CCS Case Studies

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Workshop on development of natural gas resources with high CO2 & Carbon Capture and Storage (CCS) in CCOP,

Bali, Indonesia, 17-20 March 2009

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Topics covered

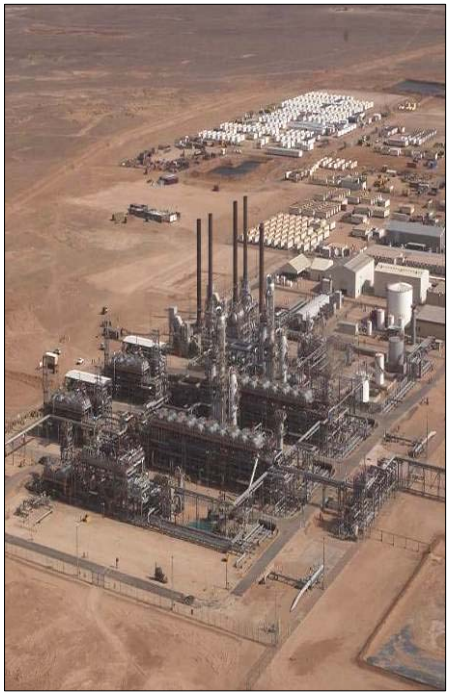
- An overview of CCS-projects world-wide
- The four large projects and history of development
  - Sleipner, Norway
  - In Salah, Algeria
  - Snøhvit, Norway
  - Weyburn, Canada
- What did they cost?
- Things can go wrong
- Some other projects
- Exploring for CO_2-storage

An overview of CCS-projects world-wide

So far only four large and some smaller CO_2-storage projects in operation

Sleipner, Norway

In Salah, Algeria



Snøhvit, Norway

Weyburn, Canada

Numerous aspiring CCS projects in the power generation sector

→ how many will go ahead?

→ and are we seeing too little focus on the below ground aspects?

Map credit: Scottish Centre for Carbon Storage, School of Geosciences, University of Edinburgh (www.geos.ed.ac.uk/ccsmap)

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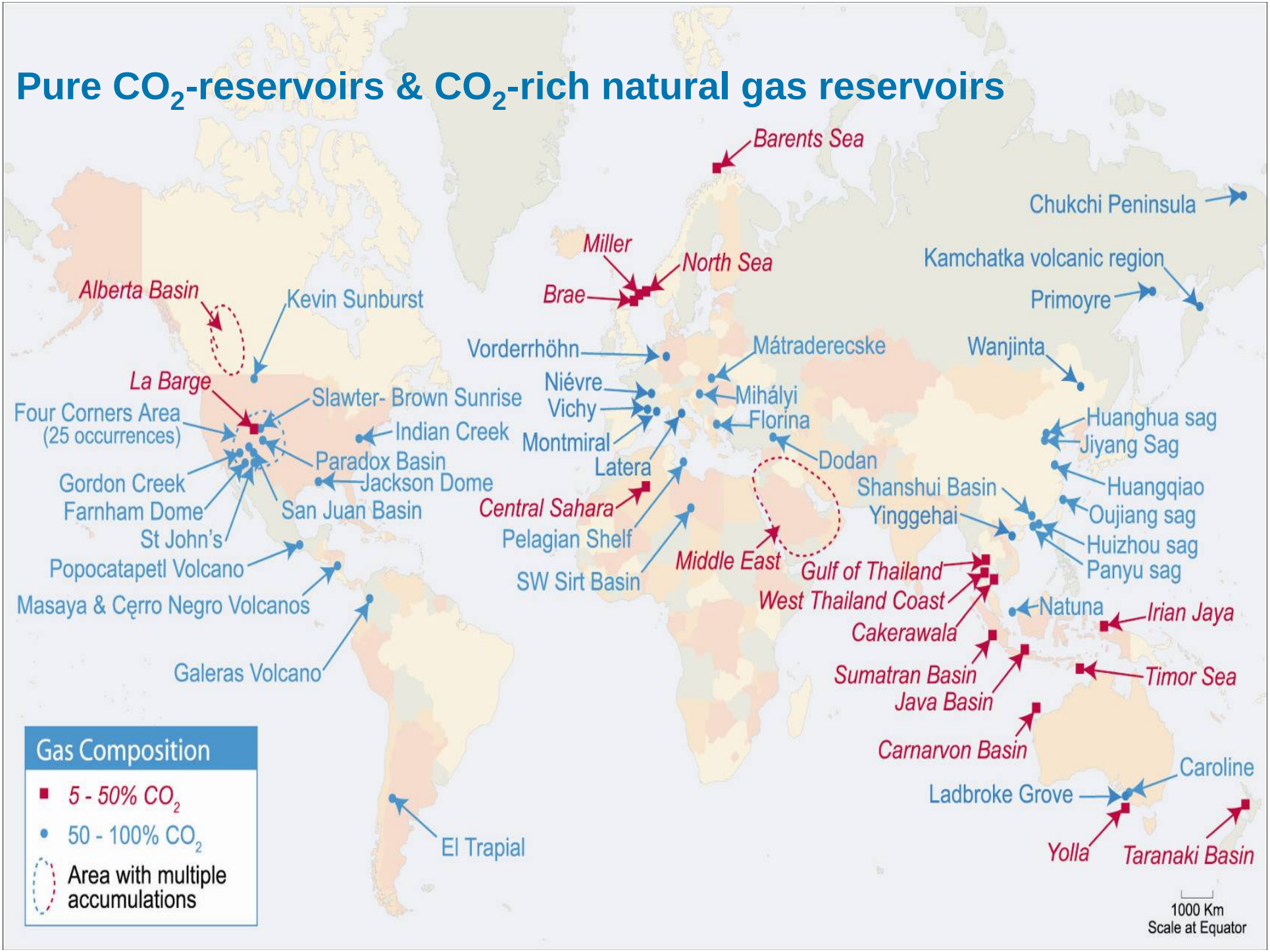
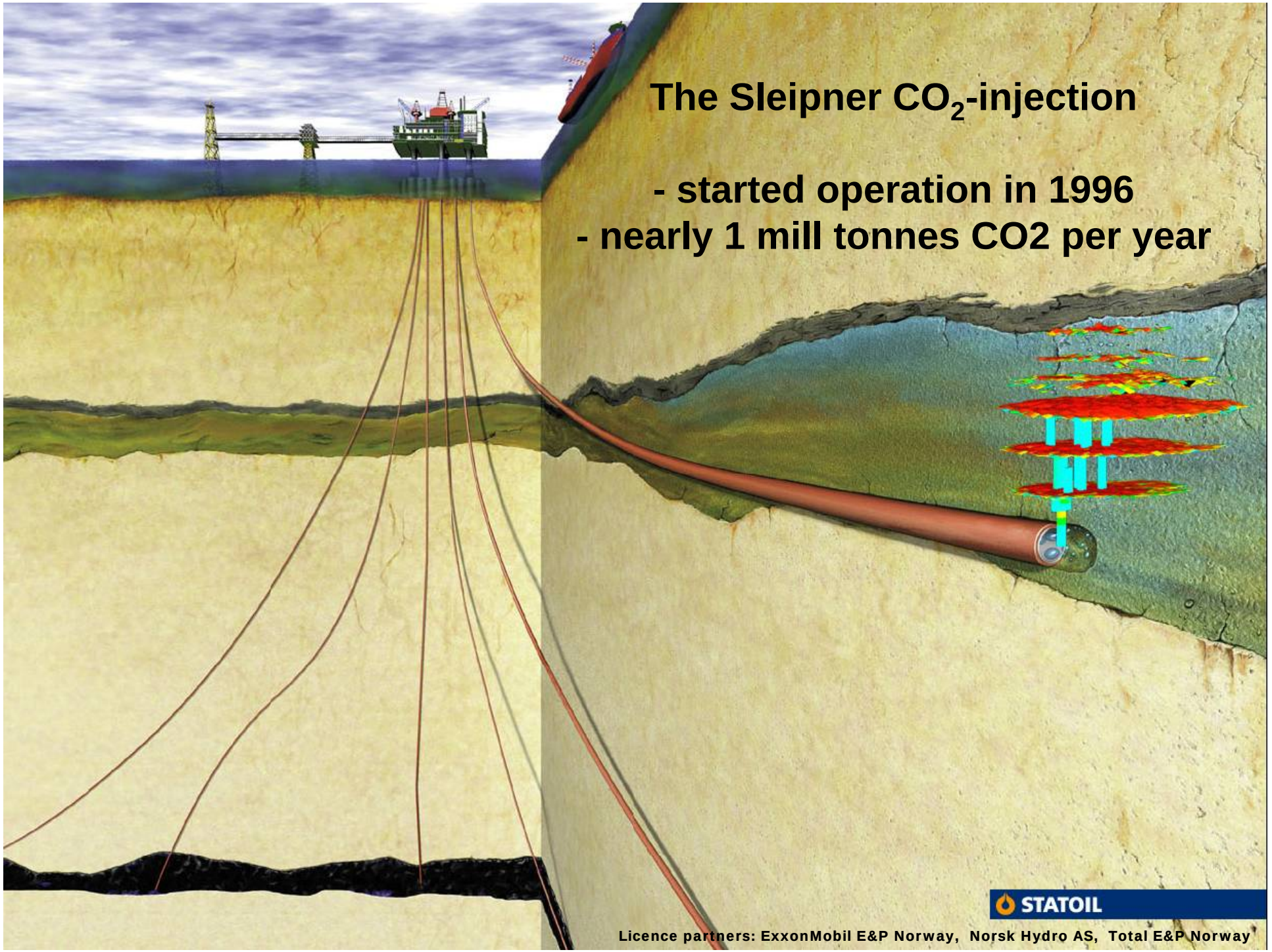
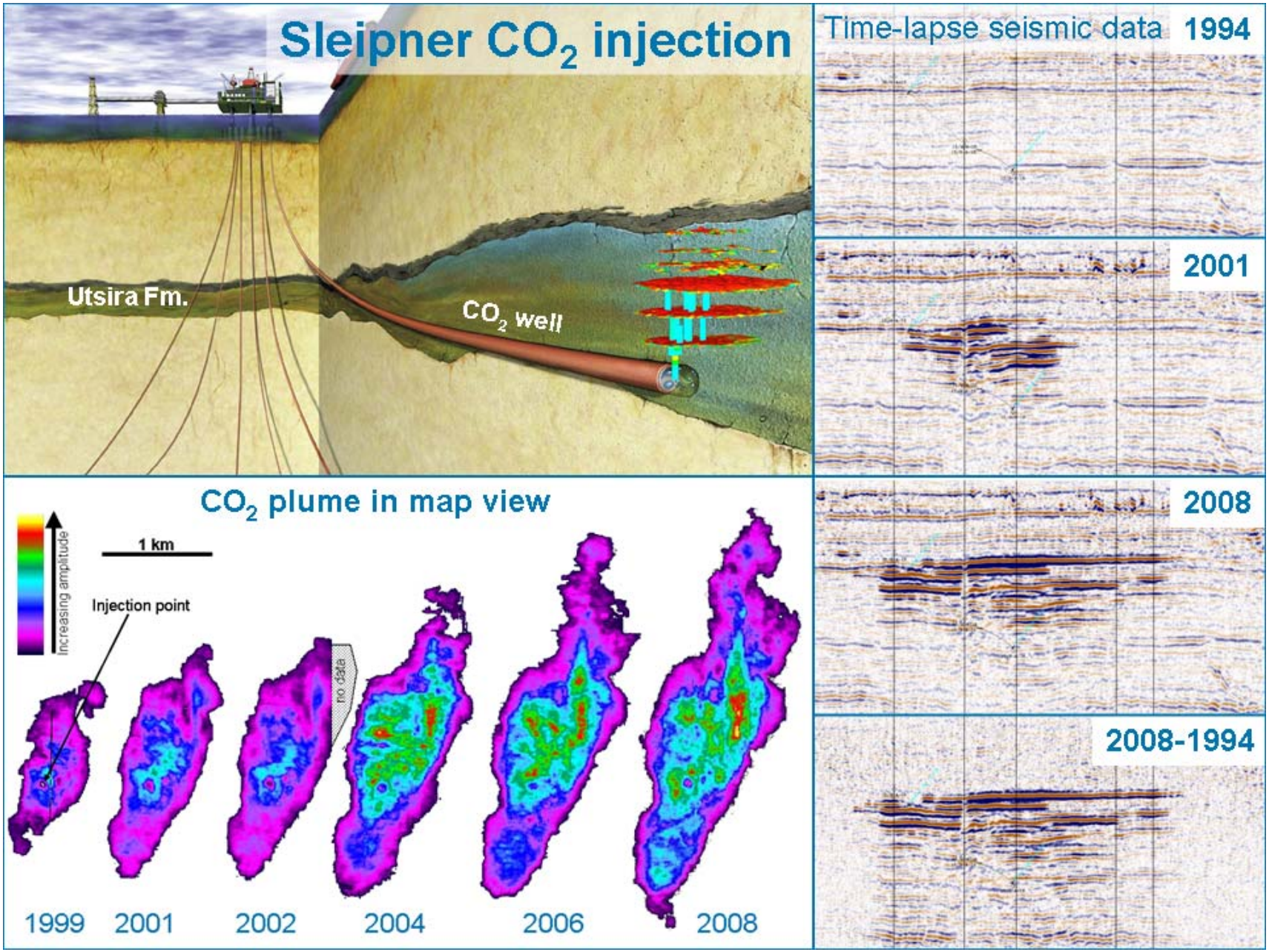
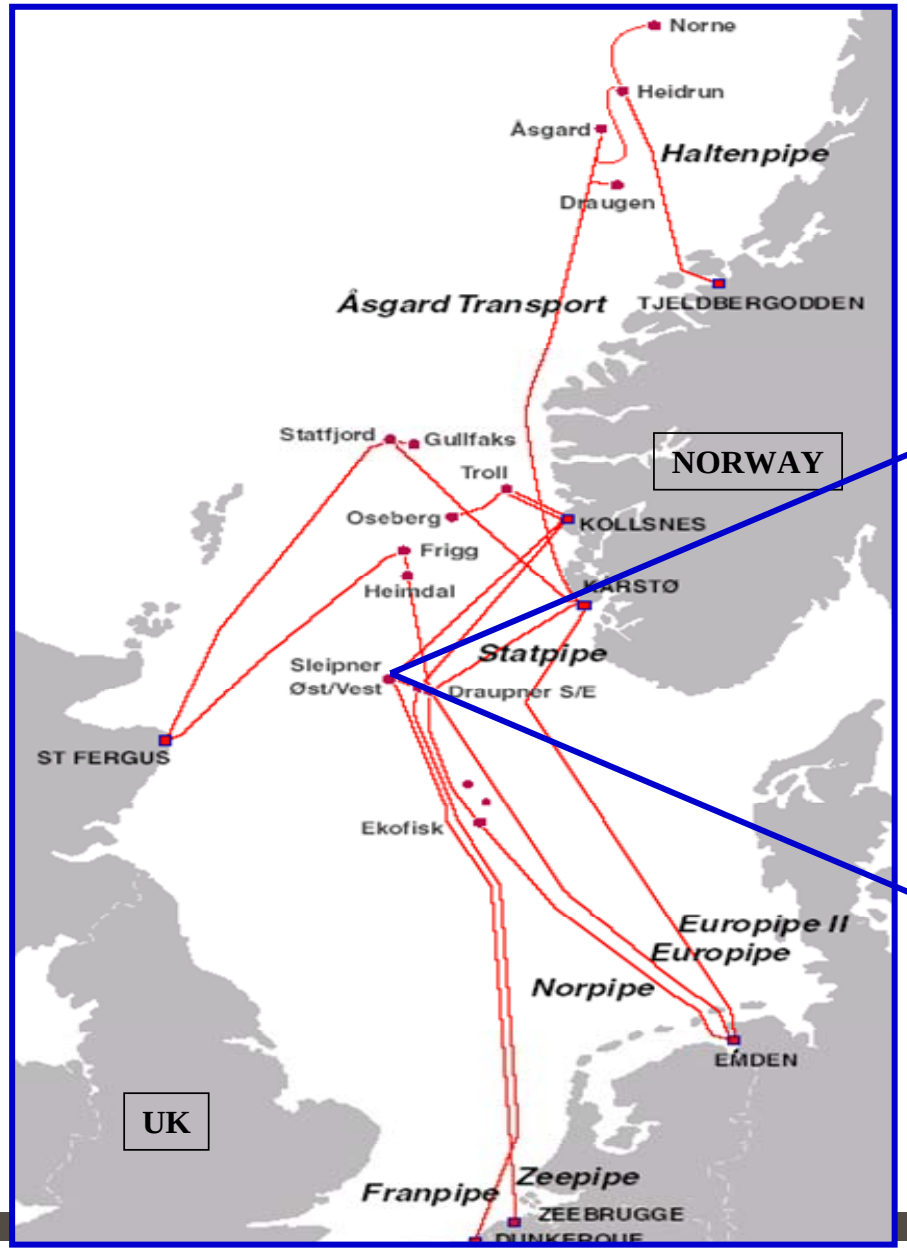
Pure CO_2-reservoirs & CO_2-rich natural gas reservoirs




The Sleipner CO_2-injection
- started operation in 1996
- nearly 1 mill tonnes CO2 per year
STATOIL
Licence partners: ExxonMobil E&P Norway, Norsk Hydro AS, Total E&P Norway


Sleipner CO_2 injection
Utsira Fm.
CO_2 well
Time-lapse seismic data
1994
2001
2008
2008-1994
CO_2 plume in map view
1 km
Increasing amplitude
Injection point
no data
1999
2001
2002
2004
2006
2008



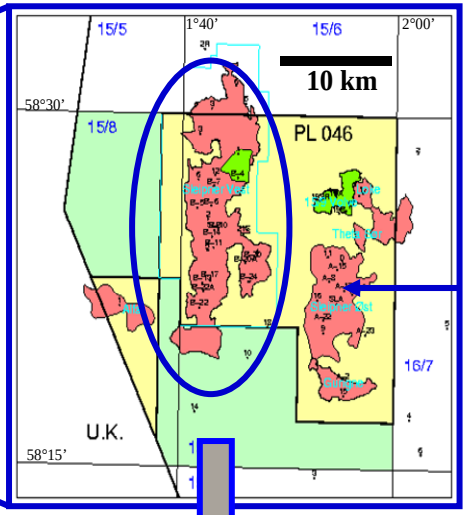
Sleipner Vest

Production start 1996

Natural gas with 9 mol% CO_2

GIIP: 5.6 TSft³
(160 GSm³)

CIIP: 427 mill.bbl
(70 MSm³)



Sleipner Øst

Production star 1993

Natural gas with < 1 mol % CO_2

Gas sales specifications:
< 2.5 mol% CO_2

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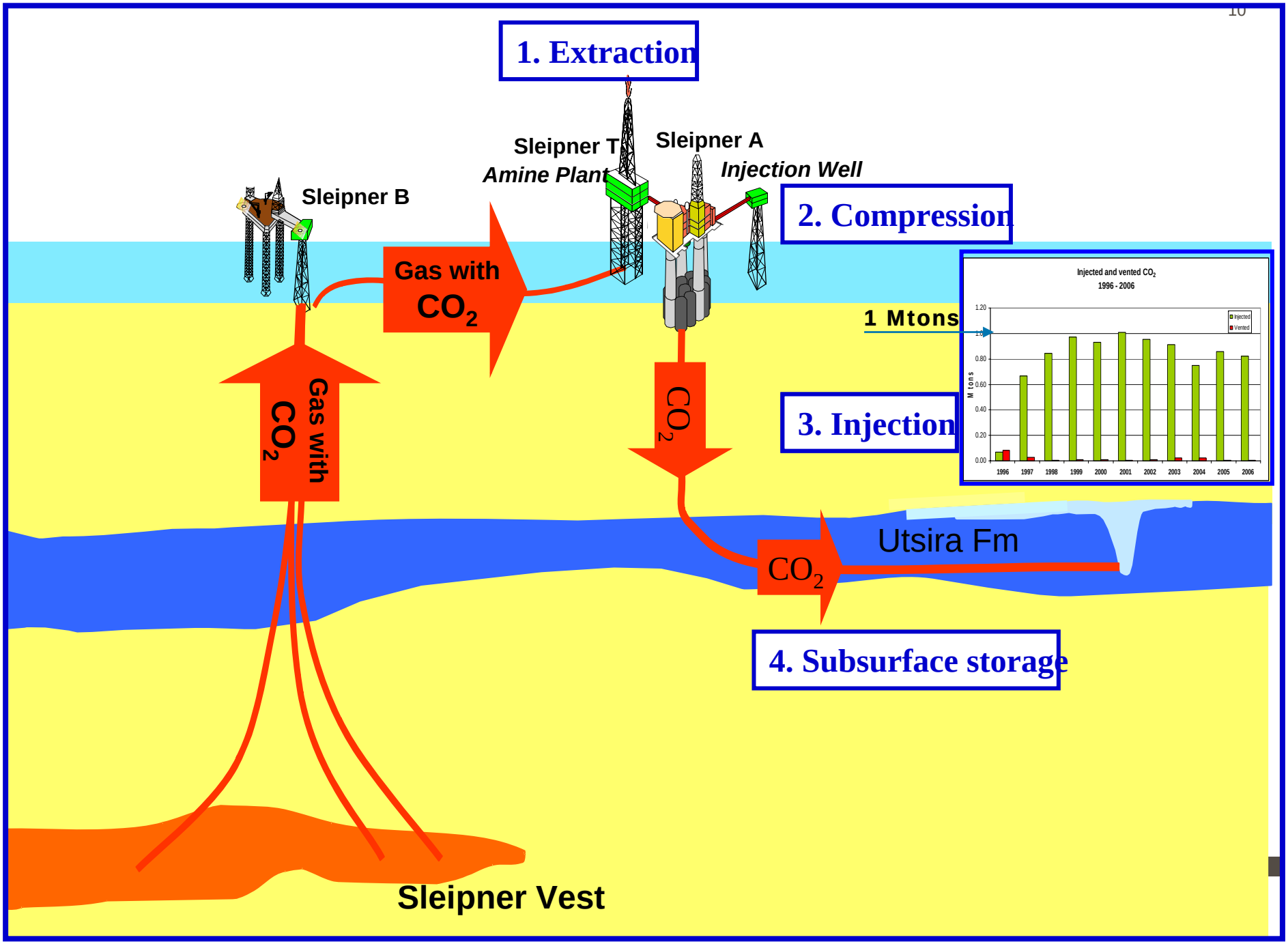
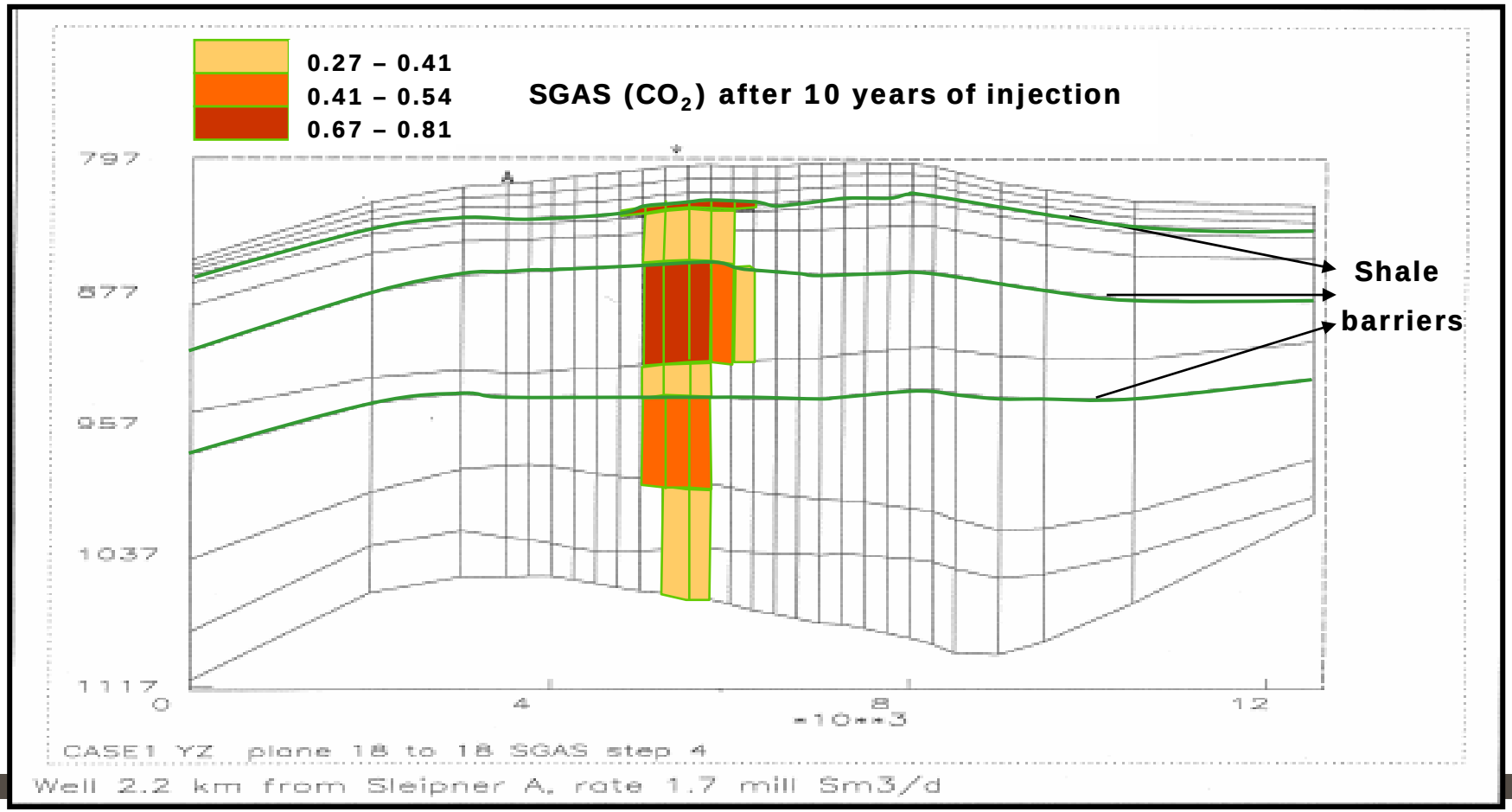

1. Extraction
Sleipner T
Amine Plant
Sleipner A
Injection Well
Sleipner B
2. Compression
Gas with
CO2
1 Mtons
Injected and vented CO2
1996 - 2006
Injected
Vented
Mtons
1.20
1.00
0.80
0.60
0.40
0.20
0.00
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
3. Injection
Gas with
CO2
CO2
Utsira Fm
CO2
4. Subsurface storage
Sleipner Vest

Main issues focused on prior to injection - INJECTIVITY

→ Reservoir Simulation (black oil, oil-gas model)

Temperature critical, 27 ^{0}C



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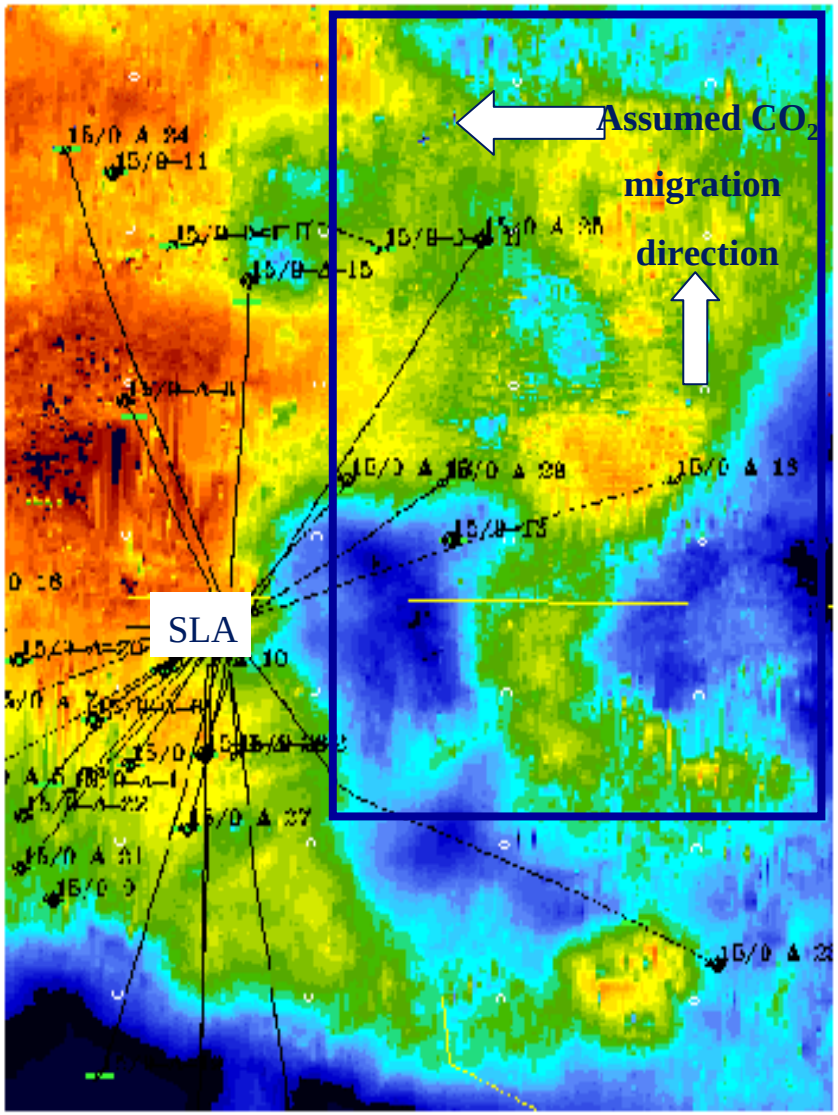
Main issues focused on prior to injection - MIGRATION



No migration of the CO_2 back to the Sleipner wells

- **New seismic survey in 1994 → changed the location from NW to 2.8 km NNE of the SLA (the current location)**
- **Structural trap identified, saddle area northwards**

  Predicted migration direction → northwards
- **Base Utsira Fm shows shale diapirs east of SLA → expected to reduce the horizontal distribution of the CO_2 towards the SLA**

The In Salah CO_2-injection in Algeria

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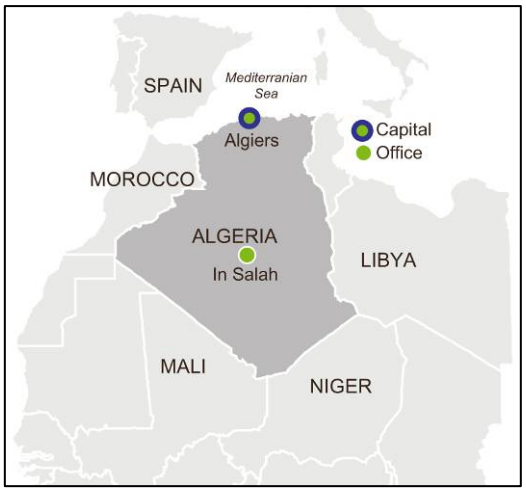

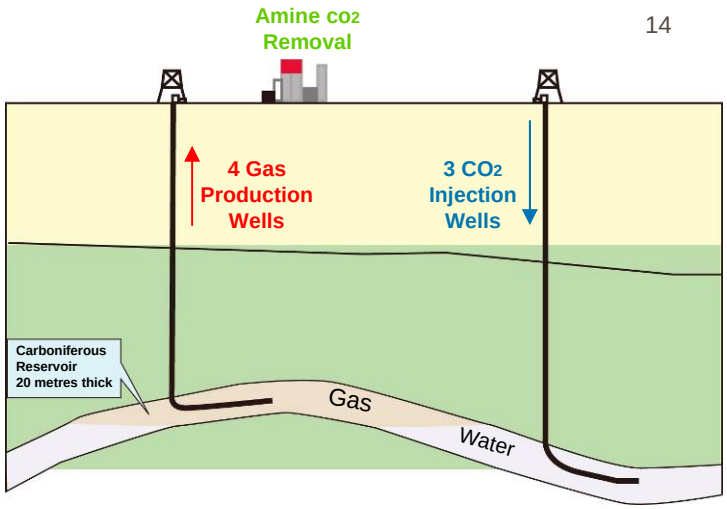

The In Salah CO_2 injection

- **From left to right:**
  - Location map
  - Picture of the gas processing plant
  - Schematic illustration of CO_2-injection in 3 wells

- **Injection of nearly 1 million tons of CO_2 per year**
- **CO_2 extracted from natural gas**

Sources: BP, Sonatrach, StatoilHydro

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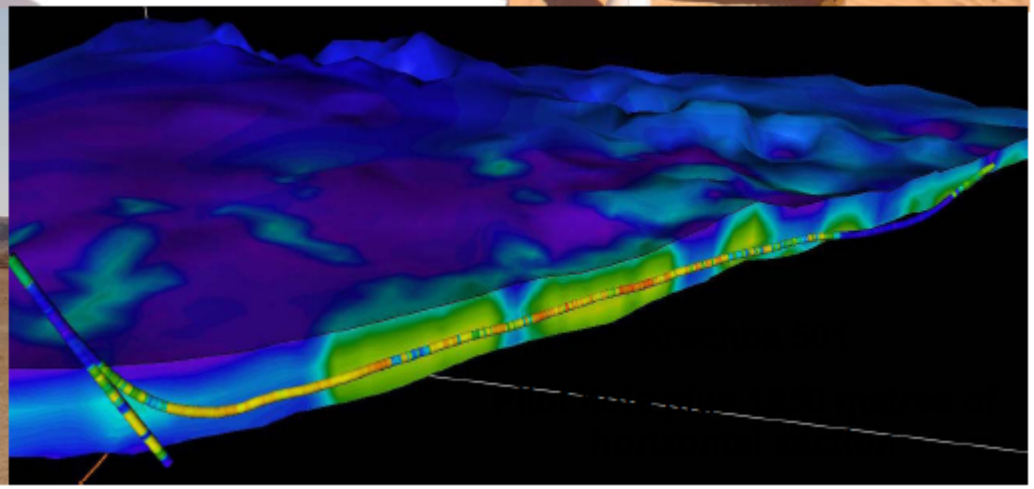
More on In Salah CO_2 injection

50mmscf/d CO2
(1mmtpa)
Compression
Transportation
Injection
Storage

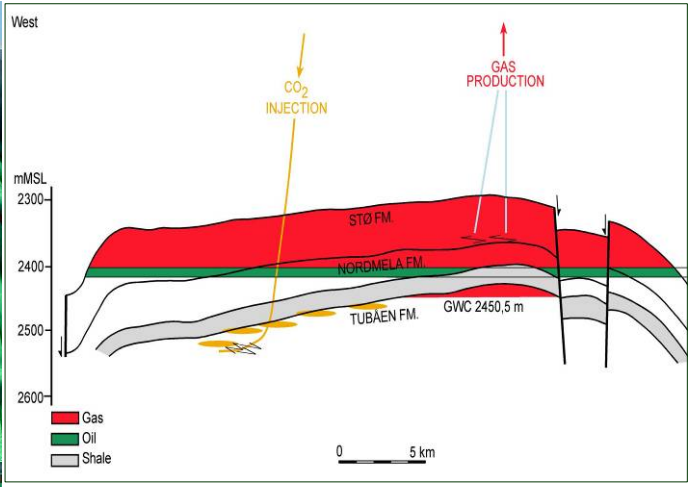



The Snøhvit CO_2-injection
- started operation in April 2008
- about 0,7 mill tonnes CO_2 per year

Snøhvit

CO_2-capture plant at Melkøya

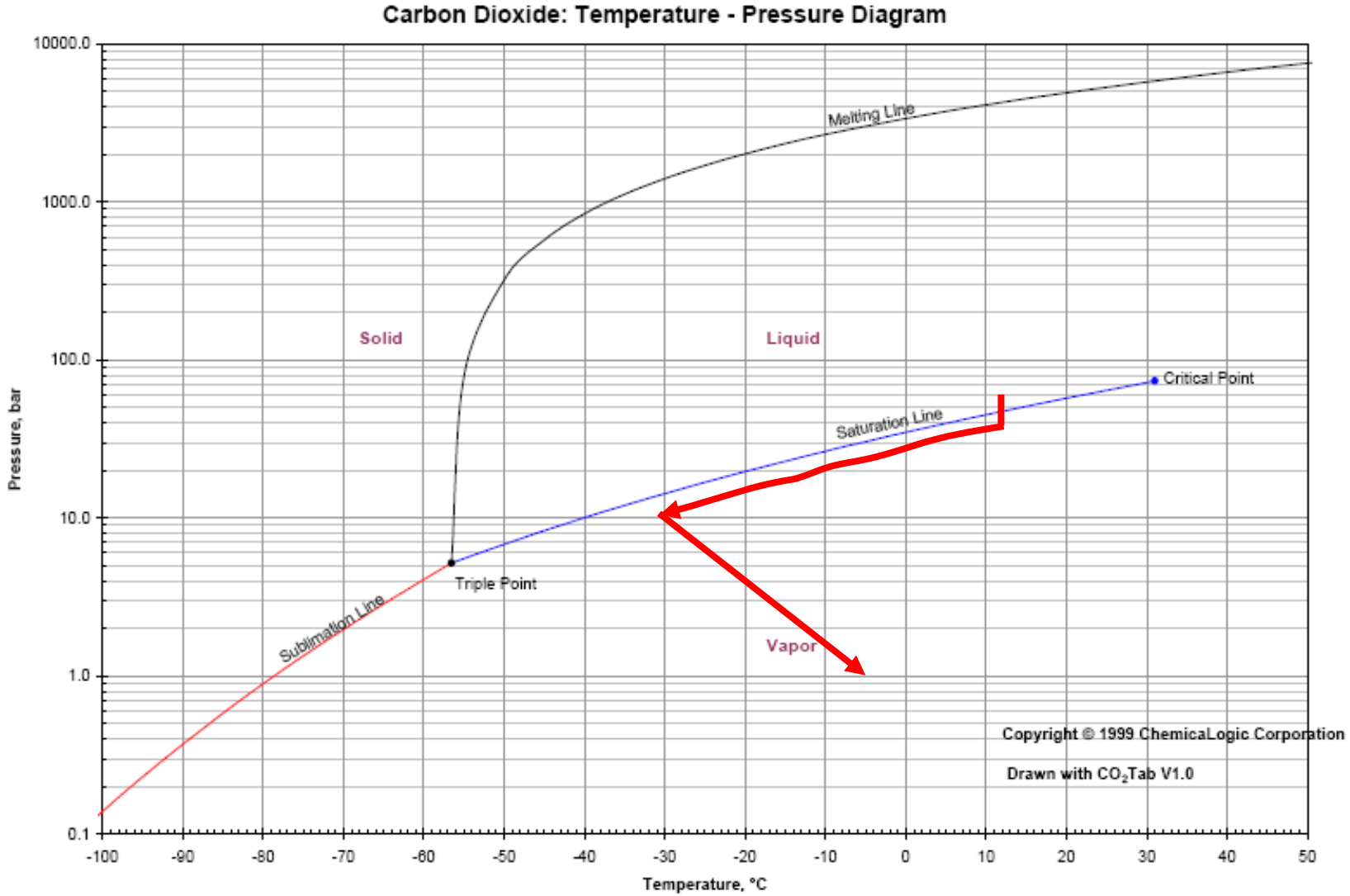
First CO_2 injected:
22. April 2008



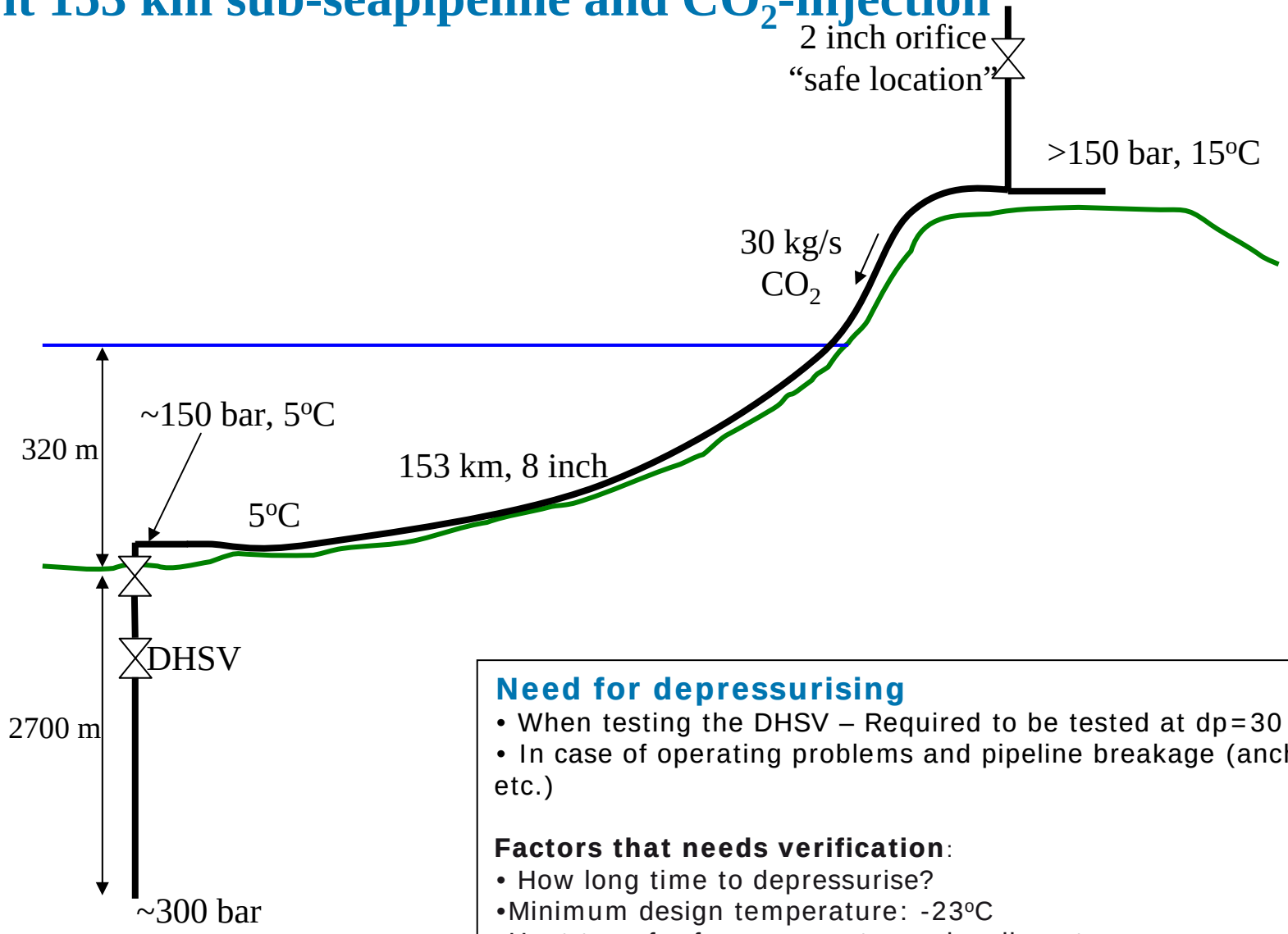
The Snøhvit LNG + CO_2 capture, -transport and -storage project

- **Above, from left to right:**
  - Location map
  - Picture of the Melkøya LNG-plant with CO_2-capture plant
  - An illustration of the sub-sea wells and pipelines
- **About 0,7 million tons of CO_2 per year injected**
- **CO_2 extracted from natural gas to be stored below the gas reservoir**

Depressurising the sub-sea CO_2-pipeline – it gets cold



Snøhvit 153 km sub-seapipeline and CO_2-injection



Need for depressurising

- When testing the DHSV – Required to be tested at dp=30 bar
- In case of operating problems and pipeline breakage (anchors etc.)

Factors that needs verification:

- How long time to depressurise?
- Minimum design temperature: -23ºC
- Heat transfer from sea-water and sediments

The Weyburn-Midale CO_2-EOR and –storage project

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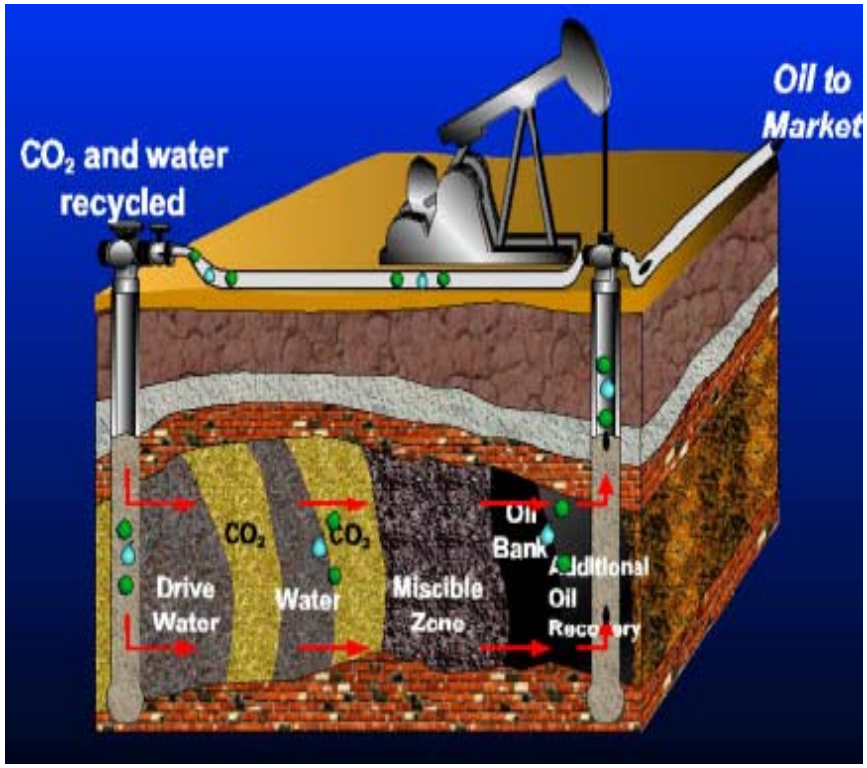
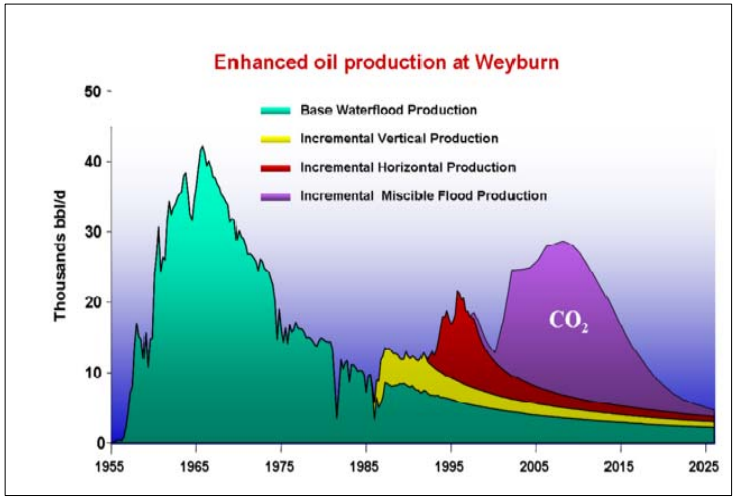
The Weyburn-Midale CO_2-EOR Projects in Canada (2)

The CO_2- compressor facility

This is where CO_2 arrives after a 320 km pipeline transport from the coal gasification at Beulah in North Dakota, USA

The Weyburn-Midale CO_2-EOR Projects in Canada (1)





What does it cost?

Investment costs for CO_2-storage projects (ex. capture)

Project		Sleipner	Snovit	Gorgon
Country		Norway	Norway	Australia
Start		1996	2007	2008-2010
		Aquifer	Aquifer	Depleted Oil
Annual Injection rate	Million T/year	1	0,7	5,2
CO2 Avoided		*	*	4,8
Onshore/Offshore		Offshore	Offshore	Onshore
Number of Wells		1	1	
Pipeline length	km	0	153	
Investment Costs				
Compression and Dehydration	$ million	*	70	
Pipeline	$ million	None	73	
Drilling and Well Completion	$ million	10	25	
Facilities	$ million	*	12	
Other	$ million	*	11	
Total Investment Costs	$ million	80	191	A$ 300-400
Operating Costs				
Annual Costs	$ million	USD 0.75 million	N/A	N/A

Sleipner CO_2 operating costs

Type of cost	Mill US$/yr
System cost (average for all systems)	5,6
Logistics, catering etc.	0,7
Monitoring of storage reservoir	1,8
CO2- and NOx-taxes	4,5
Average yearly cost	12,5

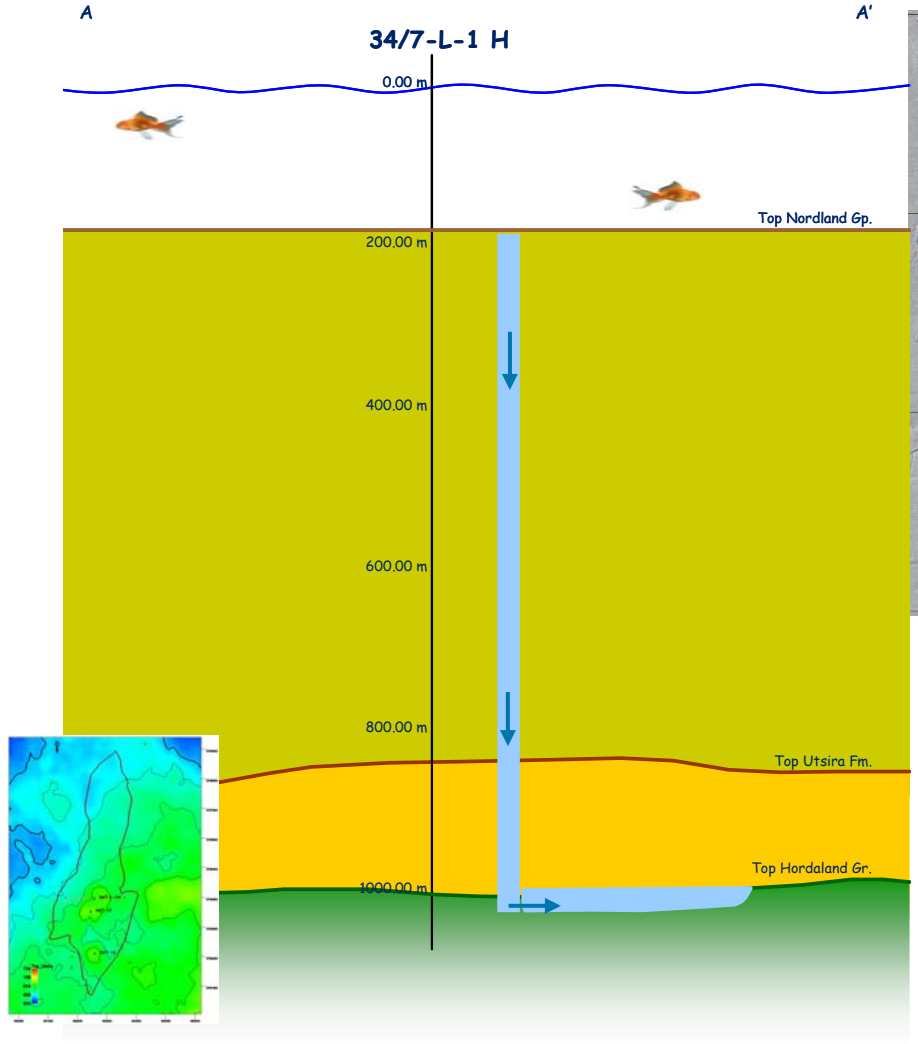
In Salah costs

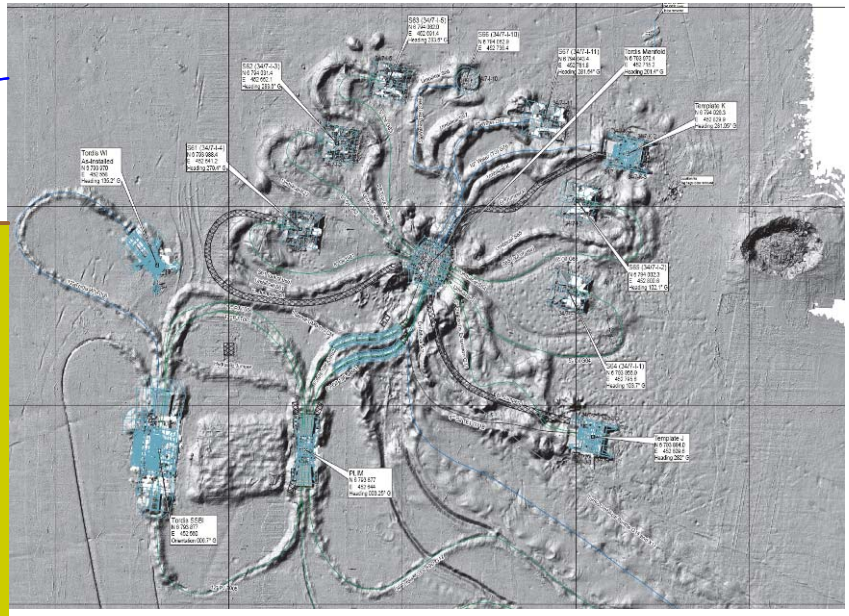
- US $100mm Incremental Cost for Storage
- No commercial benefit, no CO2-tax
- Test-bed for CO2 Monitoring Technologies $30mm Research Project

Things can go wrong

→ a lesson from a water/sand injection project

The Tordis water/sand injection incident





- **Triggering factors**
  - Injection operated at pressures and flow higher than the formation could take
- **Underlying causes**
  1. Misjudgement of potential hazard
  2. Requirements/guidelines incomplete or missing
  3. Inadequate follow-up / control of work
  4. Important information not communicated/understood
  5. Consequences of the modification was inadequately assessed

A couple of other, smaller scale CCS-projects

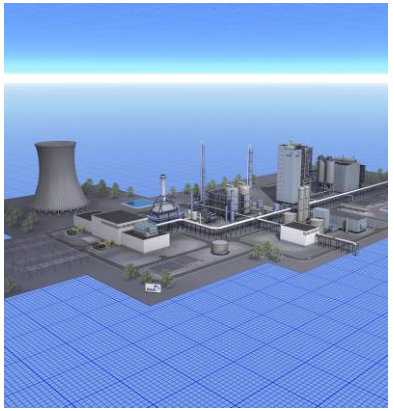
Ketzin, Germany

CO_2 injection facilities at Nagaoka, Japan

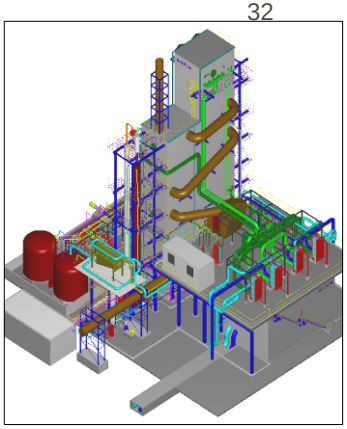
Castor pilot, DK

Aker Clean Carbon, N

Vattenfall oxy-fuel, D



RWE full scale, D



Test Center Mongstad, N

Capture from power plants and industrial sources;

- Capture from flue gases can be a magnitude more difficult than CO_2-capture from natural gas
  - Volume, pressure, concentration, energy consumption, emissions to air and so forth
- Large activity in EU and globally wrt. finding better technologies
  - Lots of pilot and a few demo units, numerous industrial scale engineering projects
  - Many more than shown in the above pictures

The next step at StatoilHydros Mongstad refinery

Combined heat and power plant being built

The next big step for CO_2-capture from flue gas sources;
The European CO_2 Test Centre (TCM) plus full scale CO_2-capture at StatoilHydros Mongstad refinery

- **From the left:**
  - Location map, picture of the Mongstad refinery, an illustration of the power plant
- **Rule of the thumb: the capture part may be ¾ of the total CCS-cost**
- **The primary objective of TCM is to test and qualify technology for the capture of CO_2 in order to reduce the costs and risks associated with large-scale plants**

Exploring for CO_2-storage
StatoilHydro's COSMaP programme

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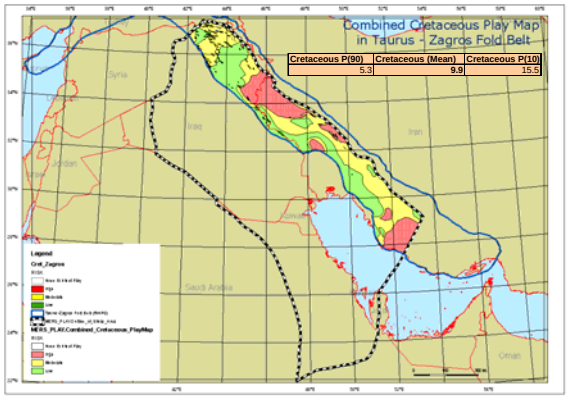
Methodology – HOW Mapping activities

Capacity
"Final" numbers

Capacity
Large uncertainty



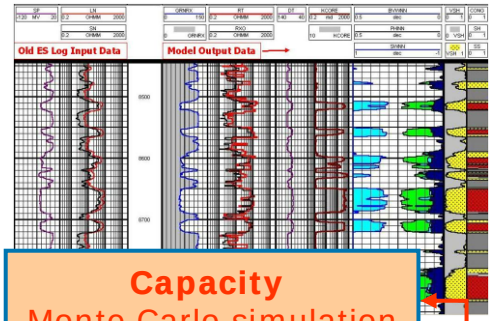
DG1

Feasibility
Appraisal drilling

Basin evaluation &
"YTF-figures"

DG0

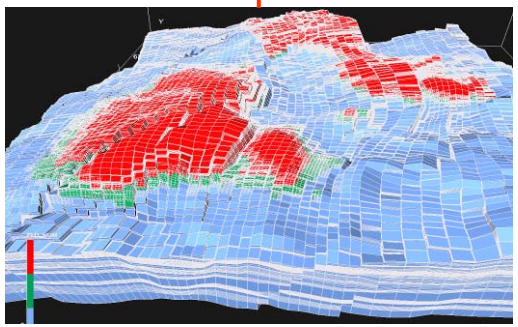
DGA



Drilling

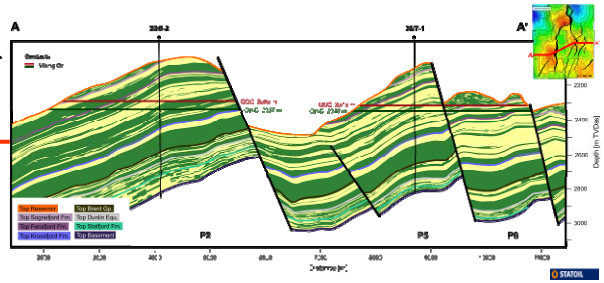
Data collection
/gathering

Capacity
Monte Carlo simulation



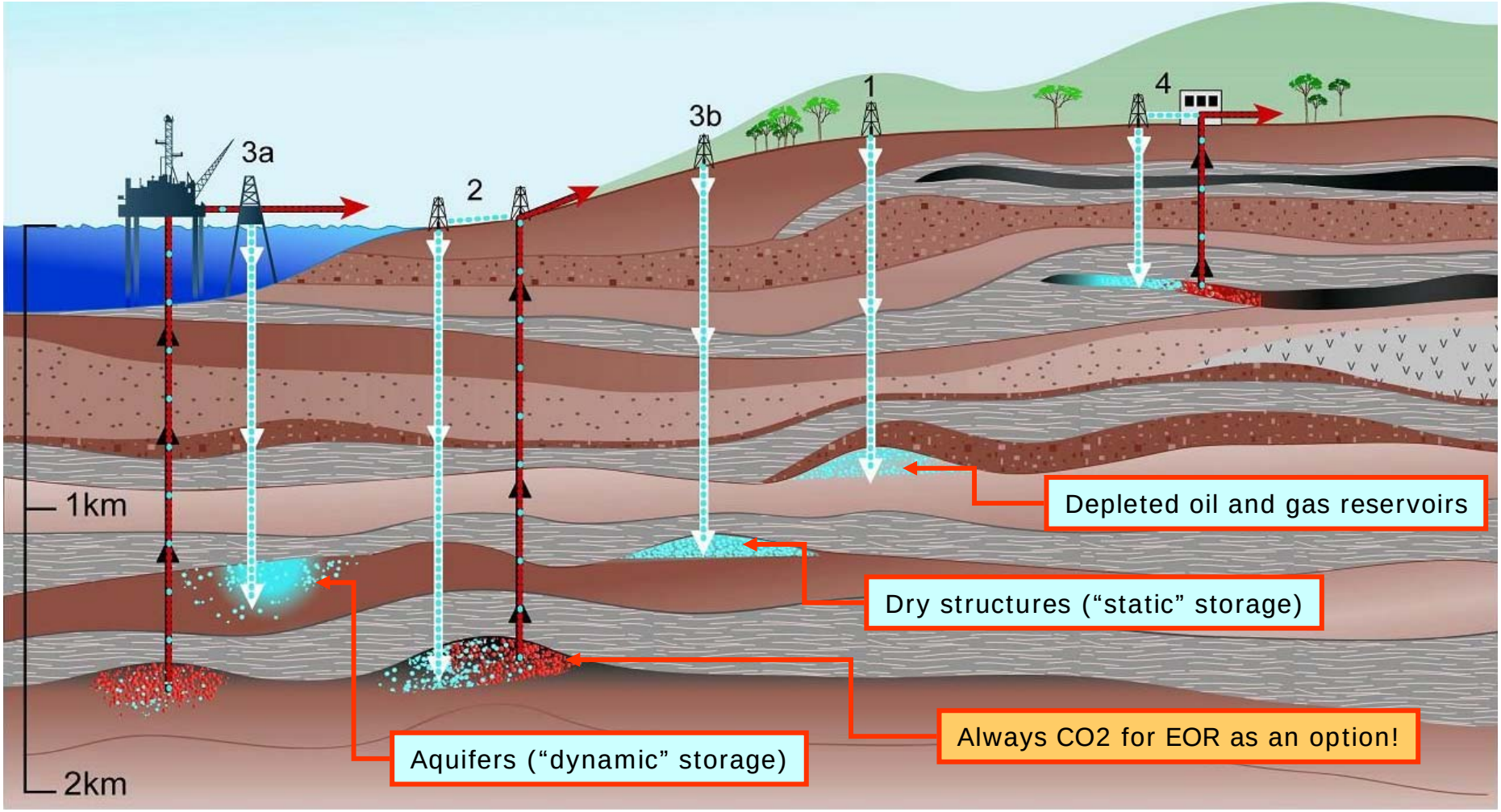
Static and dynamic
3D modelling

Prospect evaluation
Uncertainty analysis

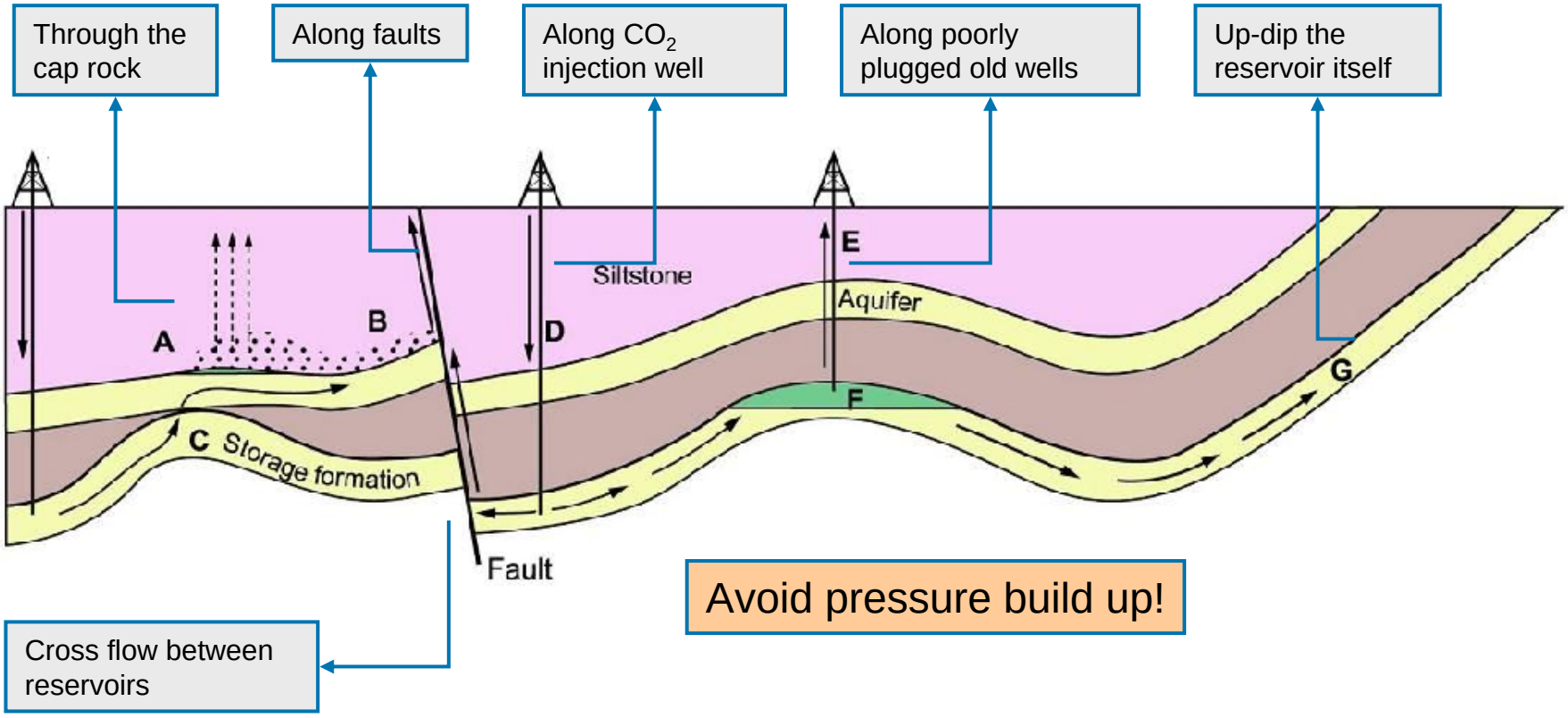


Capacity
Moderate uncertainty

Methodology – HOW Storage options



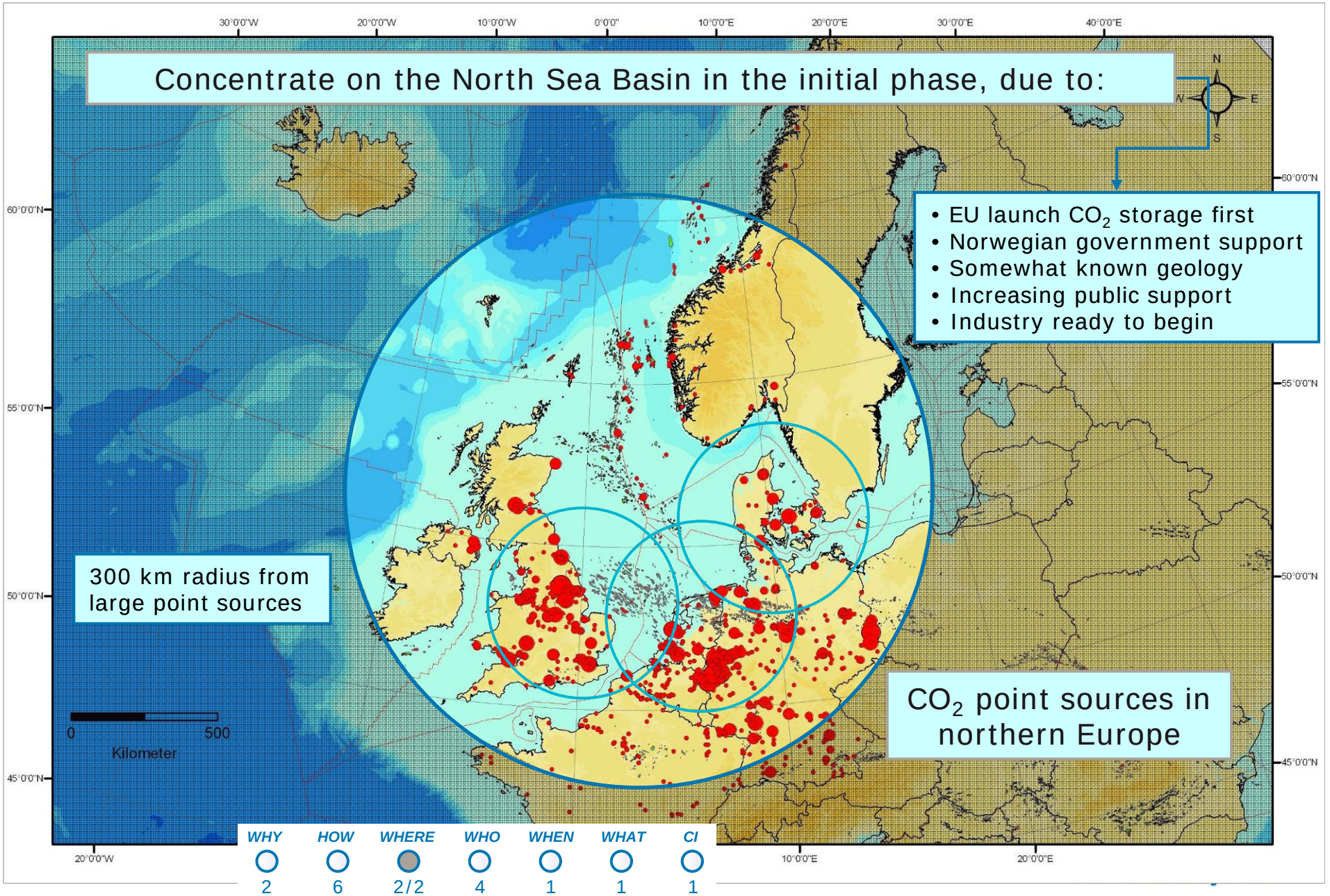
Methodology – HOW Evaluate leakage risks



Avoid pressure build up!

Site specific - Each storage needs individual attention

Screening – Where Geographical area selection



WHY	HOW	WHERE	WHO	WHEN	WHAT	CI
2	6	2/2	4	1	1	1

In sum

- → CCS is doable for oil and gas companies with their experience
- → The CO_2-rich gas operators are most likely to continue pioneering CCS
- → The challenge is primarily to find ways to finance such projects
- → There is still some way to go wrt. technology and (not least) cost
- → Let us not underestimate the challenges of geological storage
- → Let us keep a focus on the opportunity of using CO2 for EOR