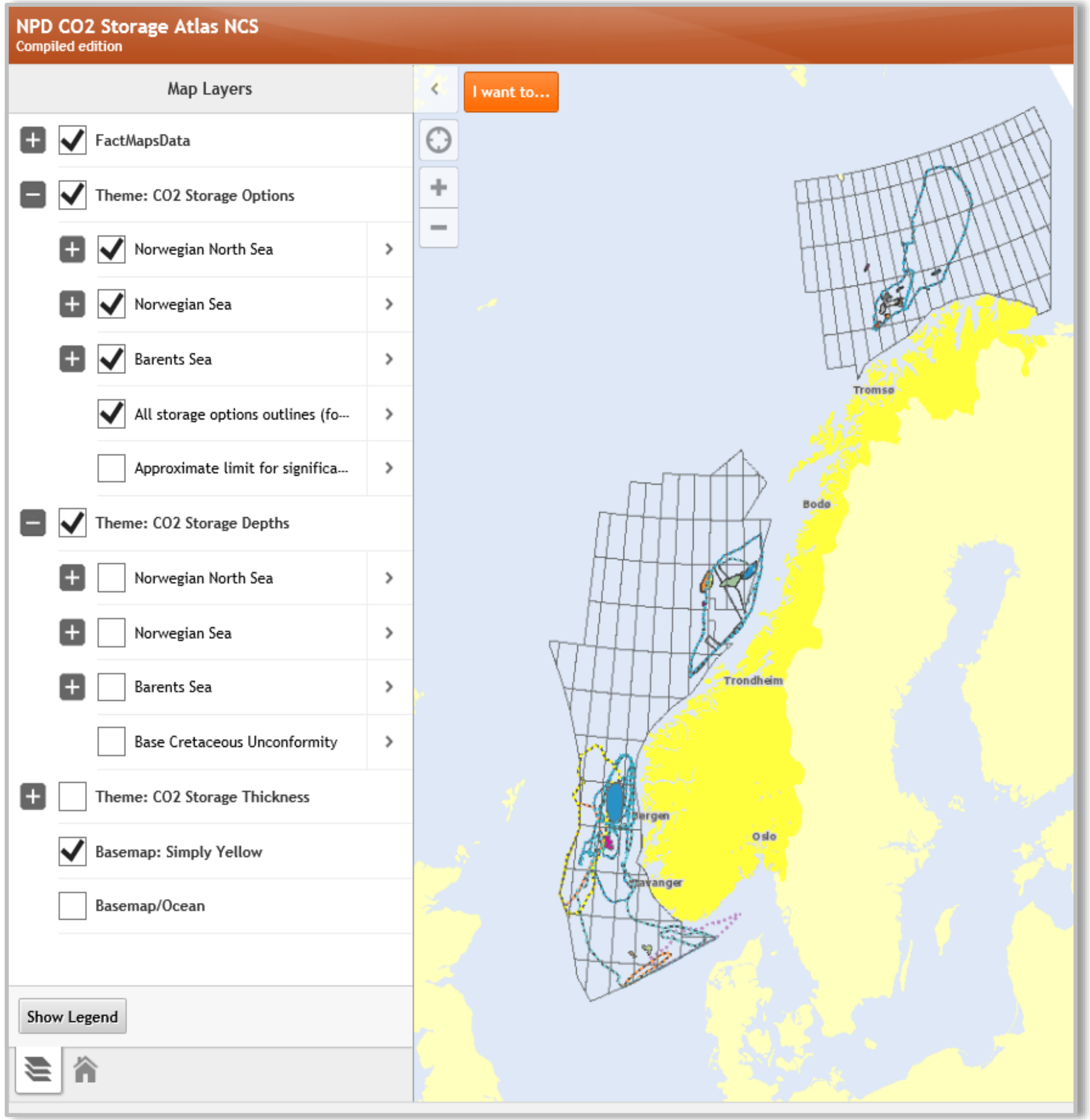
source:Gemini nr 1, 2004
(NTNU og Sintef)

Storage capacities, characterization and maturation of potential CO_2 storage sites on The Norwegian Continental Shelf

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		
Norwegian Sea aquifers					
Garn and Ile Formations	0,4	3	3		
Tilje and Åre Formations	4	2	2/3		
Barents Sea aquifers					
Realgrunnen Subgroup, Bjarmeland Platform	4,8	3	2		
Realgrunnen Subgroup, Hammerfest Basin	2,5	3	2		
Evaluated prospects					
North Sea	0,44				
Norwegian Sea	0,17				
Barents Sea	0,52				
Abandoned fields					
North Sea	3				
Producing Fields_2050					
North Sea 2050	10				
North Sea_Troll aquifer	14				
Norwegian Sea	1,1				
Barents Sea	0,2				

Interaktive CO2 Storage Atlas

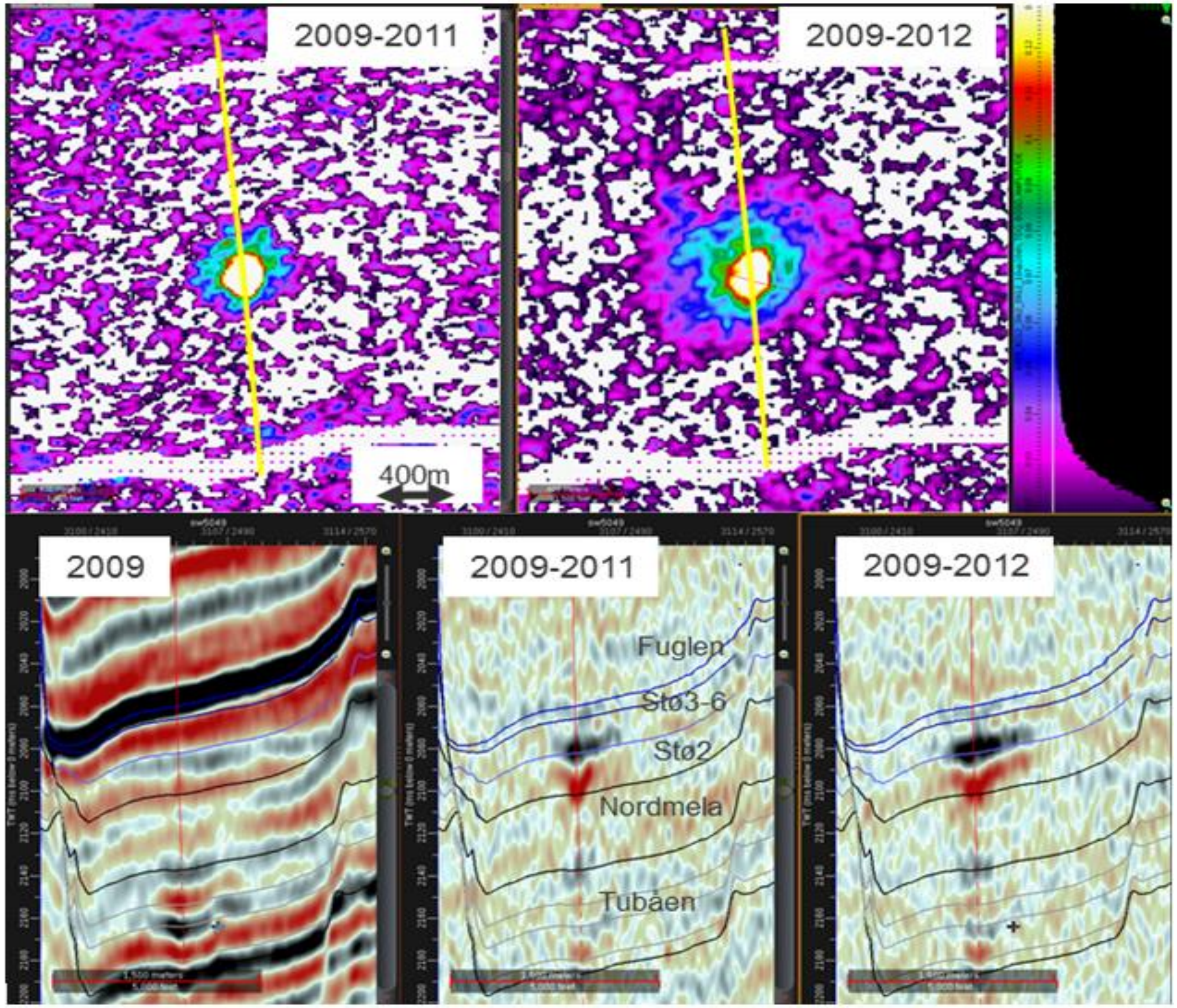
http://gis.npd.no/themes/co2storageatlas/



CO_2 Storage Capacity
Norwegian Continental Shelf

Safe carbon dioxide (CO_2) storage in geological formations depends on careful storage site selection.

Snøhvit 4D Monitoring and pressure maintenace



The pressure in the Tubåen formation increased some faster then expected and the operator had to do an invterention in the well to preventmthat the pressure increase across ther established fracture pressure at 390 bar.

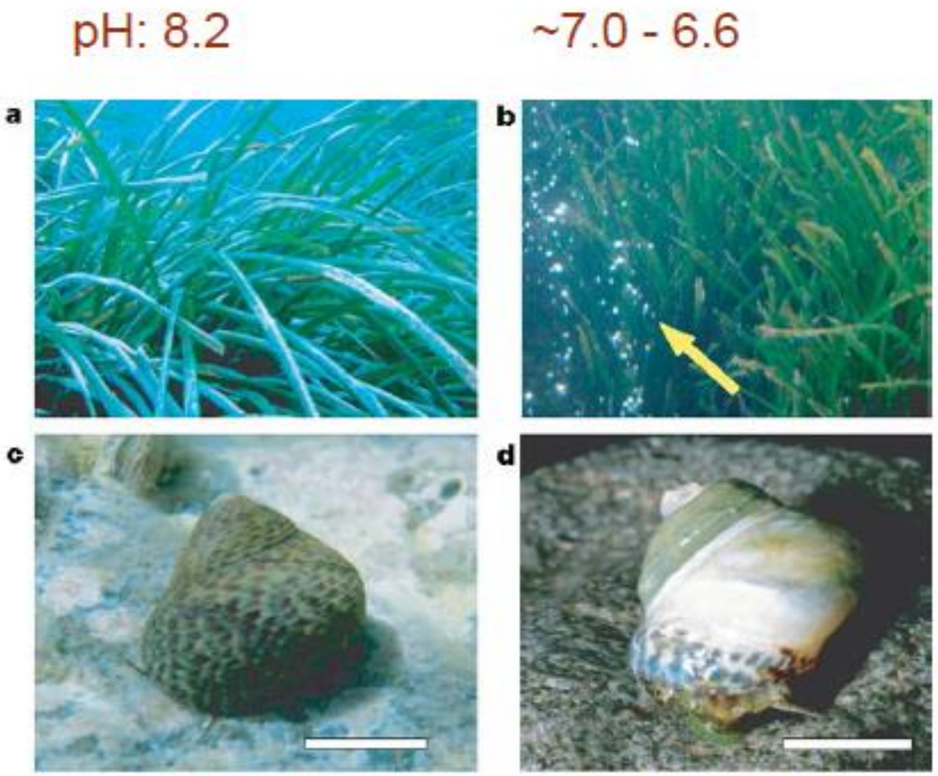
4D RMS amplitude map at Top Stø 2 (-10+20ms) for 2009-2011 (left) og 2009-2012

4D seismisk section for 2009 (left), 4D difference 2009-2011 (middle) and 2009-2012

Source: Statoil

We need to know the consequences of a possible CO_2 leakage on a short, medium and long term

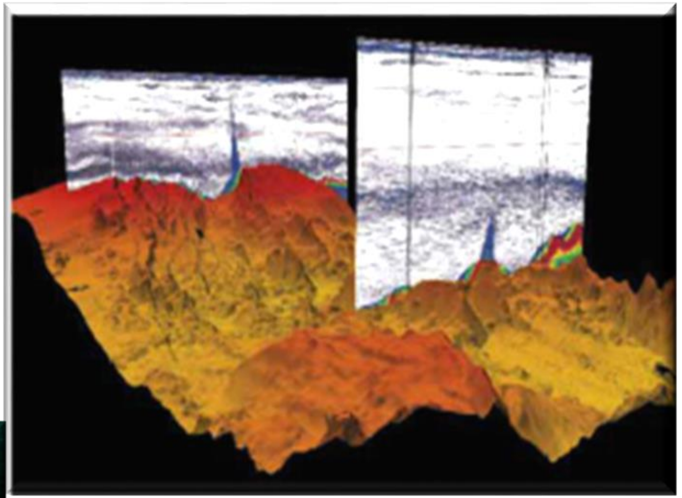
- Assess the ability of organisms and communities to adapt to elevated CO_2 levels
- Identify biological indicators & monitoring techniques to detect CO_2 seepage

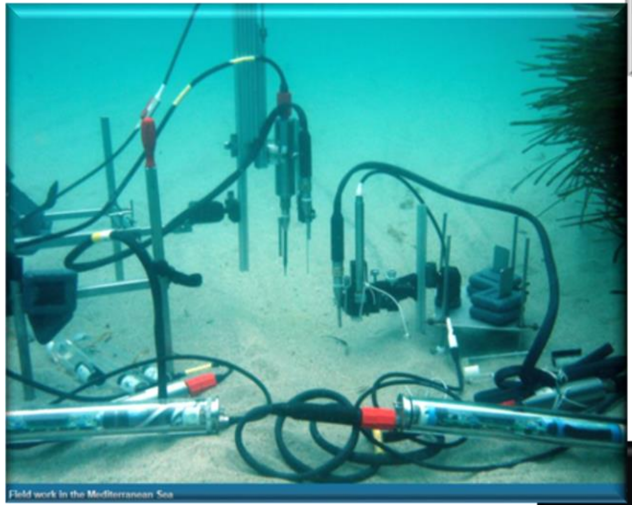


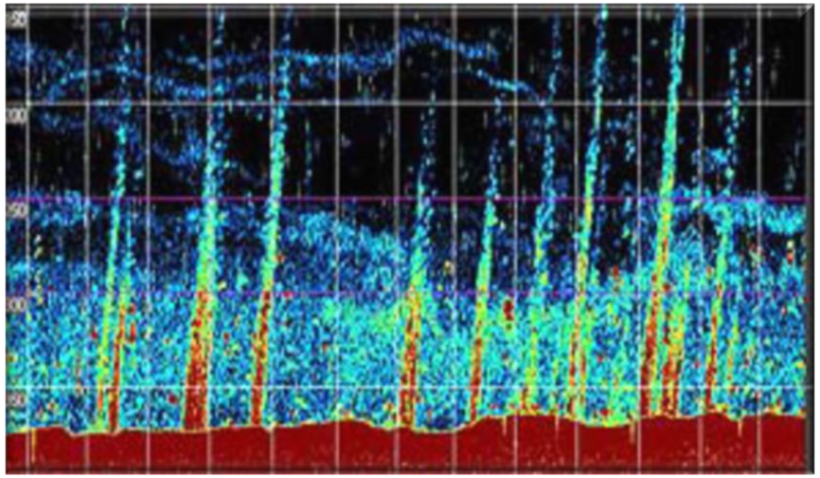
Source: Hall-Spencer et al., 2008

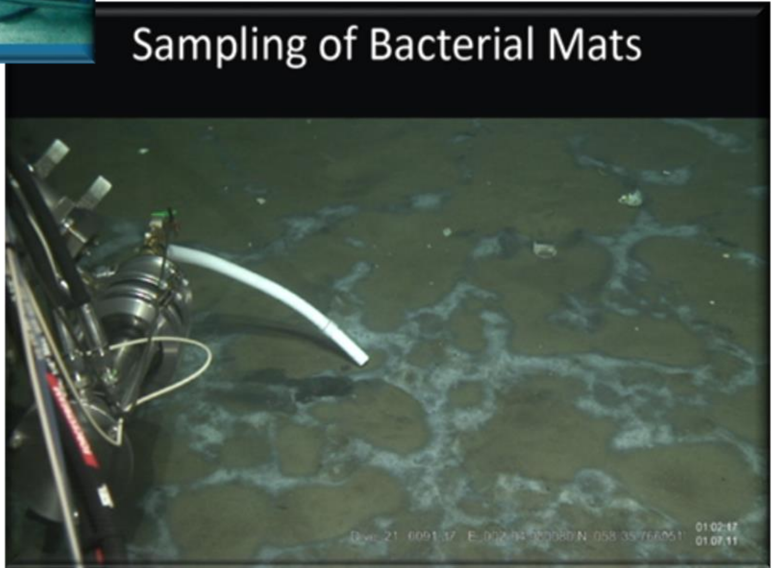
Methodes for early detection of a possible CO_2 leakage

- Pressure measurement in the wells
- Seismic
- Fauna/bacteria mats
- Monitoring of the water column









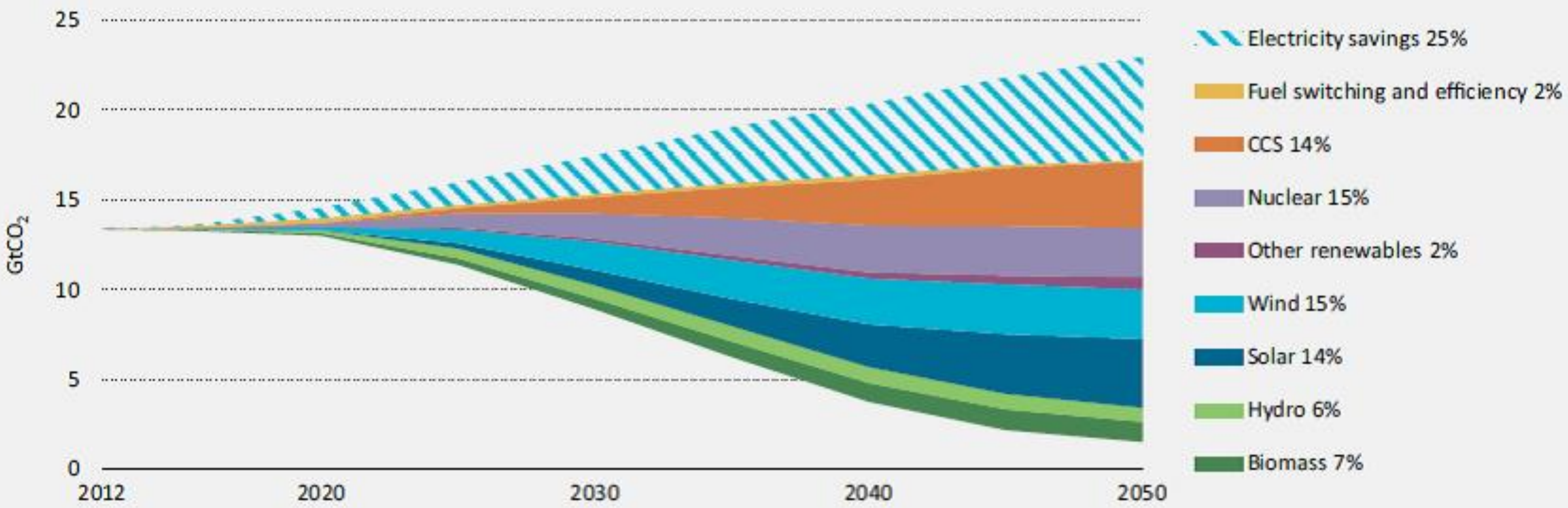
Why CCS?

NORWEGIAN PETROLEUM DIRECTORATE

COP21, the 2015 Paris Climate Conference

IEA scenarios

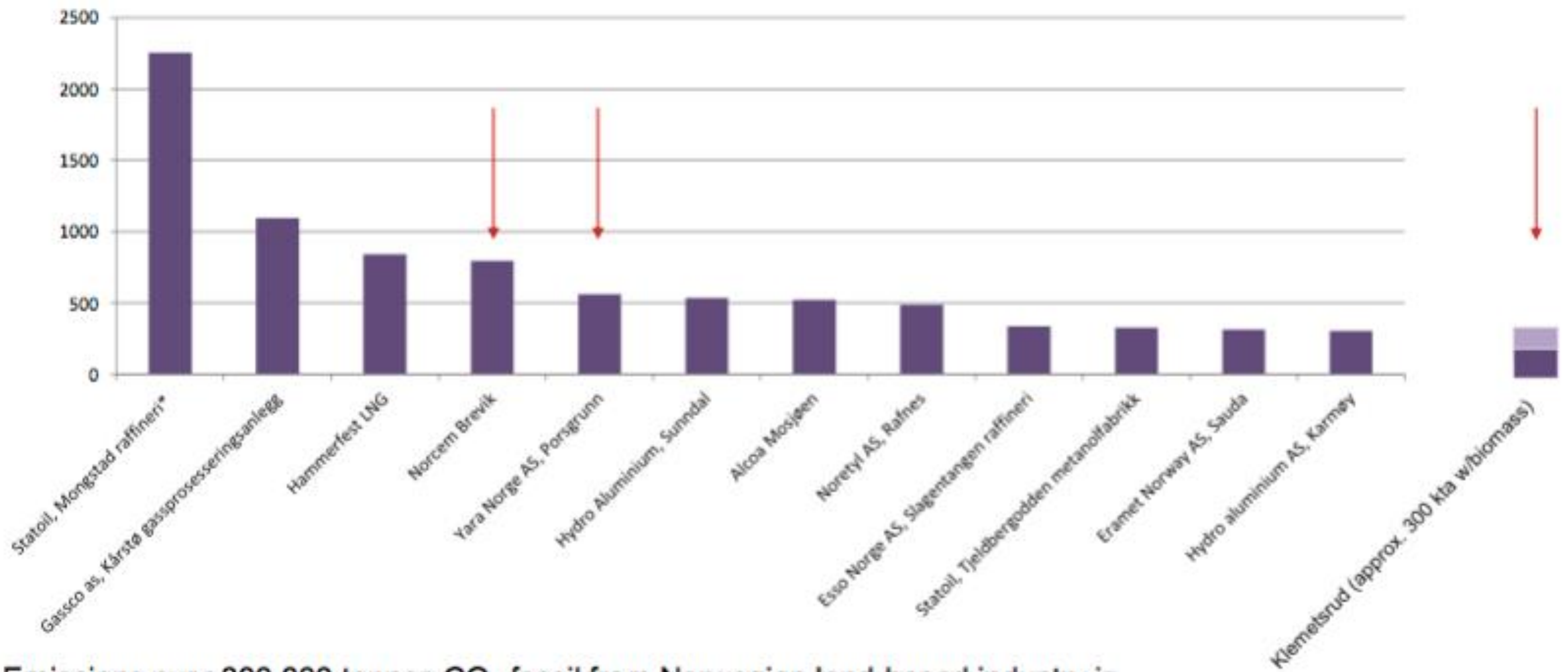
Key technologies to reduce power sector CO_2 emissions between 6DS and 2DS



Note: Percentage numbers refer to the contribution of the technology area to the cumulative CO_2 reduction between the 6DS and 2DS over the period 2012-50.

Key point *Electricity savings in the end-use sectors would stabilise power sector emissions at levels slightly above today's; a portfolio of low-carbon generation technologies is needed to sufficiently decarbonise electricity for 2DS targets.*

Norway has few suitable emission sources



Emissions over 300 000 tonnes CO_2 fossil from Norwegian land-based industry in 2013 (in 1000 tonnes) *includes emissions from Energiverk Mongstad

Source: Norwegian Environment Agency

CLIMIT is the national programme for research, development, piloting and demonstration of CO_2 capture and storage (CCS) technologies for power generation and other industrial sources.

CLIMIT supports development of knowledge, technology and solutions for CCS

- Power generation with CCS
- CO_2 capture in industry
- Compression and transport
- CO_2 storage
- EOR: CO_2 use combined with storage

The Research Council of Norway

GASSNOVA

Why is it so difficult?

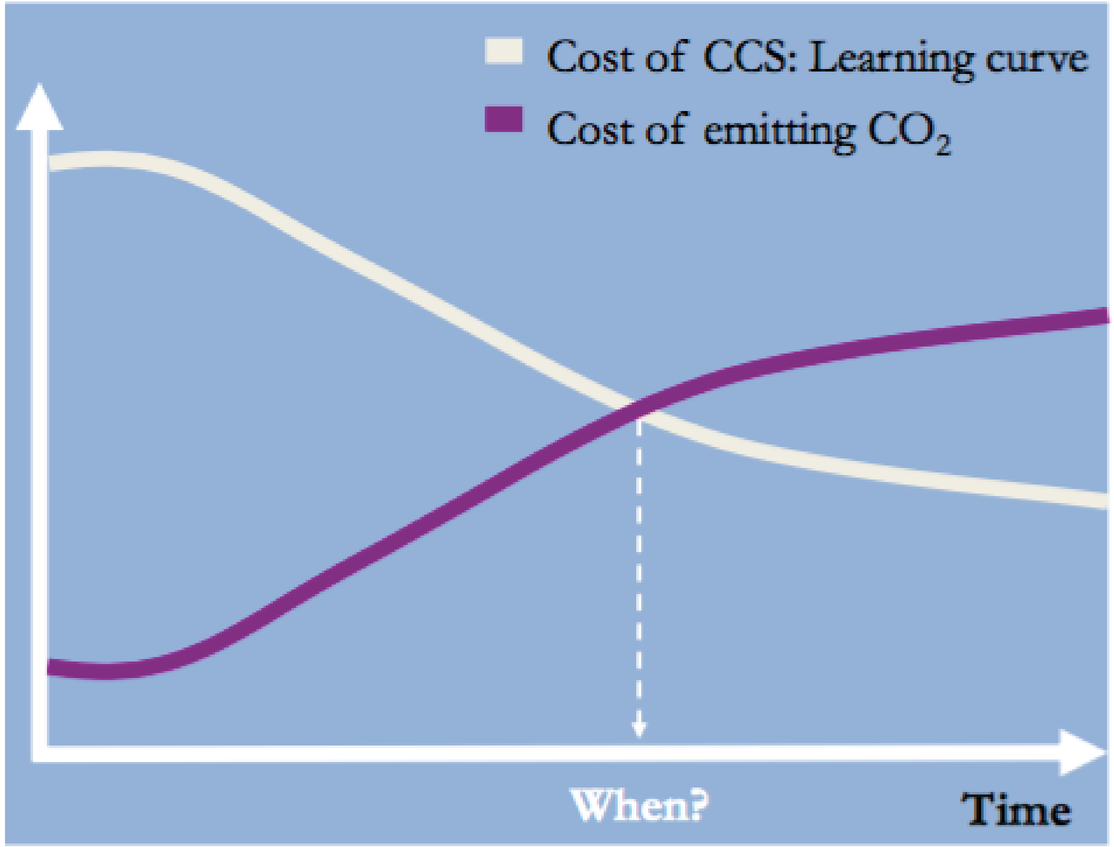
NORWEGIAN PETROLEUM DIRECTORATE

If CCS is so important why do we not have it already?

- Currently no commercial enterprise anywhere that has CCS as its core activity
- Perceived as risky and expensive
- CCS combines different activities (‘the CCS chain’) that are individually well understood but traditionally operate as separate businesses
- Successful businesses have little incentive to extend into unfamiliar & capital intensive territory
- Other energy innovation (e.g. wind, solar etc.) have used existing infrastructure. CCS infrastructure needed.

Financing – the key to crack the CCS business model

- Combining CCS and CCU and by that improving the profitability of the total capture project.
- Reducing cost and risk by technology development
- Emission limitations
- A functioning quota system with minimum prices
- Taxes on CO2 emissions



About utilization of CO_2

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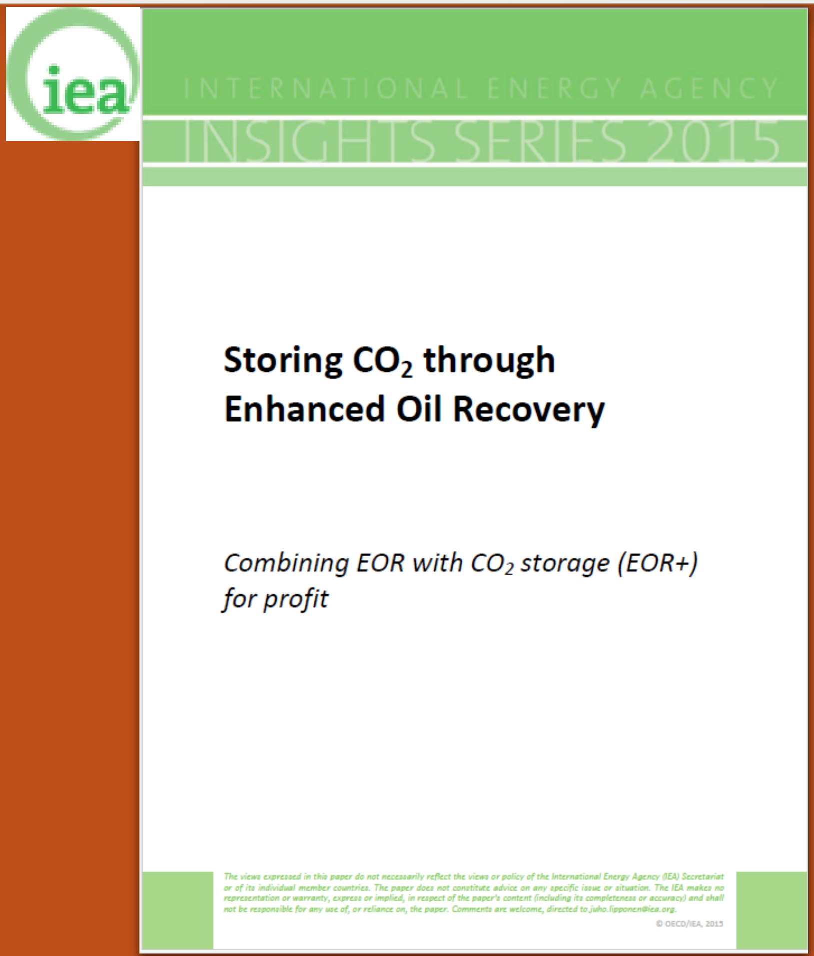

INTERNATIONAL ENERGY AGENCY

INSIGHTS SERIES 2015

Storing CO_2 through Enhanced Oil Recovery

Combining EOR with CO_2 storage (EOR+) for profit

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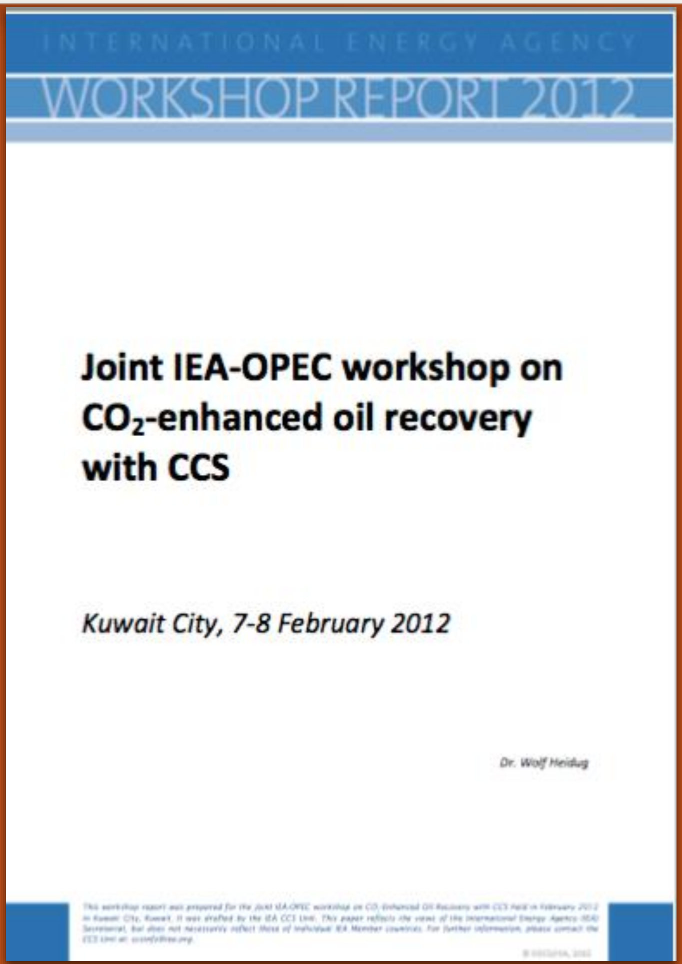


INTERNATIONAL ENERGY AGENCY

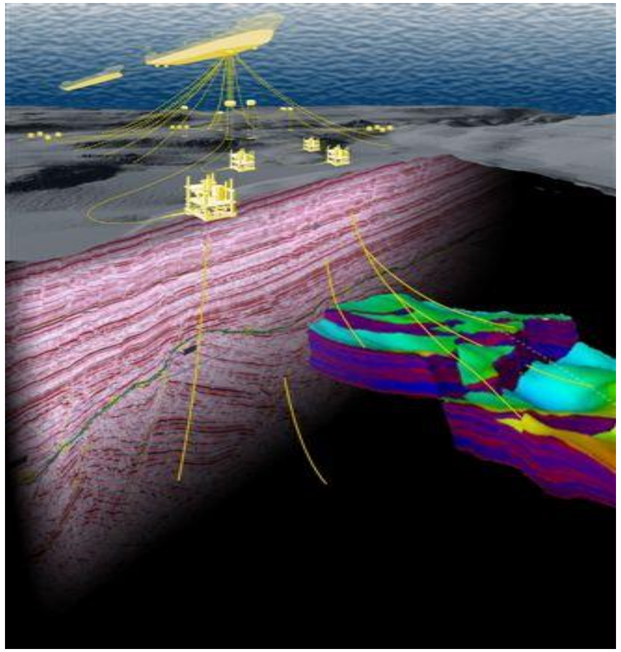
WORKSHOP REPORT 2012

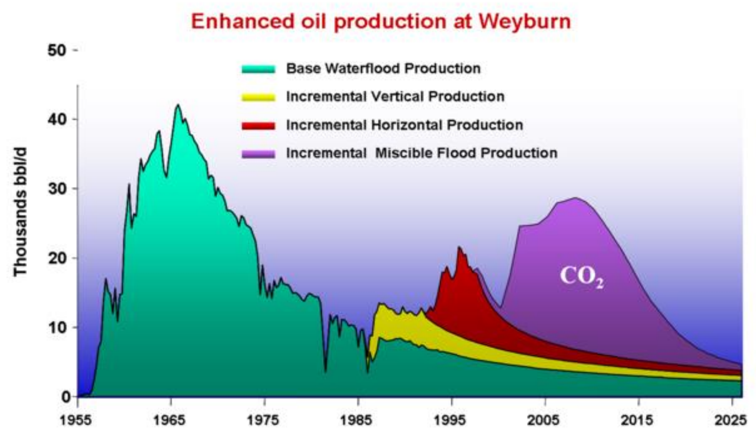
Joint IEA-OPEC workshop on CO_2-enhanced oil recovery with CCS

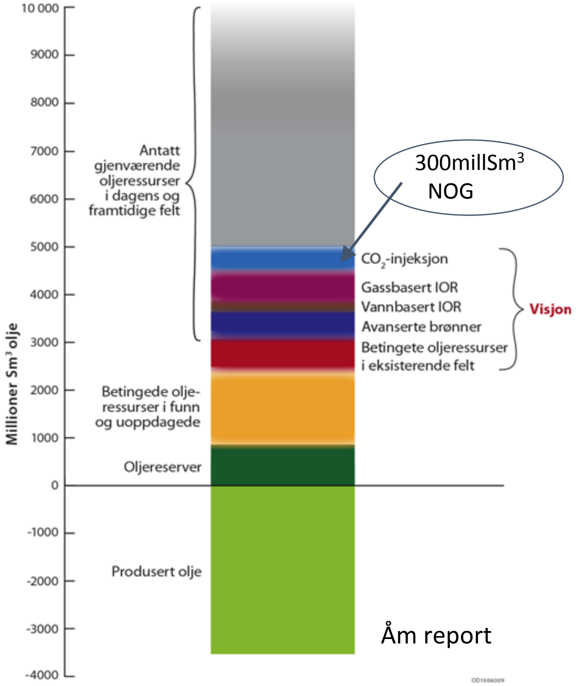
Kuwait City, 7-8 February 2012

Dr. Wolf Heidug

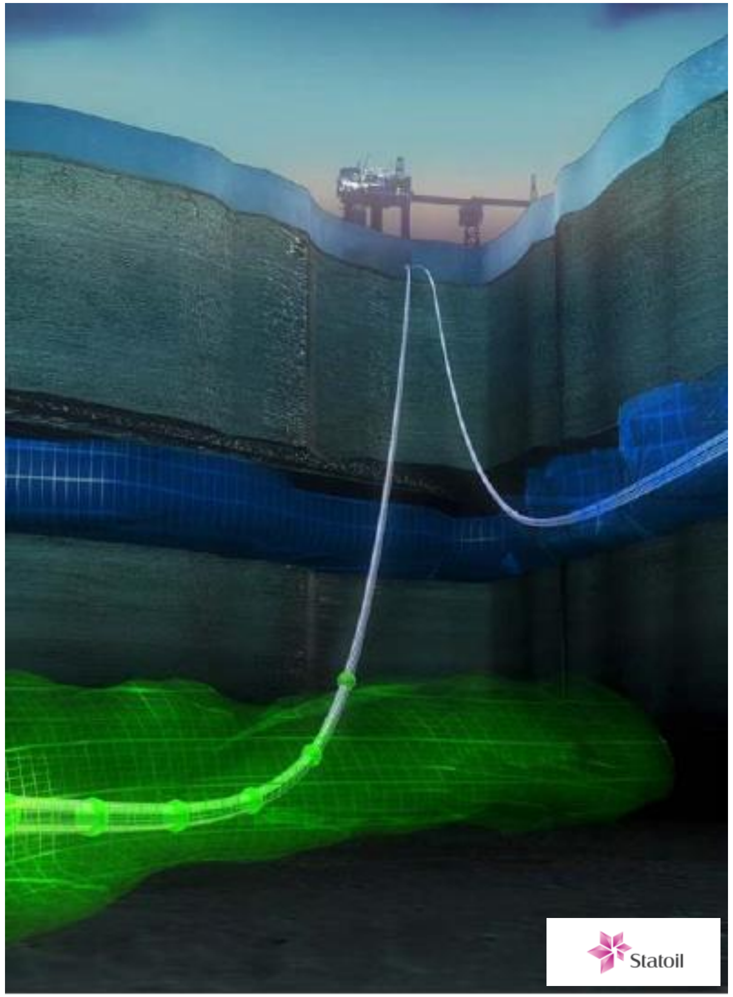
CO_2 for EOR







CO_2 storage

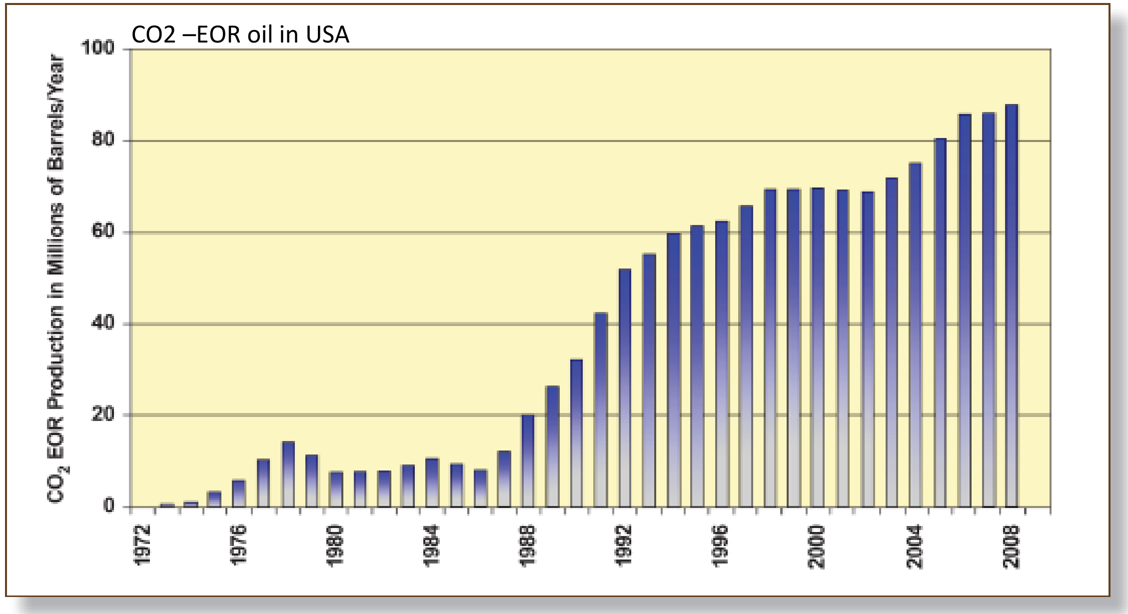


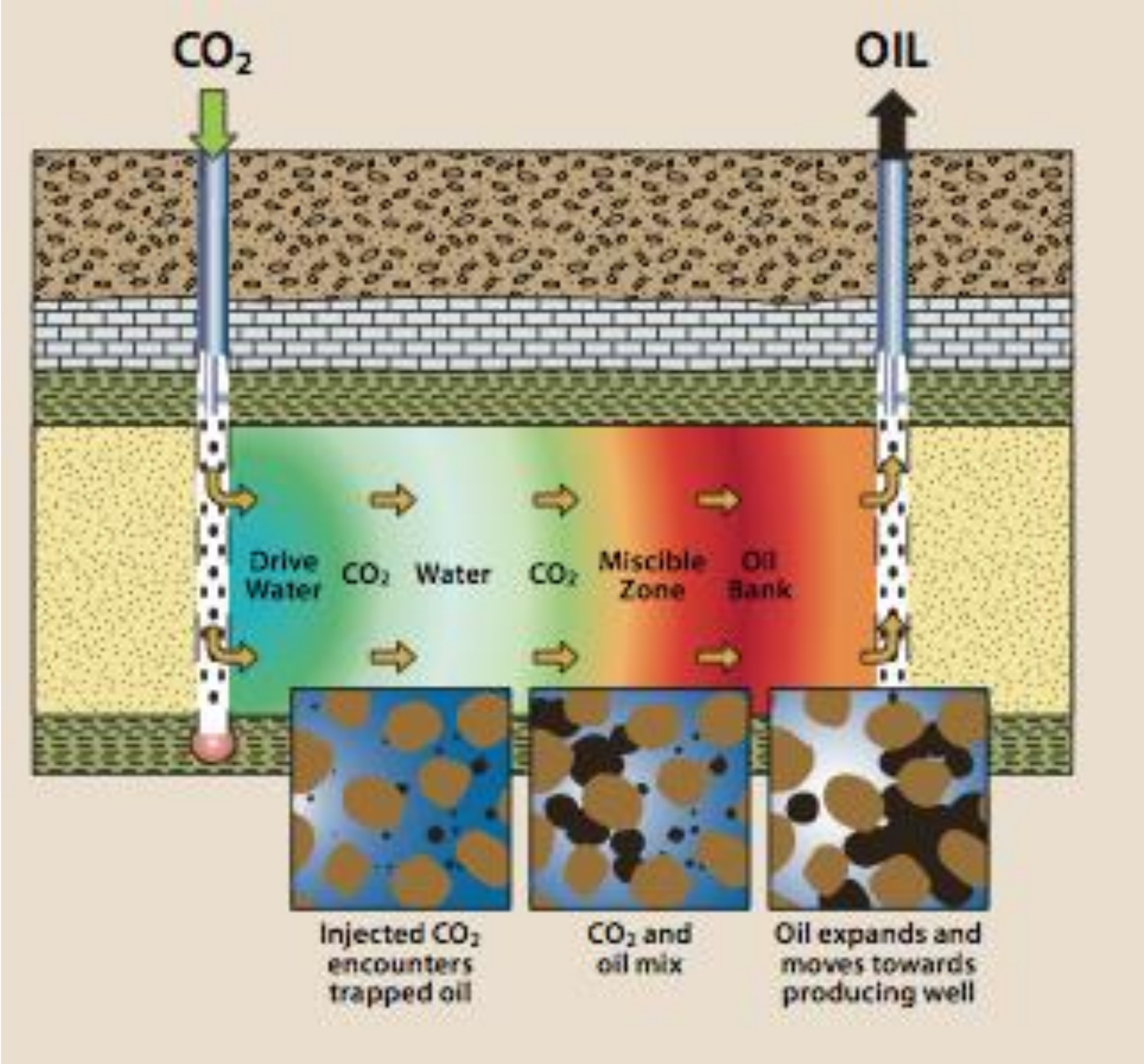
Why is CO_2 efficient for EOR?

The CO_2-EOR industry has 40 years of commercial operational experience from US and Hungary

About 65Mtons CO_2 used annually for EOR in US.

Today, CO_2-EOR produces nearly 100M bbls annually (about 6 percent of US domestic production)



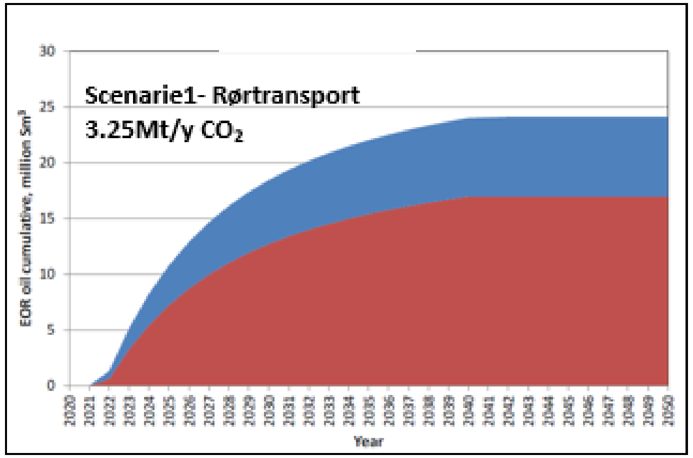


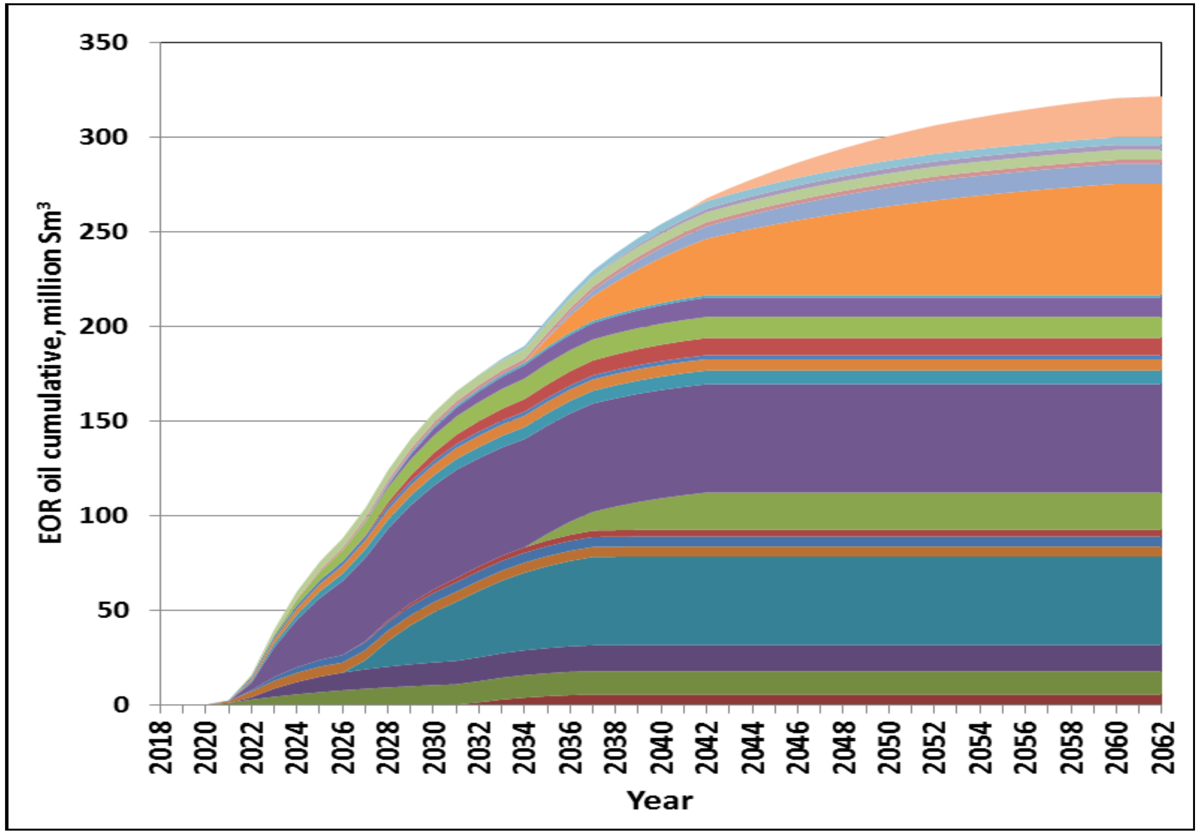
Source: DoE/NETL

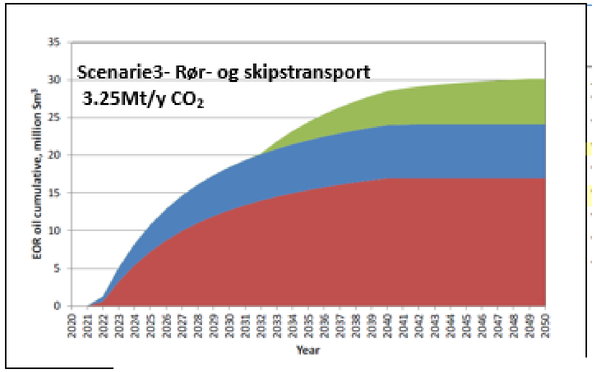
CO_2 for enhanced oil recovery (EOR) and storage

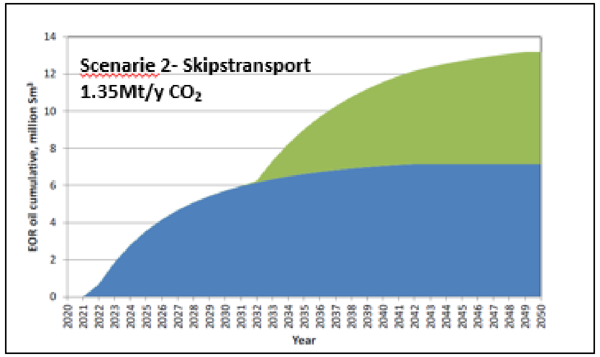
Screening-studie of 23 oil fields in the North Sea (Norwegian part)

Modeled recovery : 320 MSm^3 with ca 70 Mt CO_2 anually for 40 years





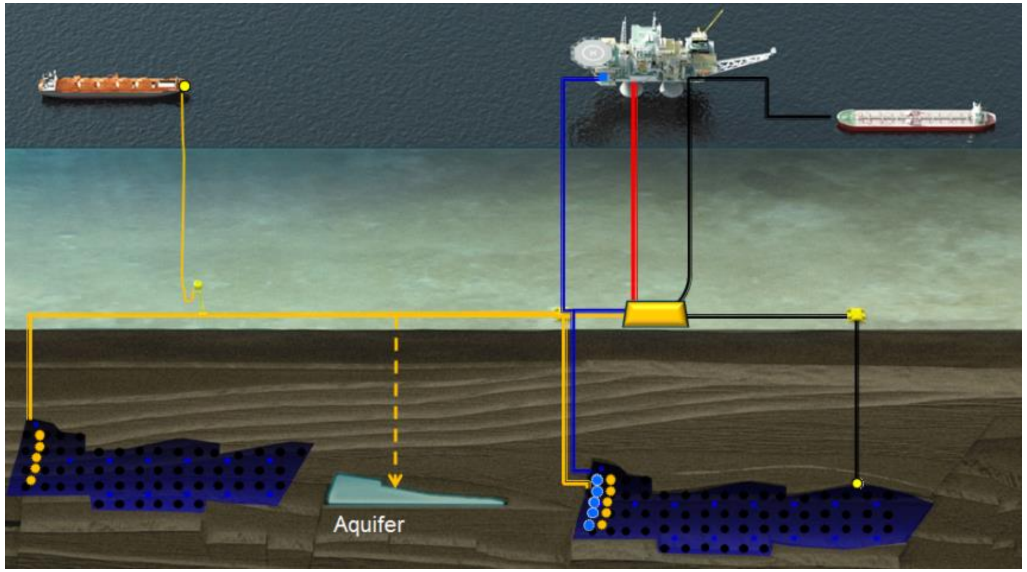


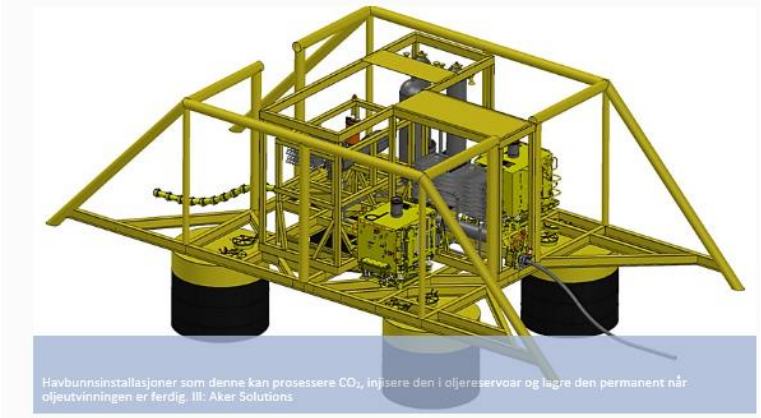


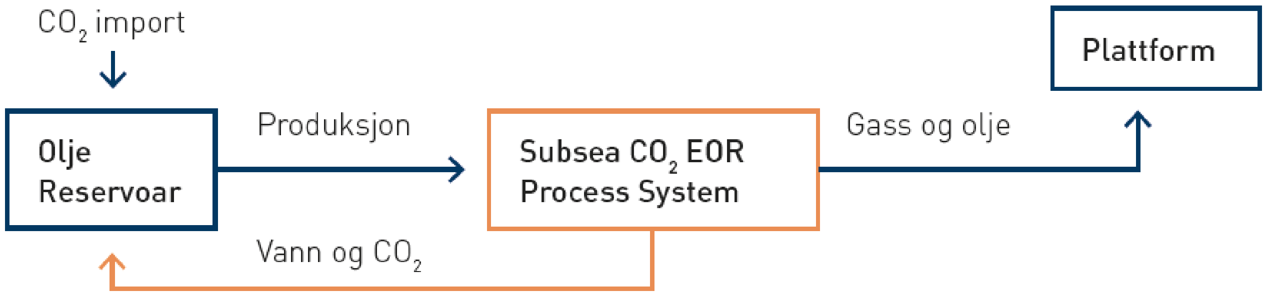
	Scenario 1	Scenario 2	Scenario 3
Annual amount of CO_2 imported, million tonnes	3.25	1.35	3.25
Total well costs, billion USD	1.1	1.1	1.7
Total investment costs, billion USD	1.8	1.8	2.9
Total NPV, billion USD	5.3	2.9	6.9
Total oil production, % of OOIP	54.1	45.5	51.0
Total EOR oil, million Sm^3	24.1	13.2	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

CO2 EOR- using subsea technology AkerSolutions concept (Climit)

- Transportation of Captured CO2 by ship or pipeline
- Direct Injection from ship
- Compression and fluid separation subsea
- Reduced need for modifications on existing hardware
- Enables reuse of subsea installations
- Reduced investments enable different strategy



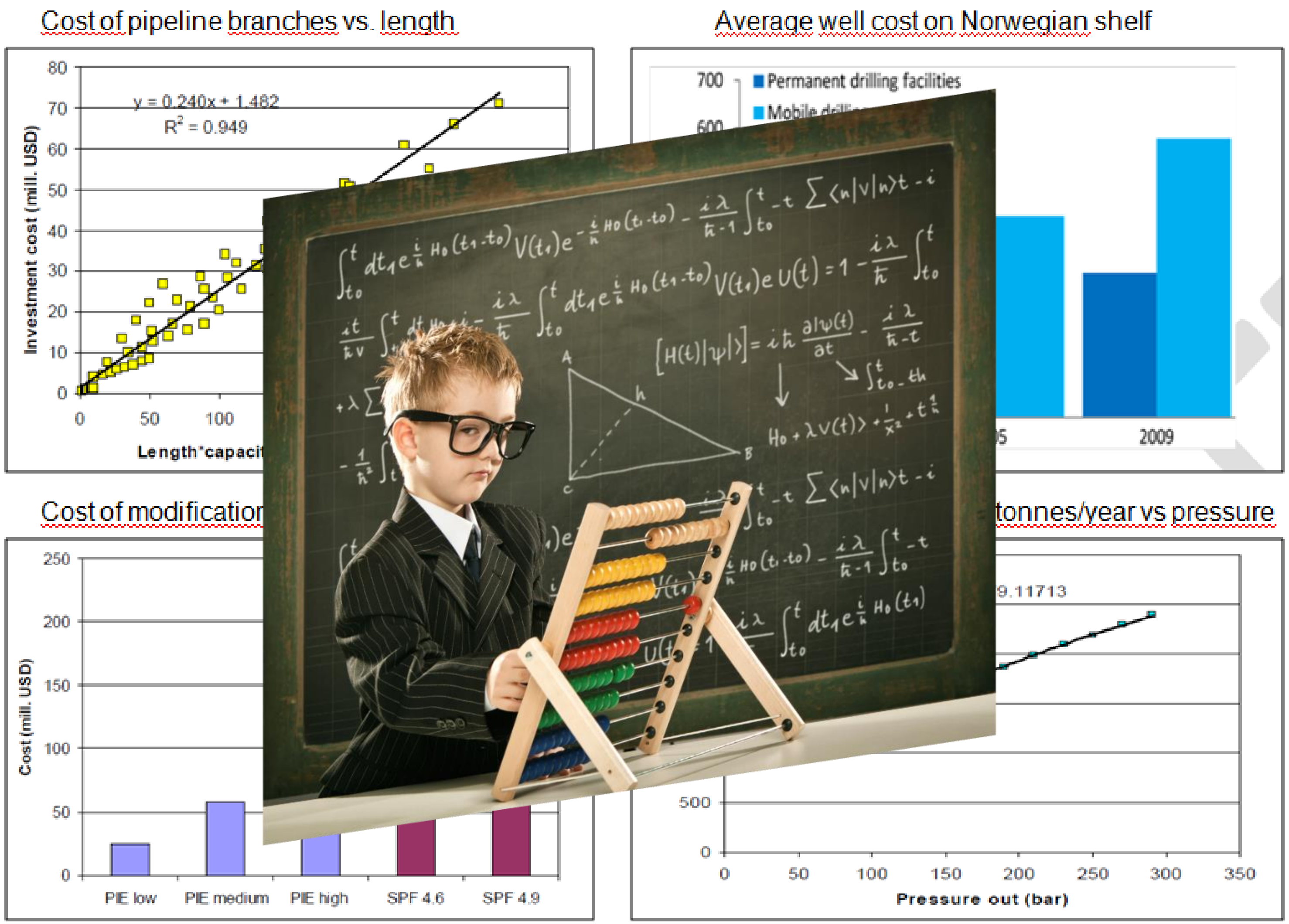


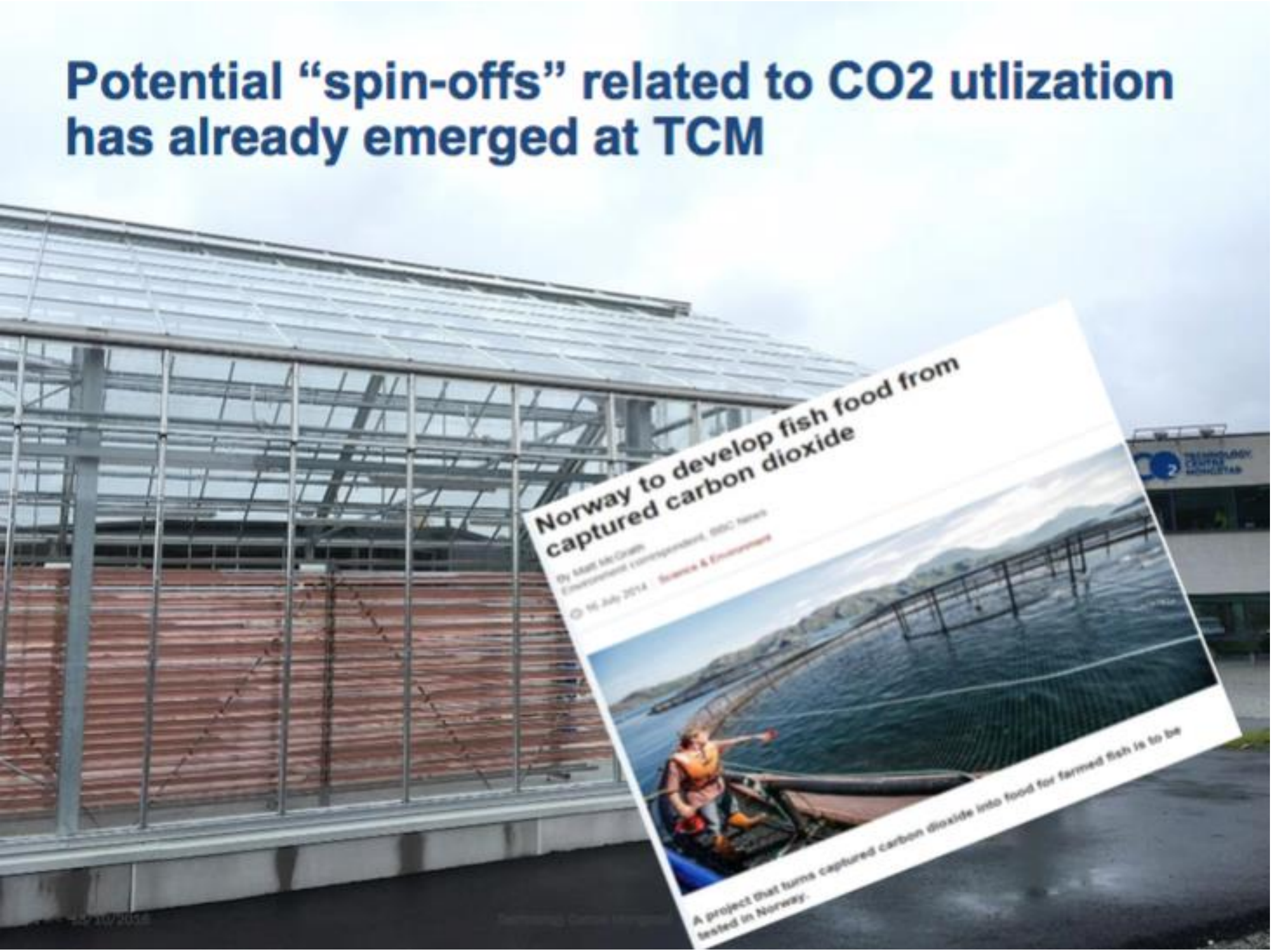


Komplett subsea-løsning for CO_2-EOR
- Gass separering
- Olje/ vann seperasjon
- Reinjeksjon av anriket CO_2
- Økt olje utvinningsgrad: 5 – 12 prosent

(Kilde: Aker Solutions)

Cost


Cost of pipeline branches vs. length
y = 0.240x + 1.482
R^2 = 0.949
Investment cost (mill. USD)
Length*capacit
Average well cost on Norwegian shelf
Permanent drilling facilities
2009
Cost of modification
tonnes/year vs pressure
Cost (mill. USD)
PIE low
PIE medium
PIE high
SPF 4.6
SPF 4.9
Pressure out (bar)



A pilot facility for algae production at TCM

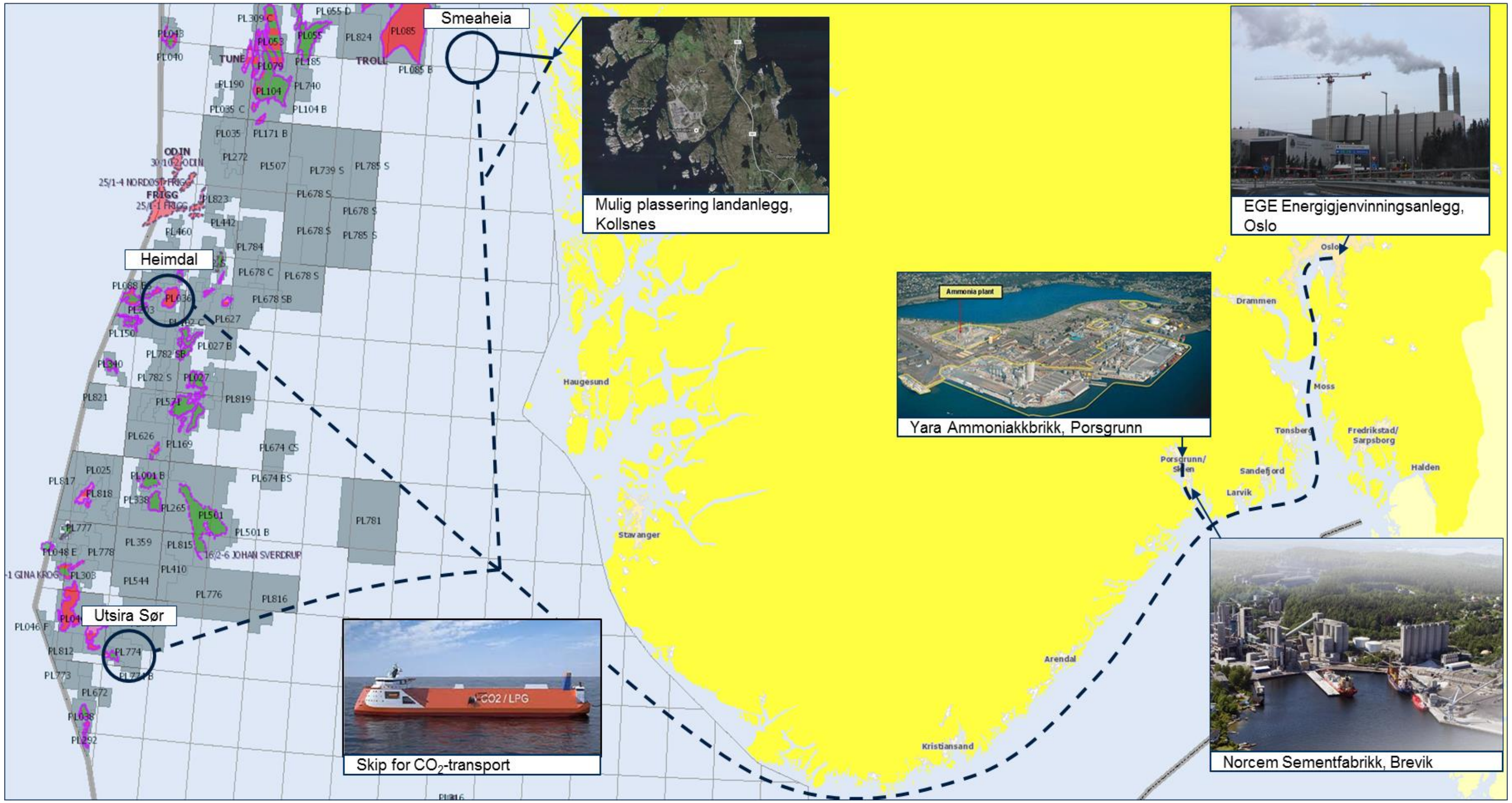
About CO2-intensive industries
- and finding solutions

NORWEGIAN PETROLEUM DIRECTORATE

Plan: A full-scale CCS chain in Norway by 2022

Feasibility study on full-scale carbon capture, transport and storage (CCS) in Norway (July 2016)

The main goal of The Norwegian CCS policy is to identify measures that can contribute to technology development and cost reductions.



Carbon capture at Klementsrud

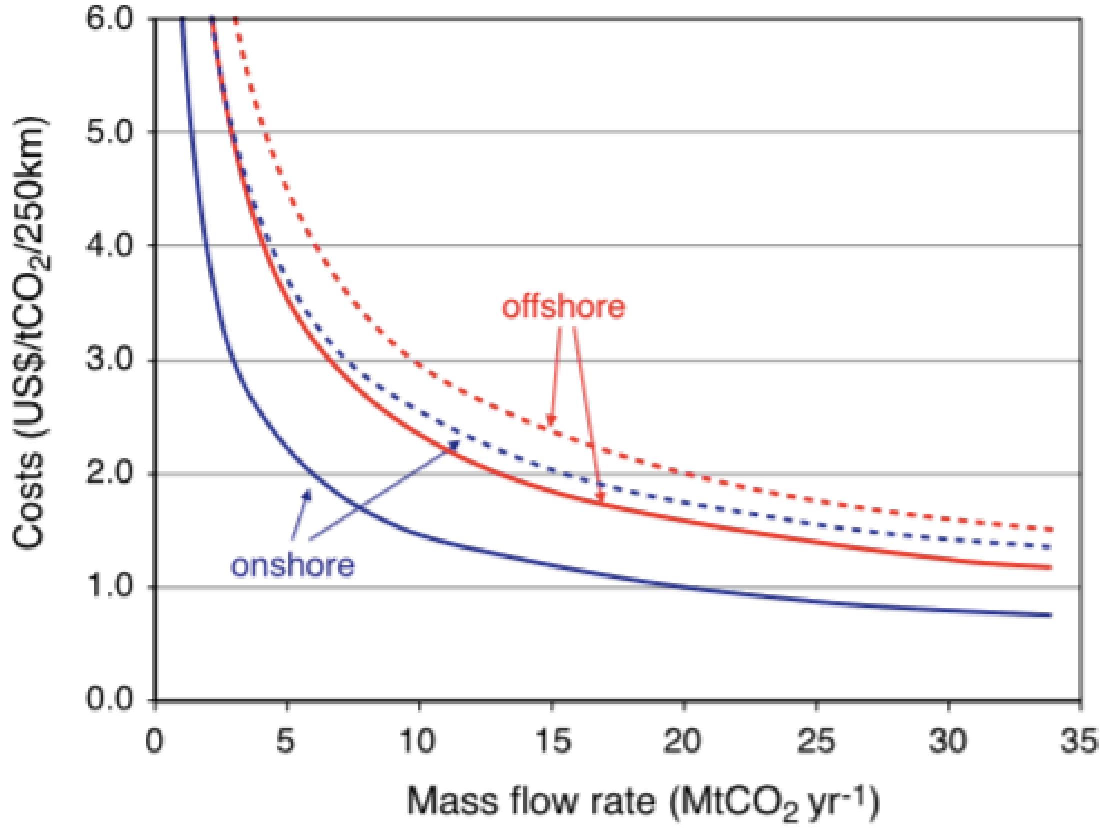
Energy recovery from waste

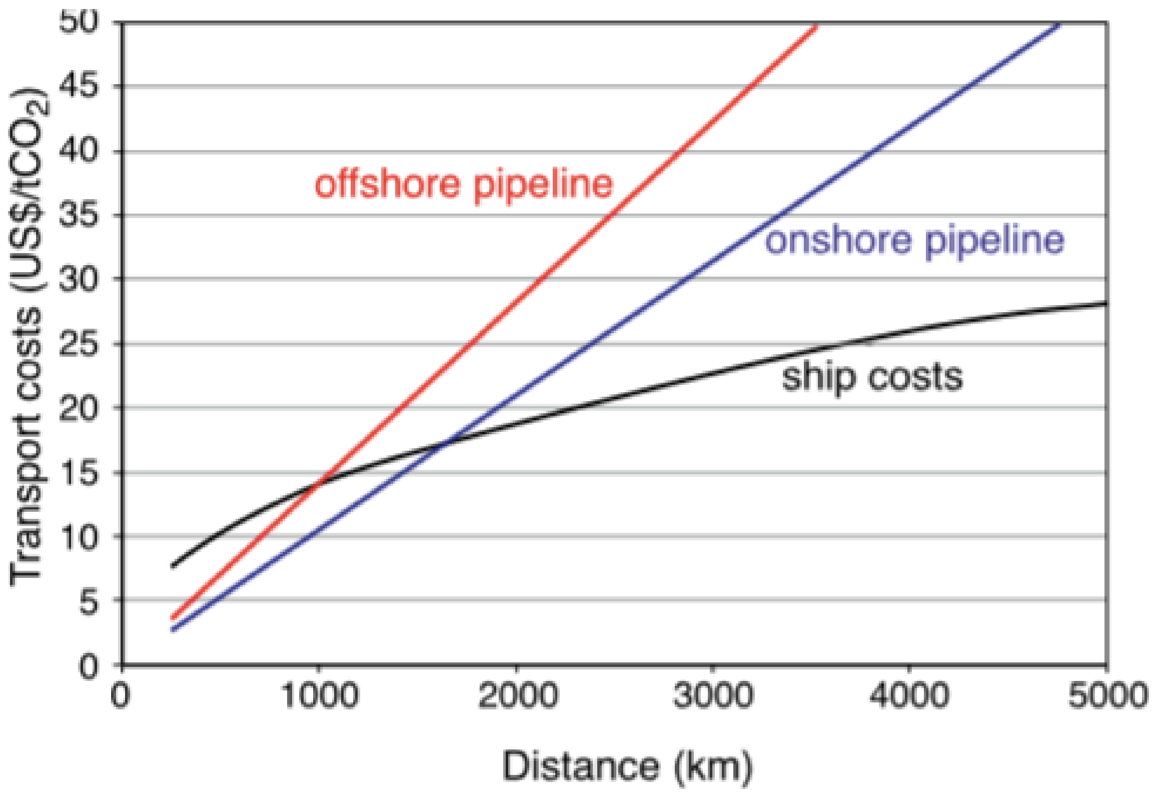
Full Scale Carbon Capture at Norcem Brevik

CO2 emissions in the cement sector	2015
Globally	5 - 6 %
Norway	2.6 %
HeidelbergCement Group	< 100 M tons/y
Norcem Brevik	~ 800 k tons/y

Cost for transport of CO_2 (IEA)

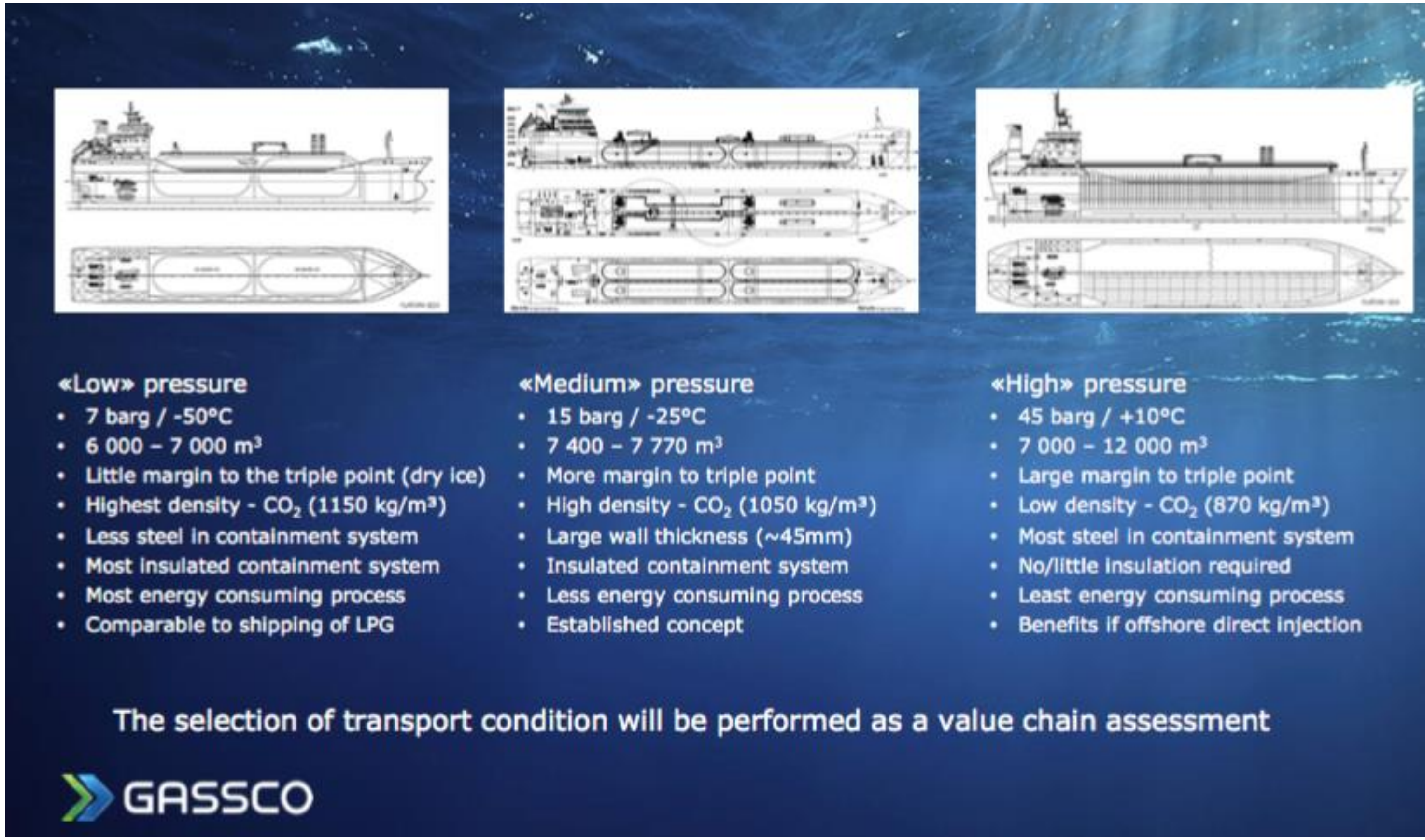
Transport costs for onshore and offshore pipelines per 250 km.



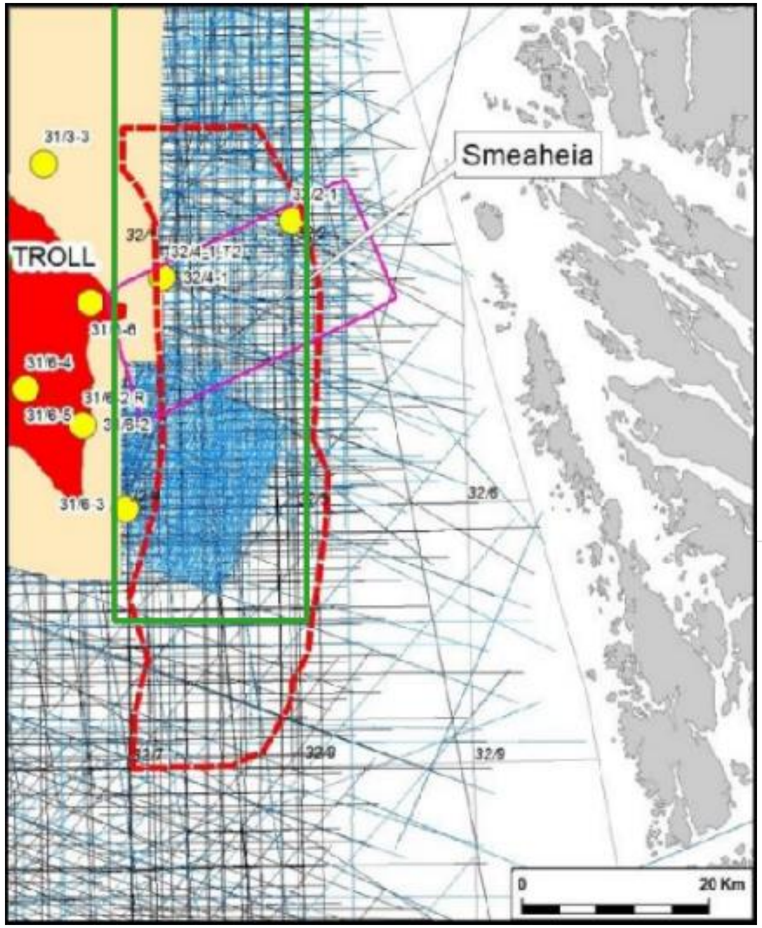


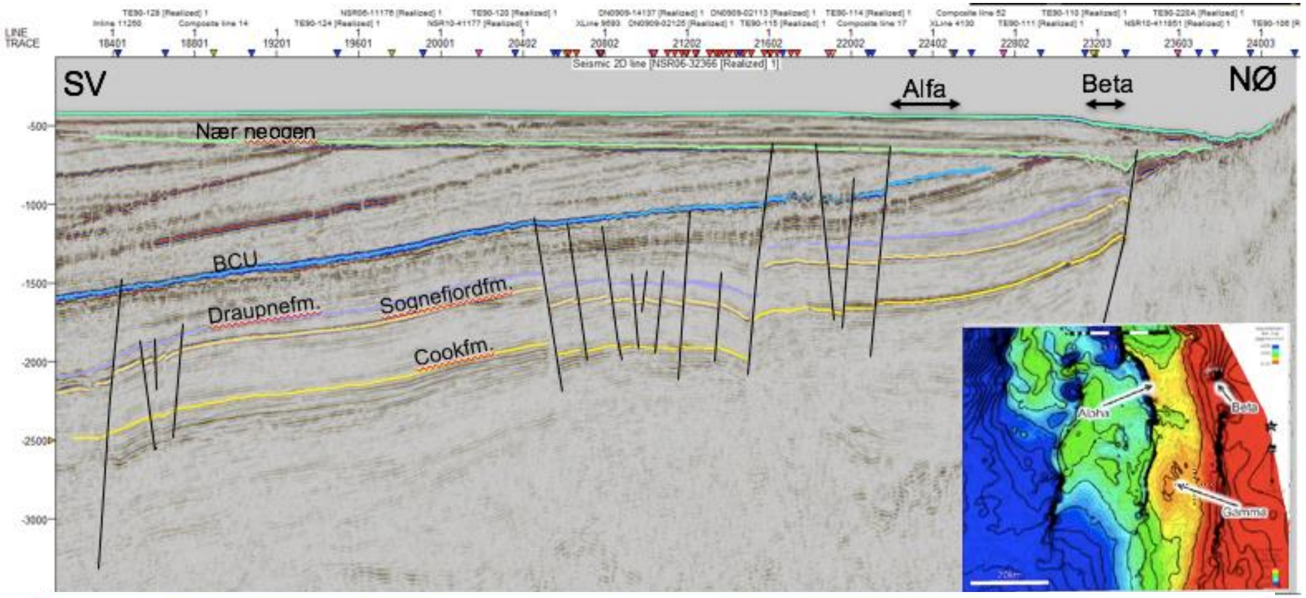
Ships transport of CO2

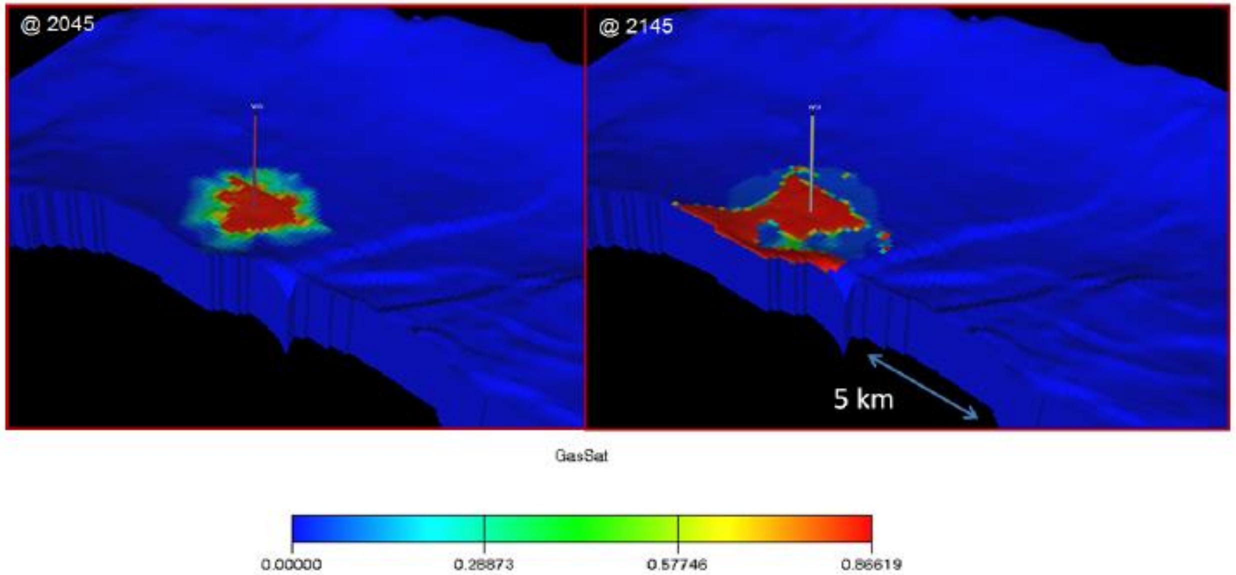
- Transportation of CO2 is proven feasible both by pipeline and ship
- Ship transportation of CO2 could be an enabler for realising big scale CCS



Smeaheia location

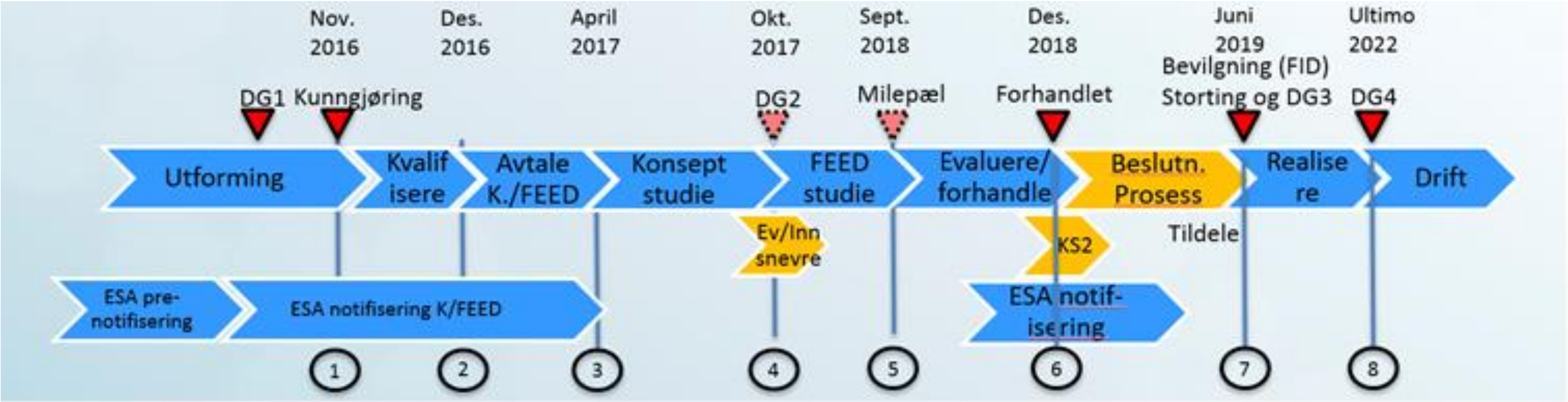






Source Statoil

Project plan



About regulation and incentives

NORWEGIAN PETROLEUM DIRECTORATE

Picture: iStockphoto © William Maher

Regulation of Carbon Transport and Storage

CCS Regulation in EU ("CCS Directive")

- **Ensuring there is no significant risk of leakage or damage to health or the environment**

Norway

- **Forskrift om utnyttelse av undersjøiske reservoarer på kontinentalsokkelen til lagring av CO_2 og om transport av CO_2 på kontinentalsokkelen**
  - based on the EU "CCS Directive" and the existing Norwegian Petroleum legislation

Ministry of Petroleum and Energy (new regulations and part of the Petroleum Law)

Ministry of Environment (amendment to Pollution Control regulations)

Risk acceptance criteria are based on the EU "CCS directive" and the London Protocol

What we need to know before a storage permit is granted

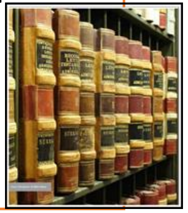
Regulators:

- What can be the consequense of a leakage?
- How fast can we detect any possible leakage?
- Is it possible to do CO_2 storage in a safe way with regard to the ecosystem?
- What will happen with the injected CO_2 after close-down of the site?
- Is it possible to volumetrically measure a leakage (CO_2 quotas)?

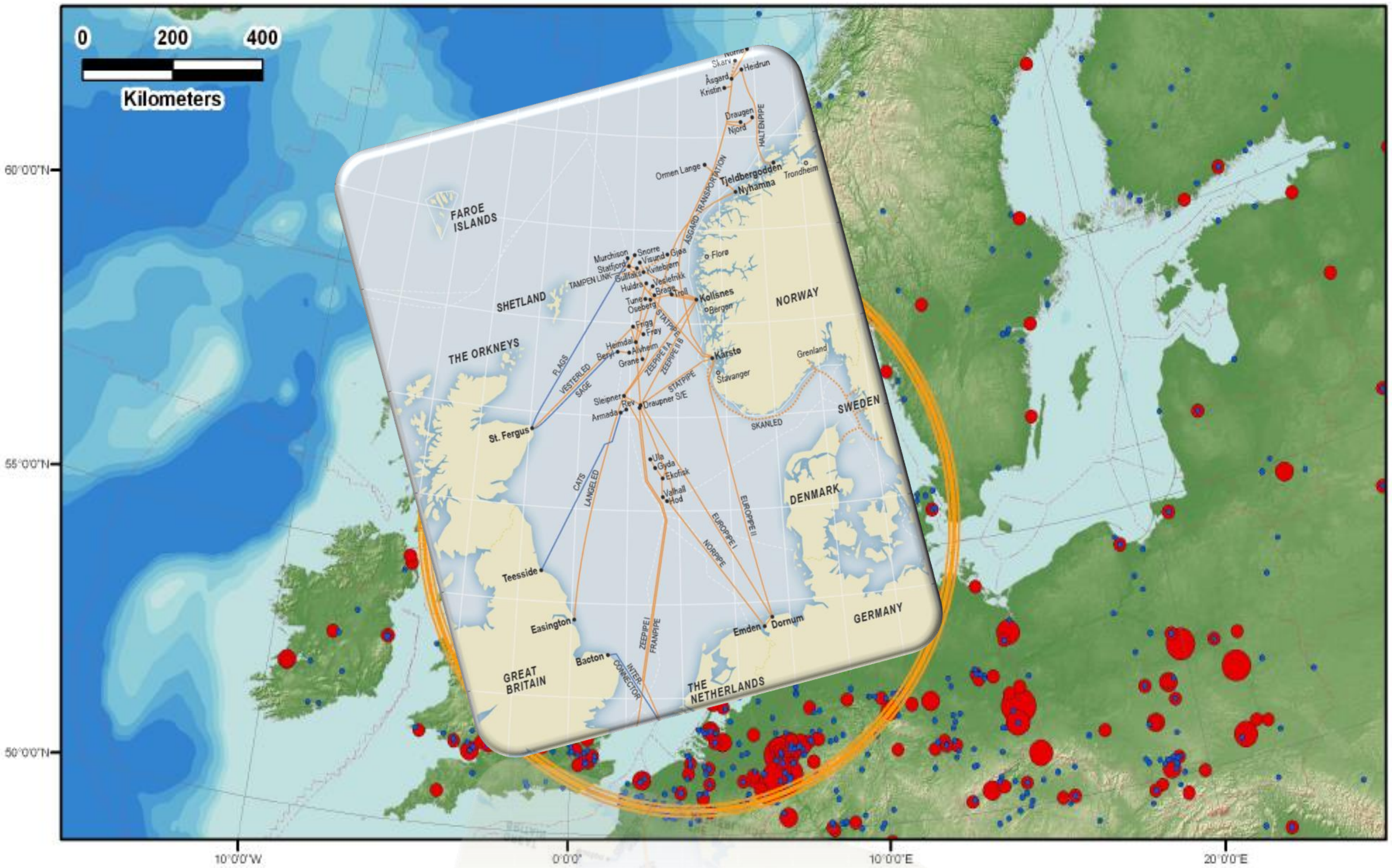
CO_2 storage Operators:

- Demonstrate that CO_2 storage can be done in a safe and secure way
- What is the consequenses of a leakage
- Design a remidiation plan
- How much will it cost and who pay what?

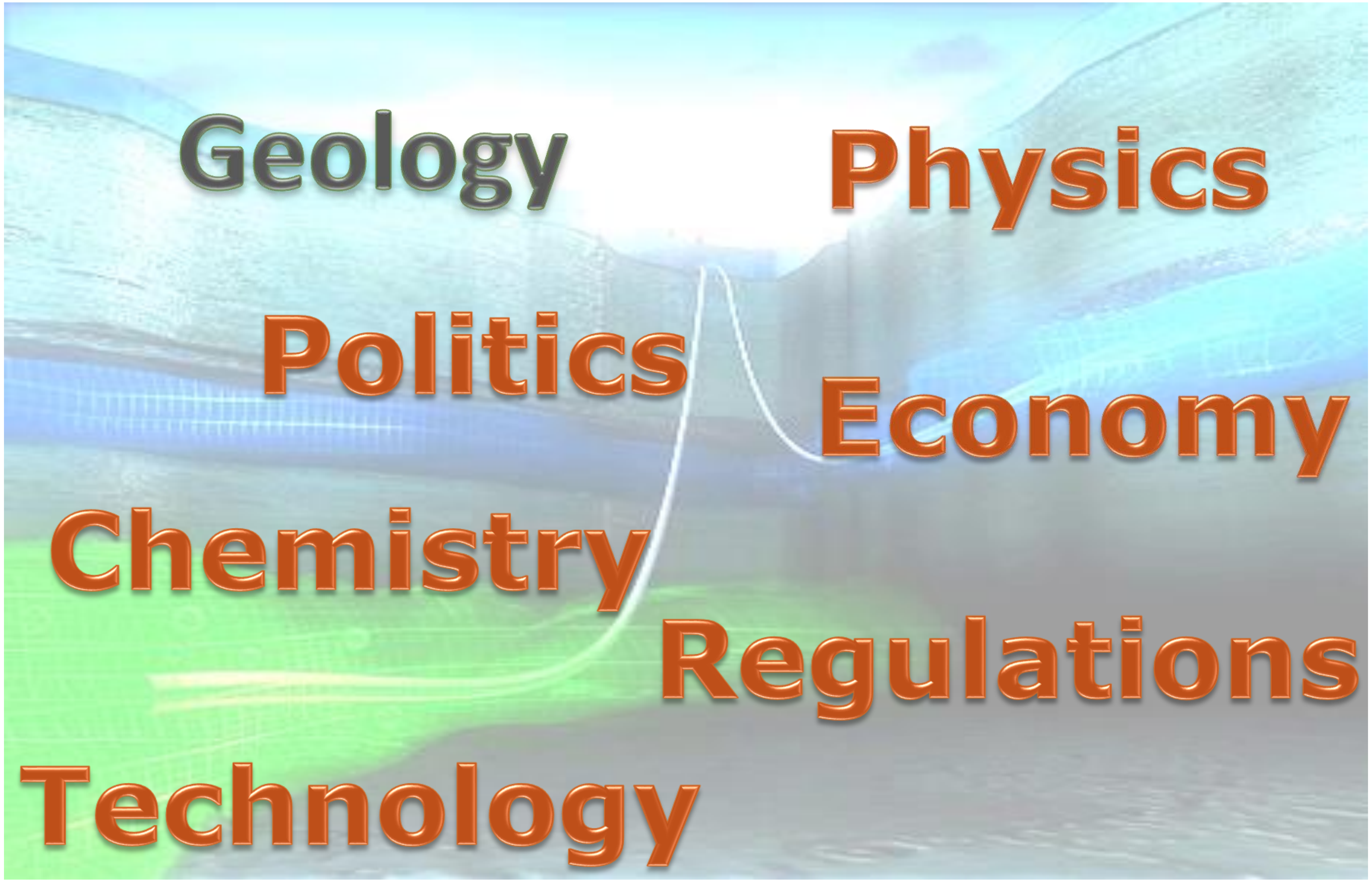
- **Exploitation :** financial strength, technical expertise and reliability considered necessary to operate and control the storage site
- **Plan for development and storage:** Impact assesment plan, monitoring plan, mitigation and plan for close down.
- **Storage of CO_2:** continuously evaluate technical solutions and take appropriate action. The operator shall monitor the injection facilities and storage complex, including the distribution of CO_2.
- The Ministry or anyone authorized shall supervise the storage locality at least **once a year until three years after the closure,** and then **every five years** until the responsibility is transferred to the state. By supervision shall the Ministry or anyone authorized examine the relevant injection and monitoring facilities, reservoir conditions, and the effect of the storage complex to the environment.
- **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



The North Sea Basin



Storage of CO_2 is about:



Thank you for listening!

Acknowledgements to Fridtjof Riis, Jasminka Mujezinovic, Rita Sande Rød, Ine T.Gjeldvik, Christian Magnus, Maren Bjørheim, Andreas Bjørnestad, Van T.H.Pham, Inge Tappel, Ann Helen Hansen
(Norwegian Petroleum Directorate)

The Norwegian CO_2 Storage Atlases can be downloaded for free from www.npd.no