NORWEGIAN PETROLEUM
DIRECTORATE

CCS & the global climate change issues

CCOP-Norway EPPM Program 3rd Seminar

Project Director

Eva Halland

Norwegian Petroleum Directorate

Bangkok 11 November 2010

Outline of my talk

1 Why CCS & what are the current issues?

Climate issue

Reduce the CO2 content in the produced gas

Use CO2 for enhanced recovery

Find storage sites

2 Mapping of suitable CCS reservoir

Criteria & process of selection

Cross-boarder collaboration- challenges and solutions

Tools & capacities needed

Case studies

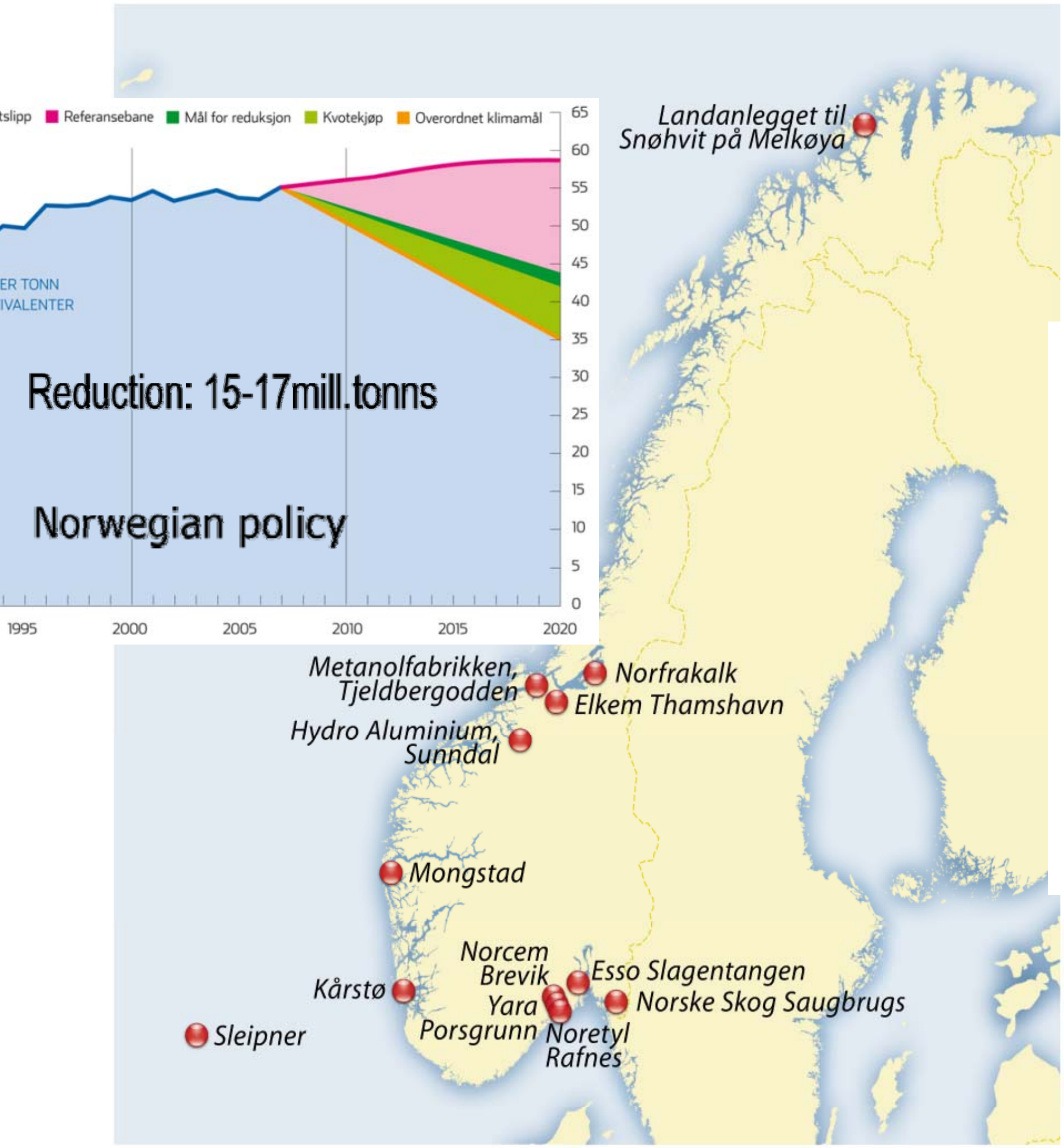
3 Role(s) of geosciences

Norwegian Petroleum Directorate

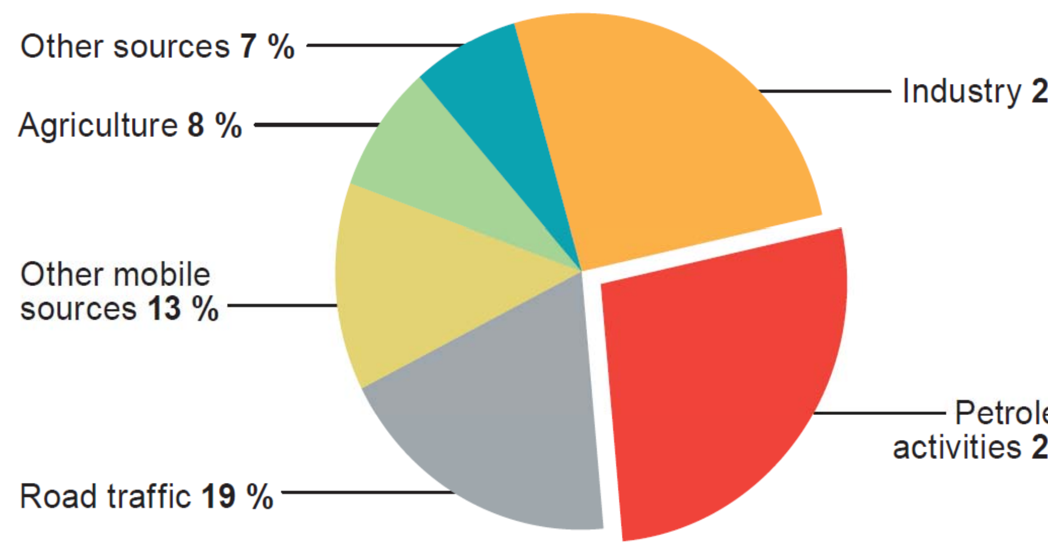
- Subordinate to the Ministry of Petroleum and Energy (MPE)
  - Advisory body to the MPE
  - Exercise management authority
- Established 1972 in Stavanger
- 220 employees; – engineers, geologists, economist etc

The Norwegian Petroleum Directorate will contribute in **creating the greatest possible value for society from oil and gas activities by means of prudent resource management**, based on safety, emergency preparedness and safeguarding the natural environment.

CO_2- emissions from Norwegian sources



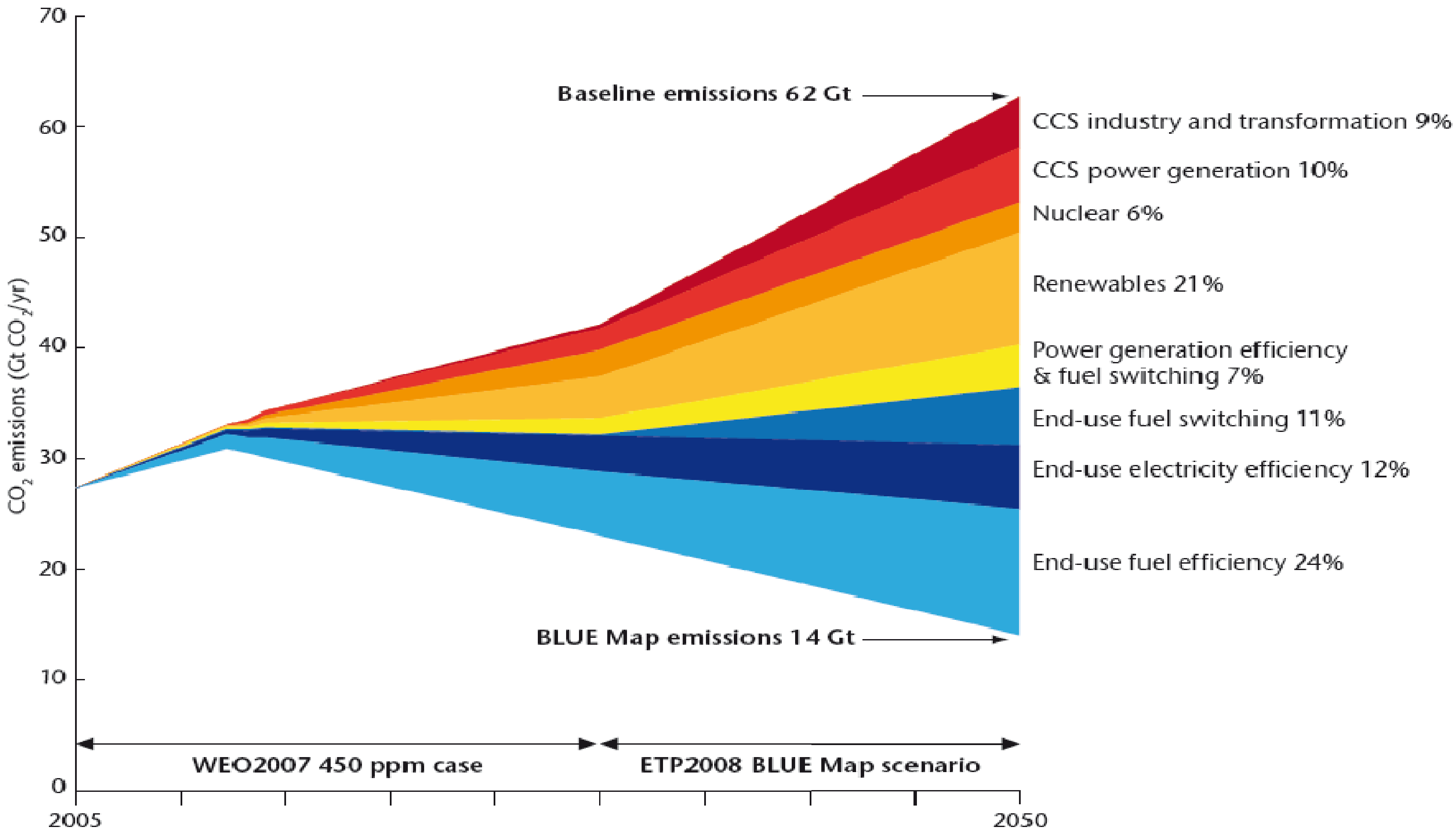
Sources of Norwegian CO_2 emissions, 2008



Total CO_2 emissions
ca. 45 million tonns/year

CS Potential: up to 20% of needed reductions

Figure 1: CCS delivers one-fifth of the lowest-cost GHG reduction solution in 2050



Source: IEA, *Energy Technology Perspectives* (2008a).

***KEY POINT:** Without CCS, overall costs to halve CO_2 emissions levels by 2050 increase by 70%.*

Internationally

The Global CCS Institute formally launched at G8/Major Economic Forum in Italy 9th July 2009

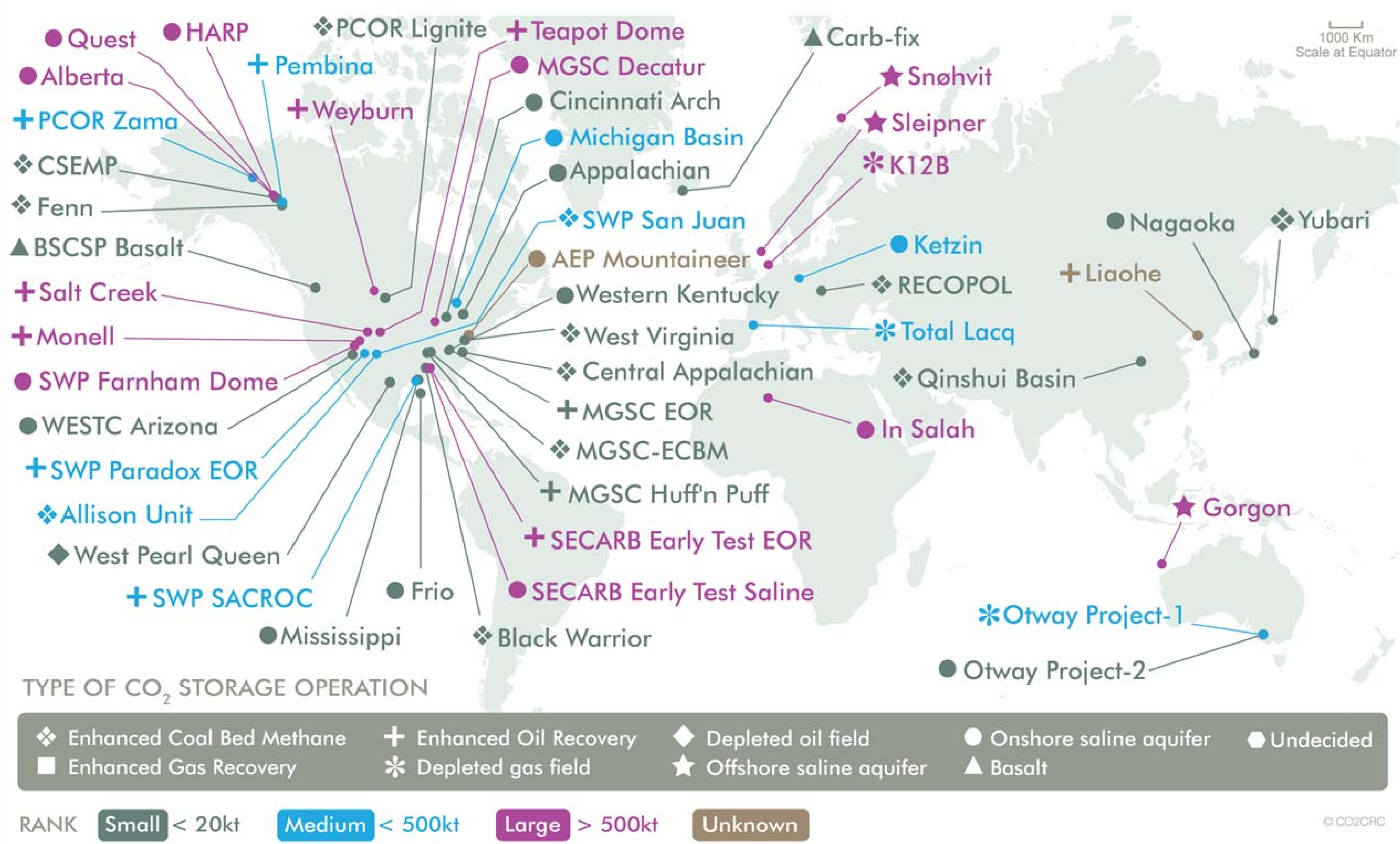
Testimonial

”If we want to reduce our greenhouse gas emissions by 80% in 2050, we certainly need Carbon Capture and Storage” (Andris Piebalgs, EU Energy Commissioner)

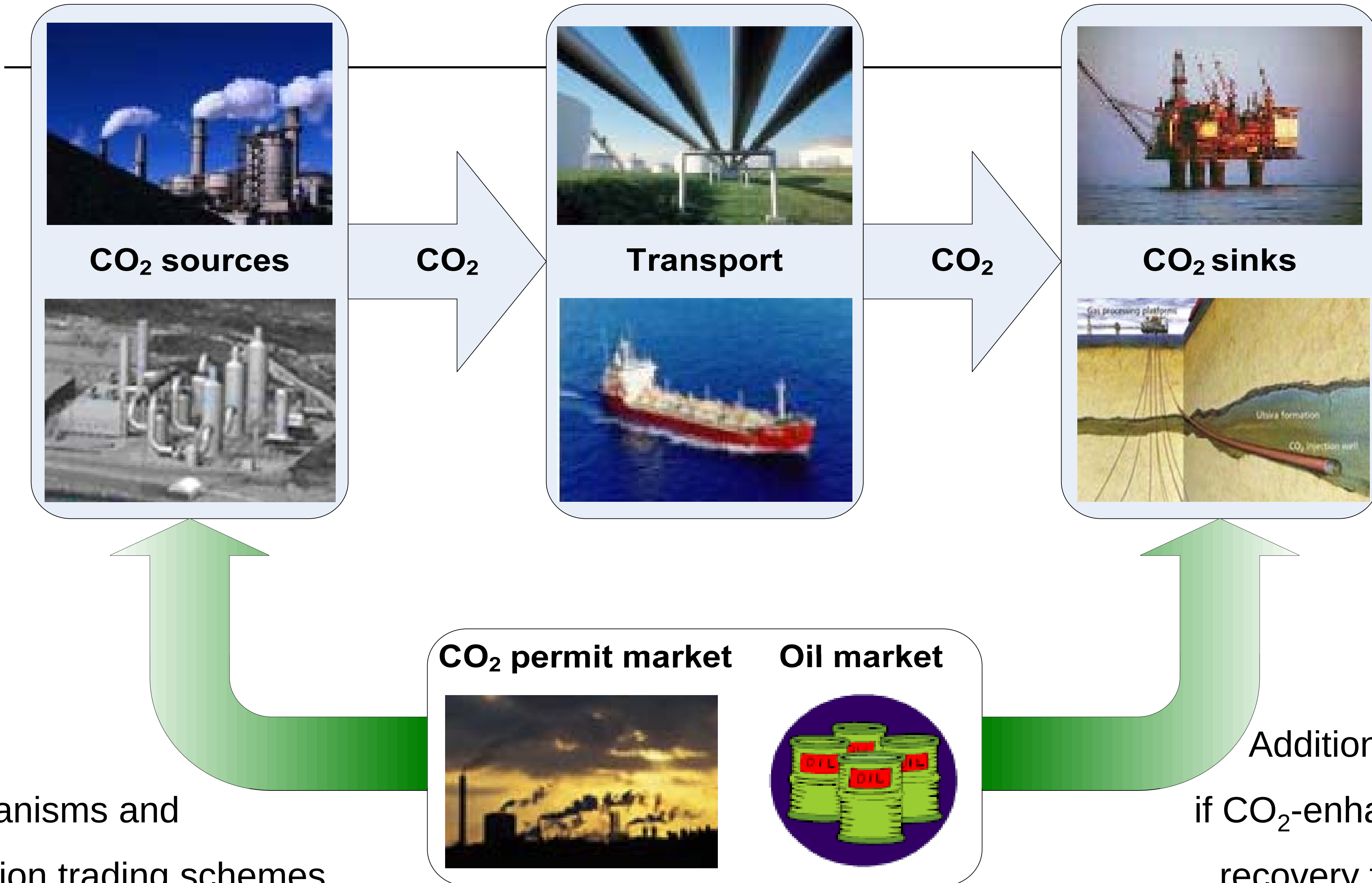
he European Council has called for a emonstration programme of up to 12 arge-scale CCS projects to be perational by 2015

“We strongly support the recommendation that 20 large scale CCS demonstration projects need to be launched globally by 2010, with a view to supporting technology development and cost reduction for the beginning of broad deployment of CCS by 2020.”
G8 Statement of June 2008

CO_2 active projects



CO2 value chain



oto
echanisms and
nission trading schemes

Additional oil
if CO_2-enhanced
recovery feasib

CCS – just expensive or good value-creation?

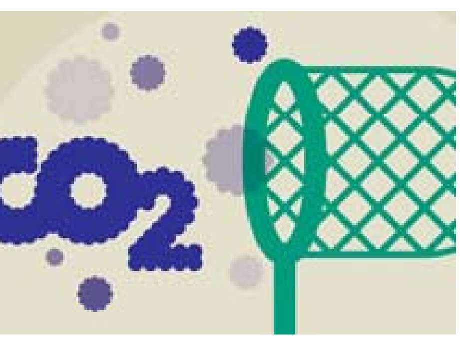
✓Gas with high CO_2 content - Sales gas specification (Sleipner, Snøhvit)

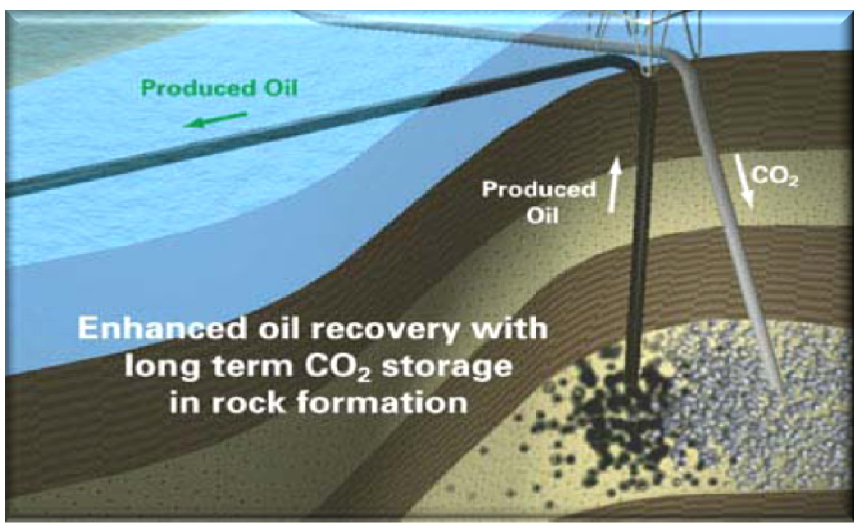
✓Enhanced hydrocarbon recovery

✓Increased industrial production

✓Offer good quality storage sites – business opportunities

..and reduce the CO_2 emission to air





Four Large CO2 Commercial Projects in Operation

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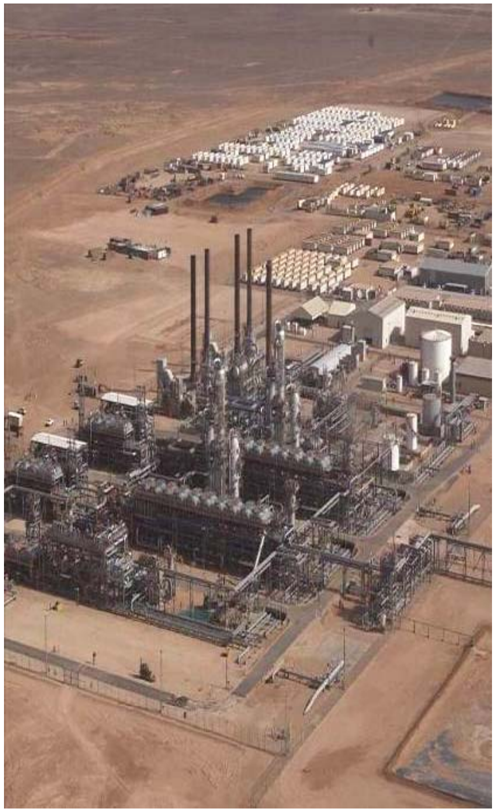
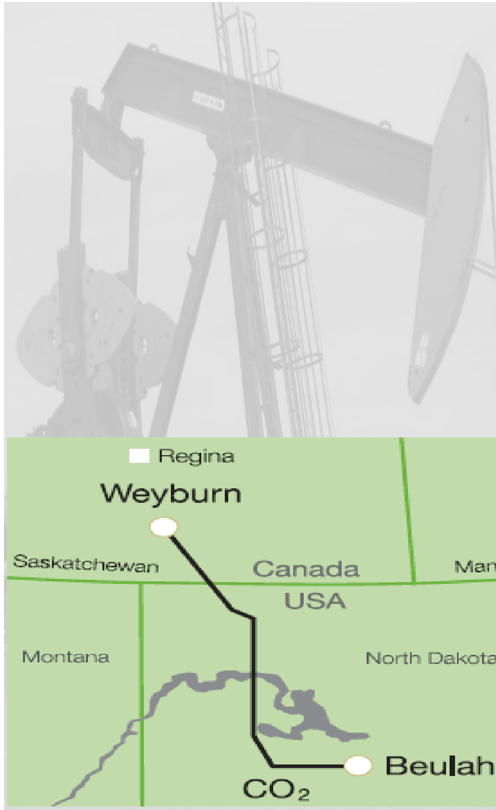
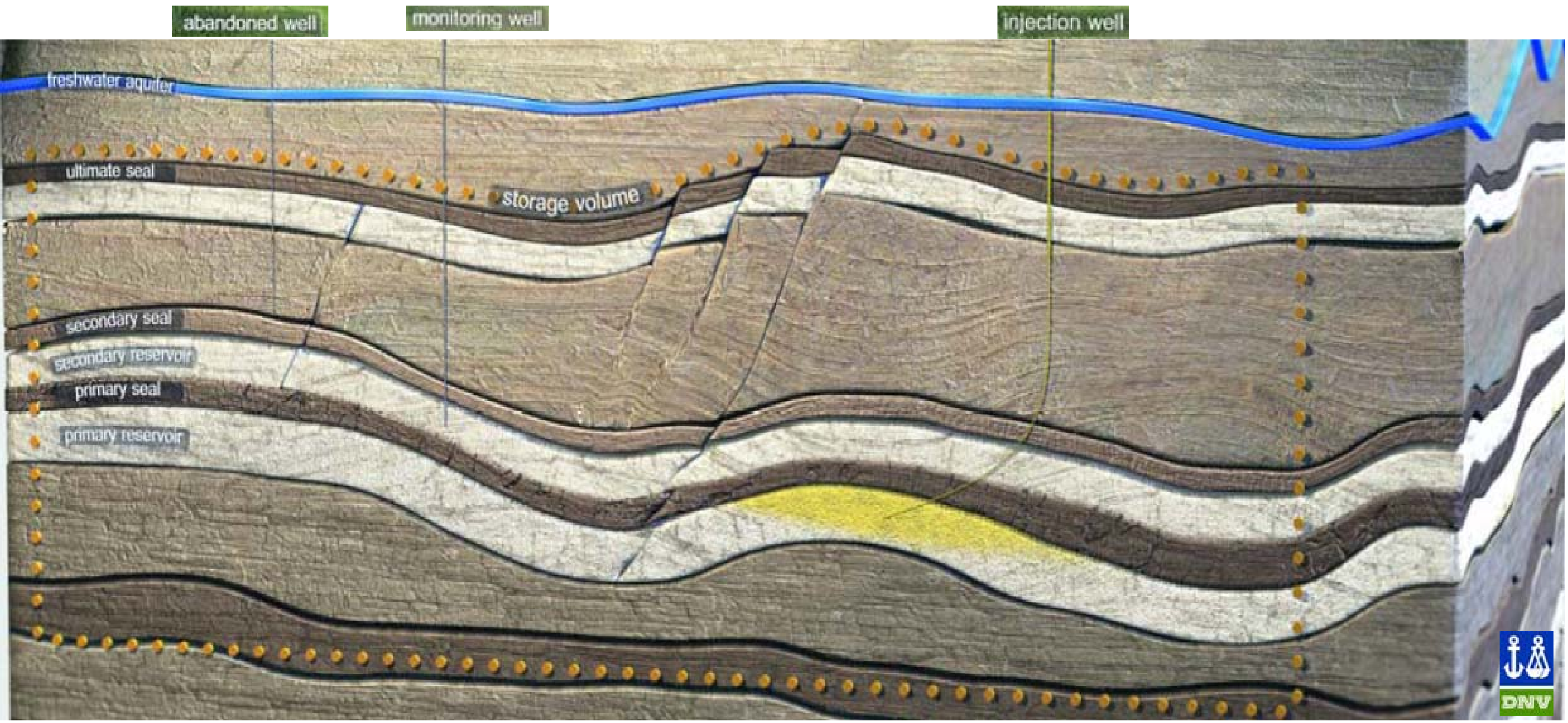
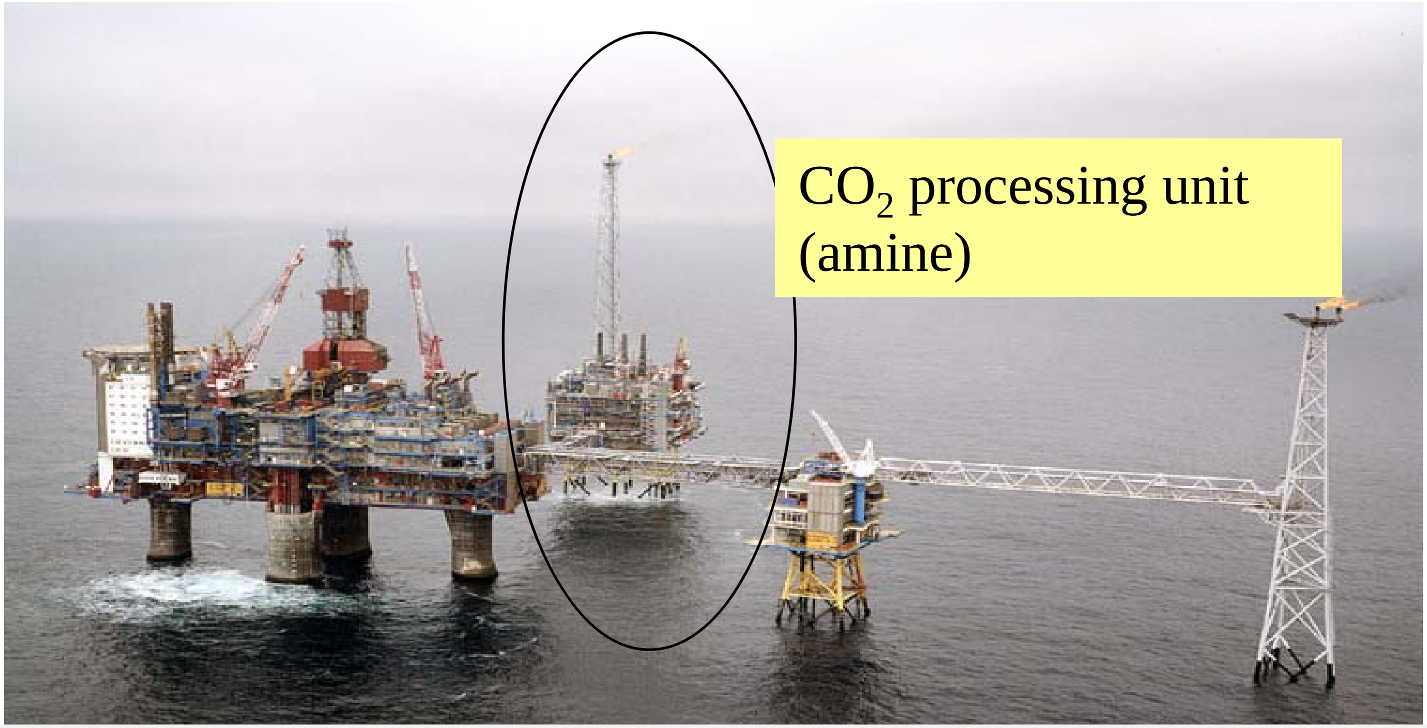
Sleipner, Norway	In Salah, Algeria	Snøhvit, Norway	Weyburn, Canada
			
Operator: Statoil 1 million tonnes of CO_2/year	Operators: BP, Statoil and Sonatrach 0.8-1.2 million tonnes of CO_2/year	Operator:Statoil 0.7 million tonnes of CO_2/year	Operator: EnCana 1.8 million tonnes of CO_2/year

Storage of CO_2 in the bedrock: an illustration

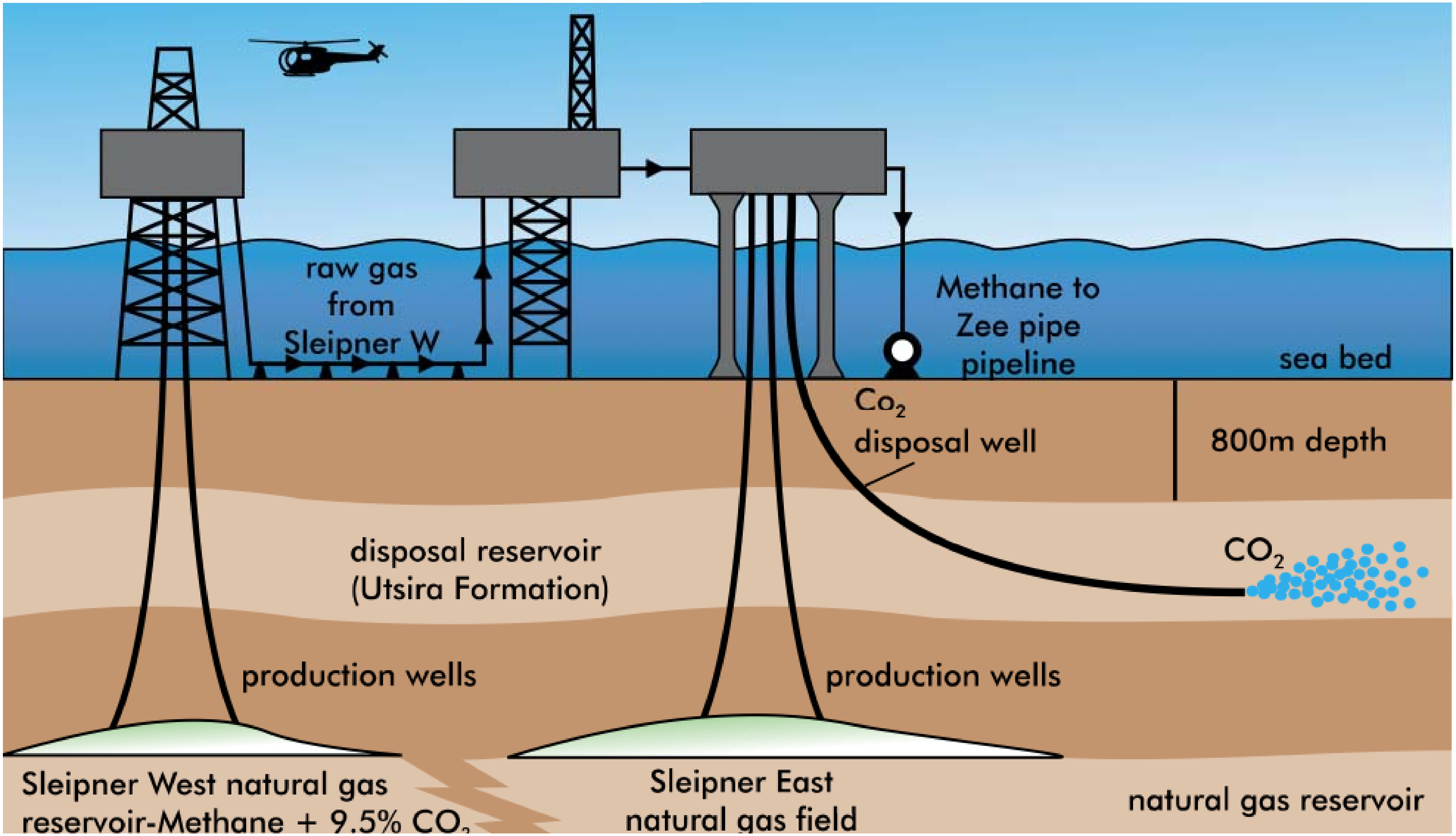


Sleipner CO_2 separation and injection



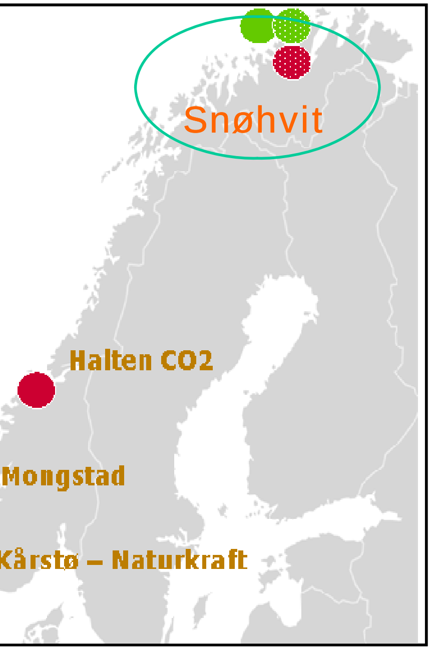
- Started in 1996 – 10 year of CO2-injection in October 2006
- Separating and injecting nearly 1 mill. tons CO2 annually
- Storing in saline aquifer above natural gas reservoir
- Driver: the ~45US$/ton CO2-tax imposed in 1992
- Learning and confidence building through a series of large EU-wide R&D programs

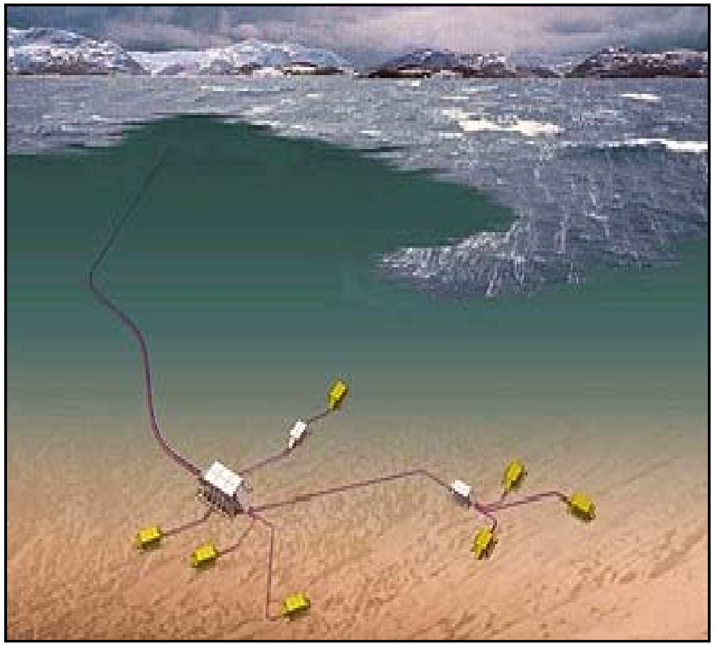
Sleipner case



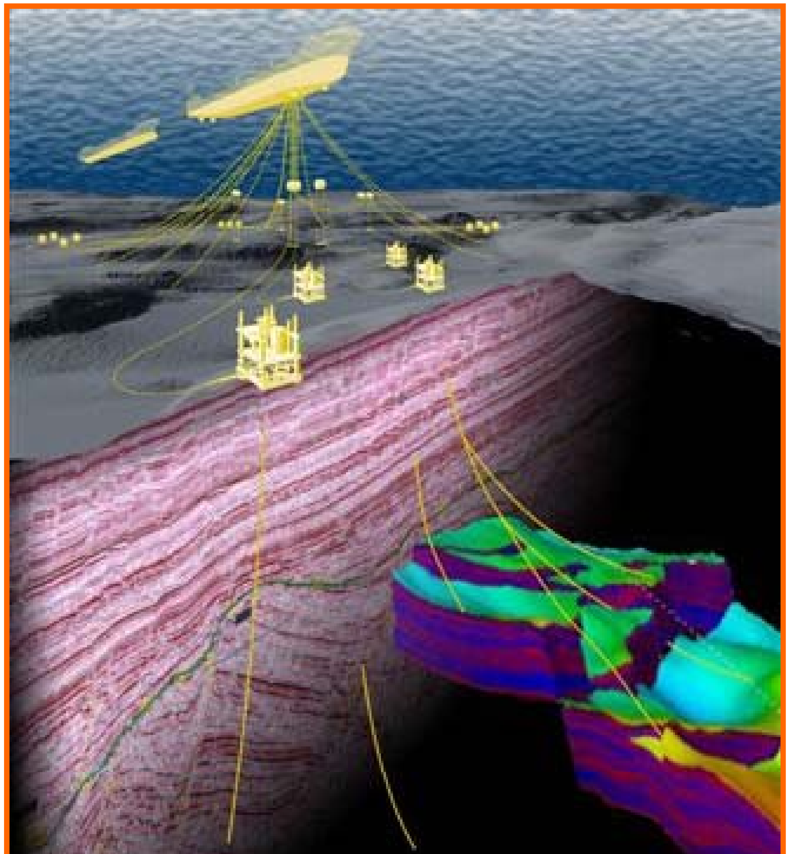
Snøhvit LNG with CCS

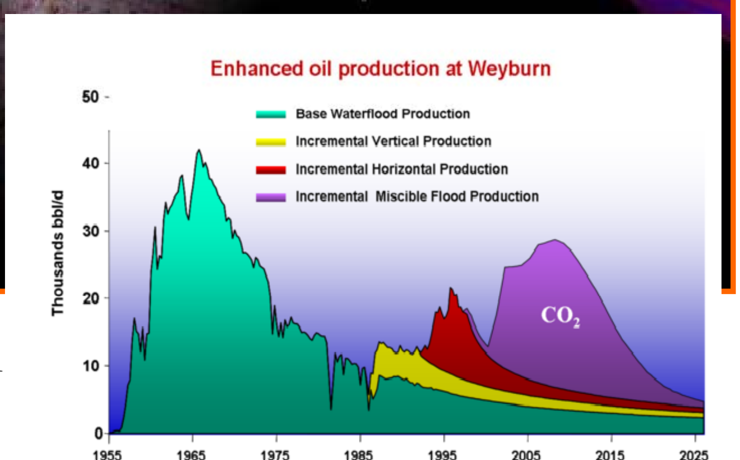
- iped CO2 separated from natural gas (5-8% CO2) in nshore LNG plant, and re-injecting in sandstone elow natural gas reservoir
- 45 km subsea pipeline transport.
- CS started April 2008 – capacity 700,000 ton/yr





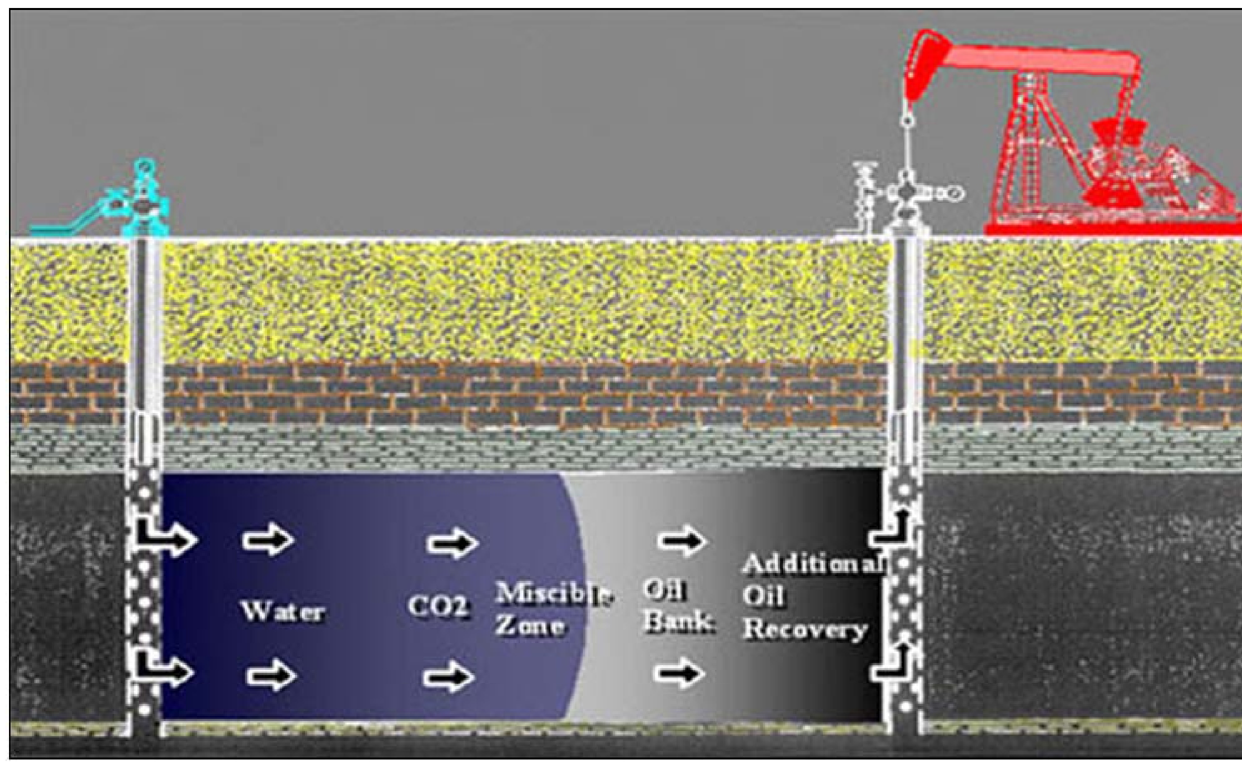
CO_2 to EOR
a technical potential in the Norwegian fields



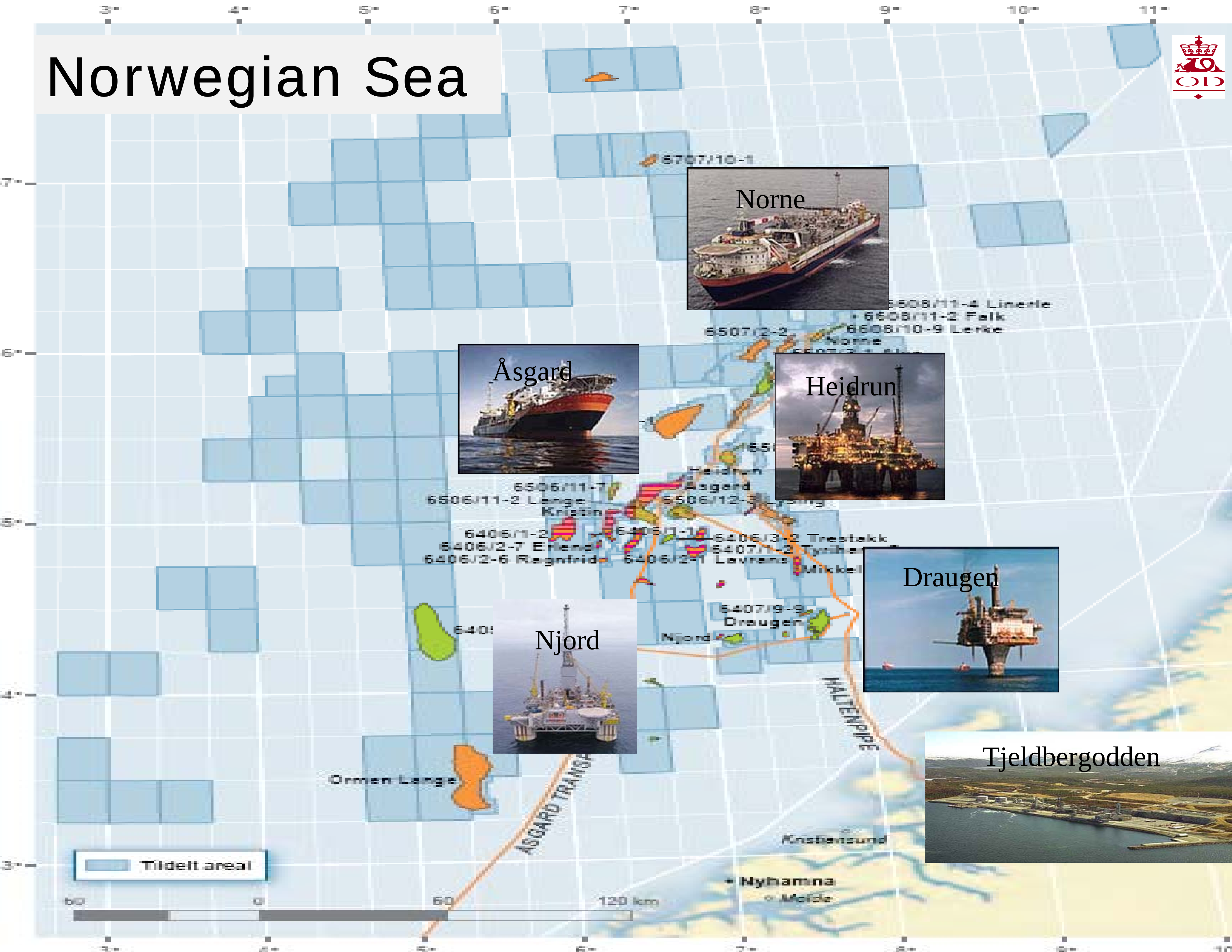


For 20 oilfields: 150-300 million Sm^3 extra oil, 3-7% (2005)
Need: 25 Mt CO_2/year for 30 years

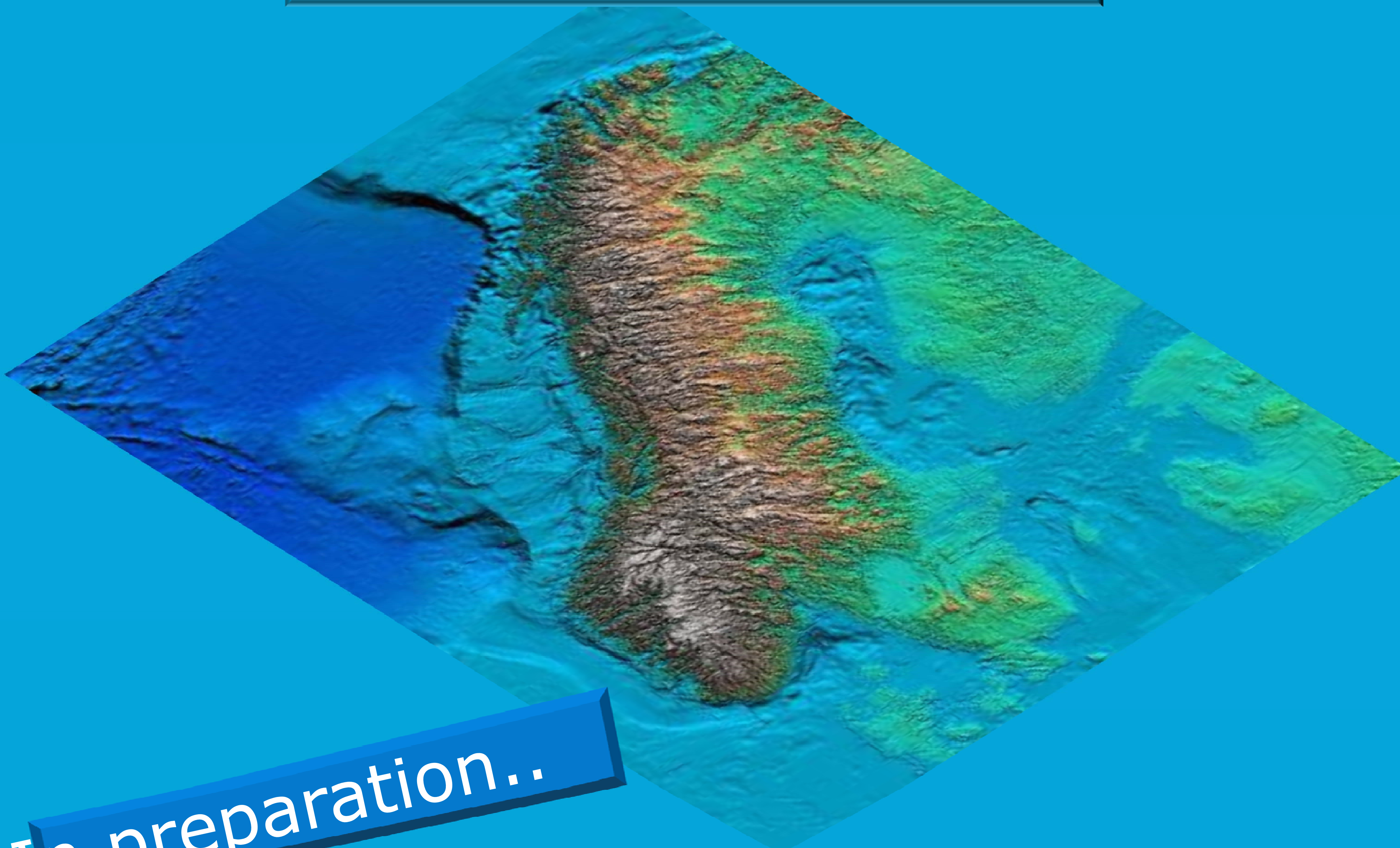
***IF** enough CO_2 could be made available at the optimum time in their production life at commercial conditions.*



Norwegian Sea

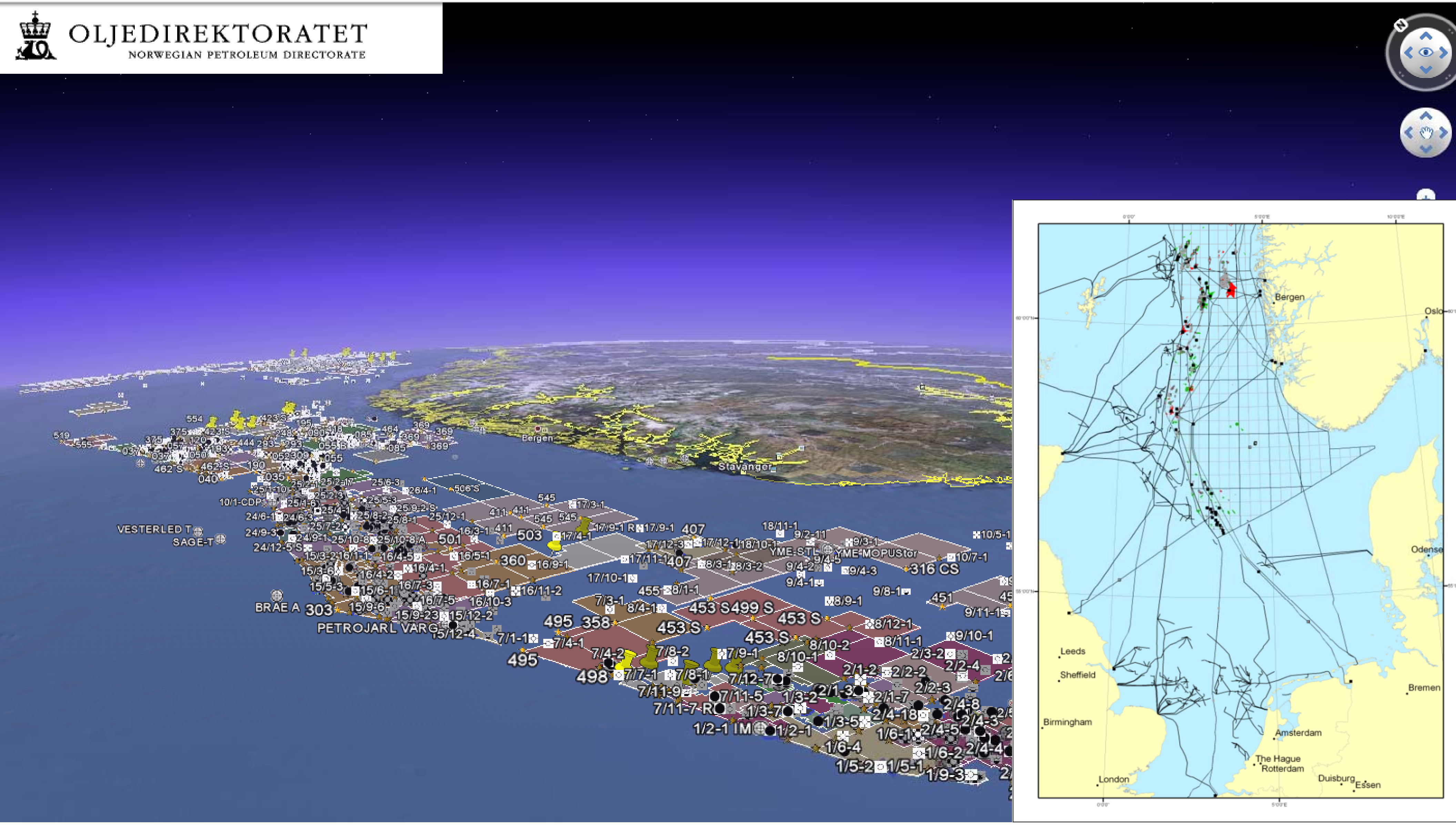


Norway
Carbon Dioxide Geological Storage Atlas



In preparation..

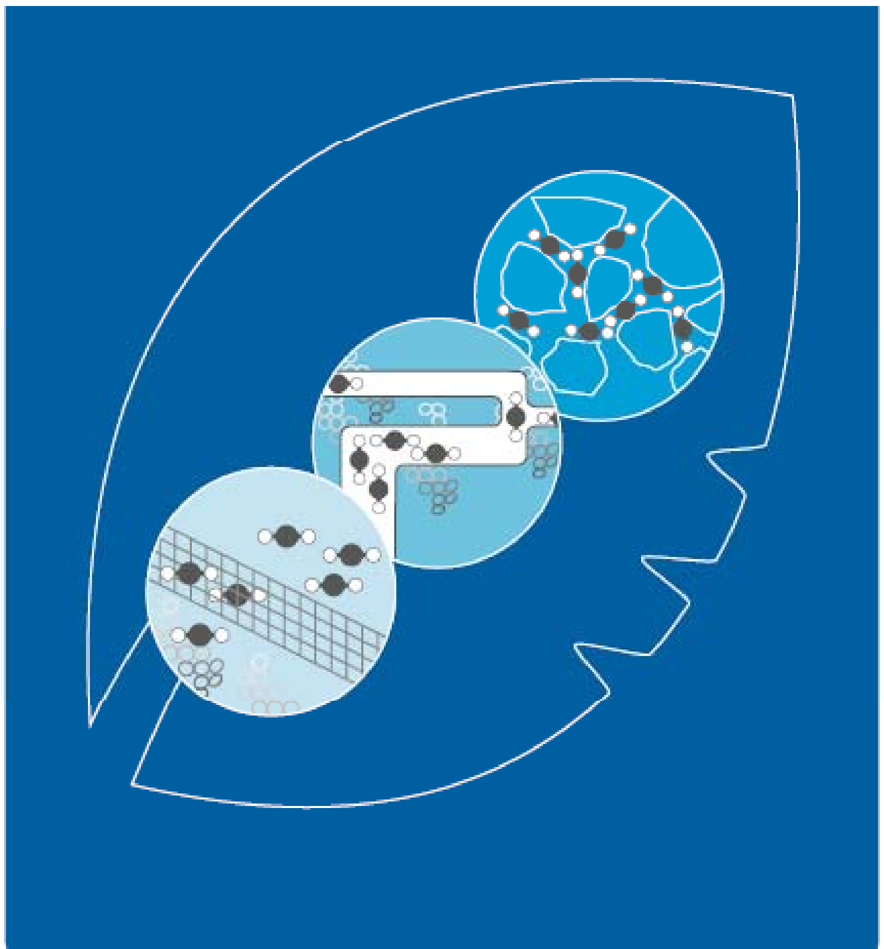
Based on collaboration with the Petroleum industry



In cooperation with Universities, Research Institutions

CLIMIT

PROGRAMME PLAN 2010–2012



Two FME in CO_2 storage (Centre for Eenvironment Friendly Energy research)

BIGCCS : 2009-2016, 22 partners
SUCCESS: 2009-2016, 8 partners

CO_2 Storage Forum, chaired by NPD

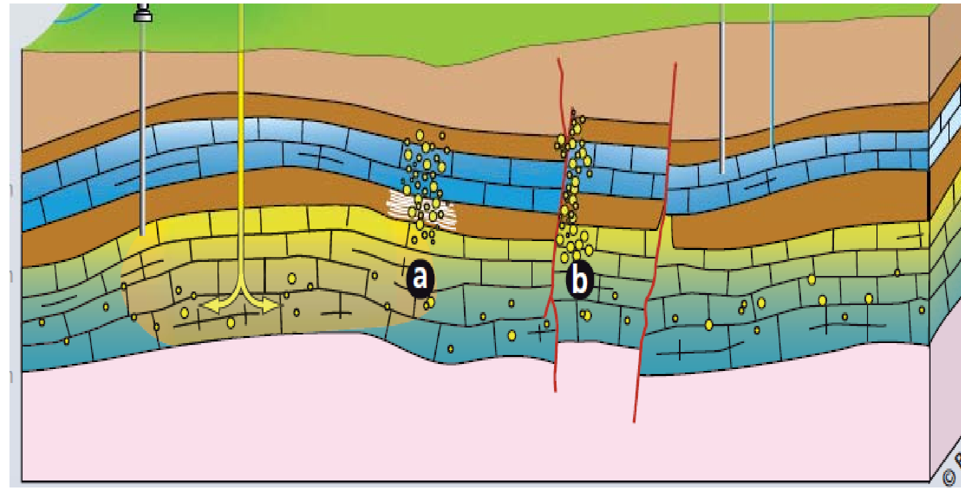
Norwegian CO_2 regulations on CO_2 Storage and Transport,are in progress

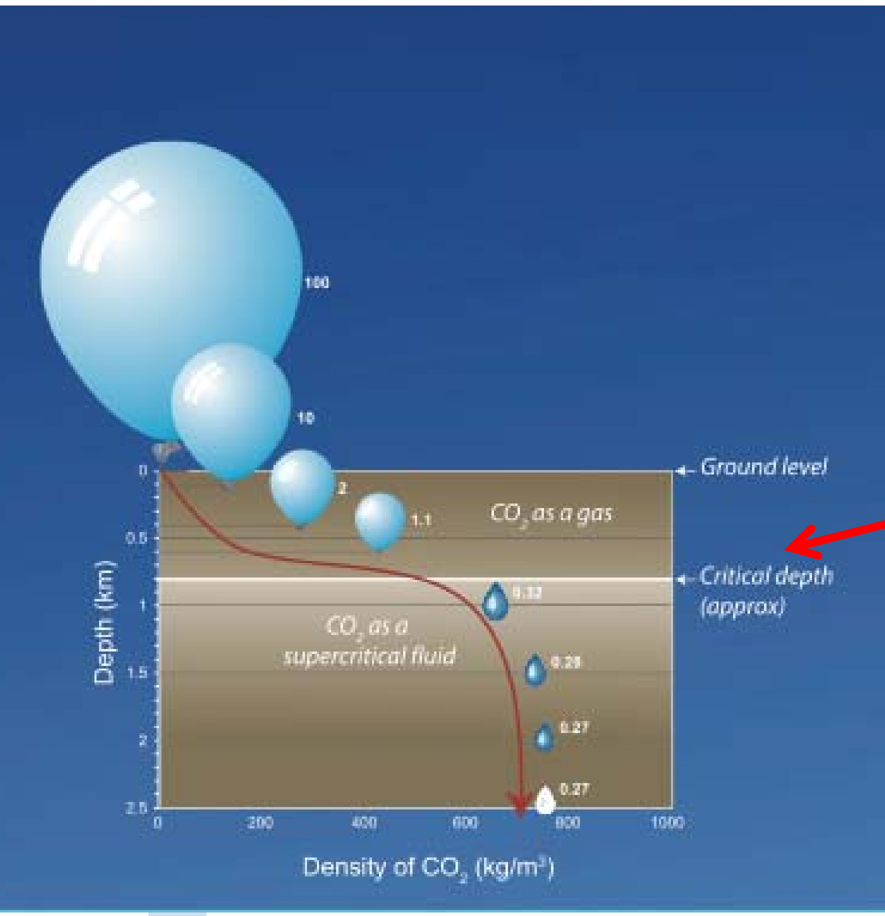
NPD will give recommendations to The Ministry regarding where to store- and who will be allowed to store CO_2 offshore Norway.

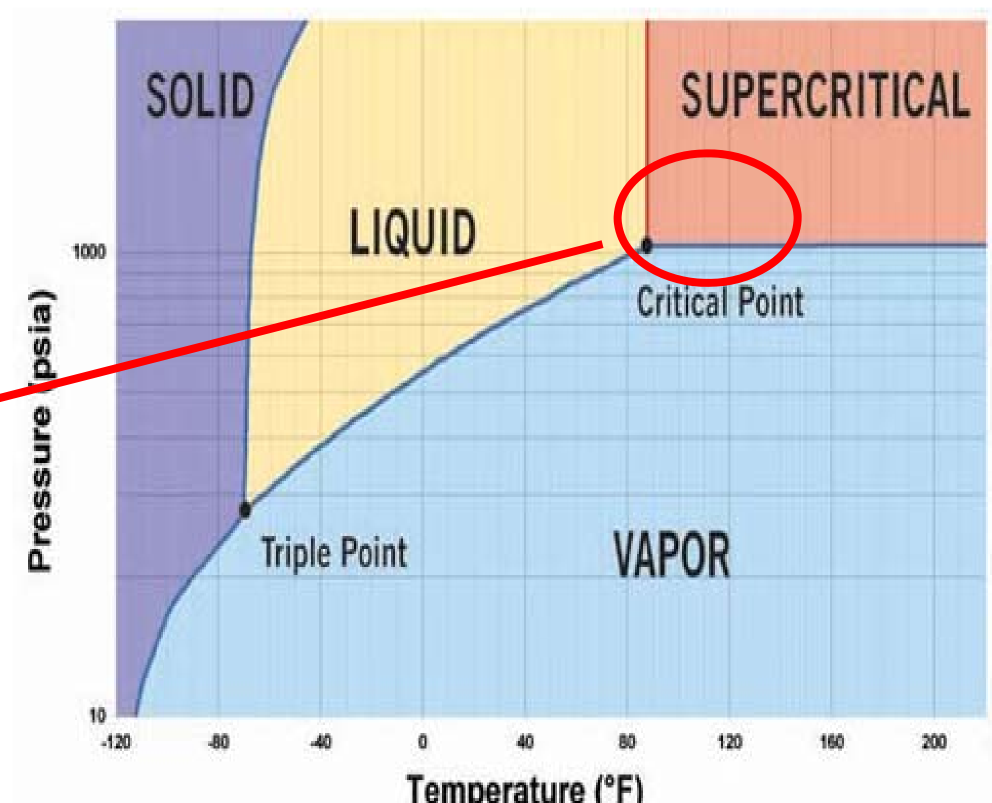
Safe storage of CO_2

NPD

- Storage depth
- Traps
- Seal
- Storage capacity
- Injectivity – pressure build up







CO_2 Temperature and Pressure diagram

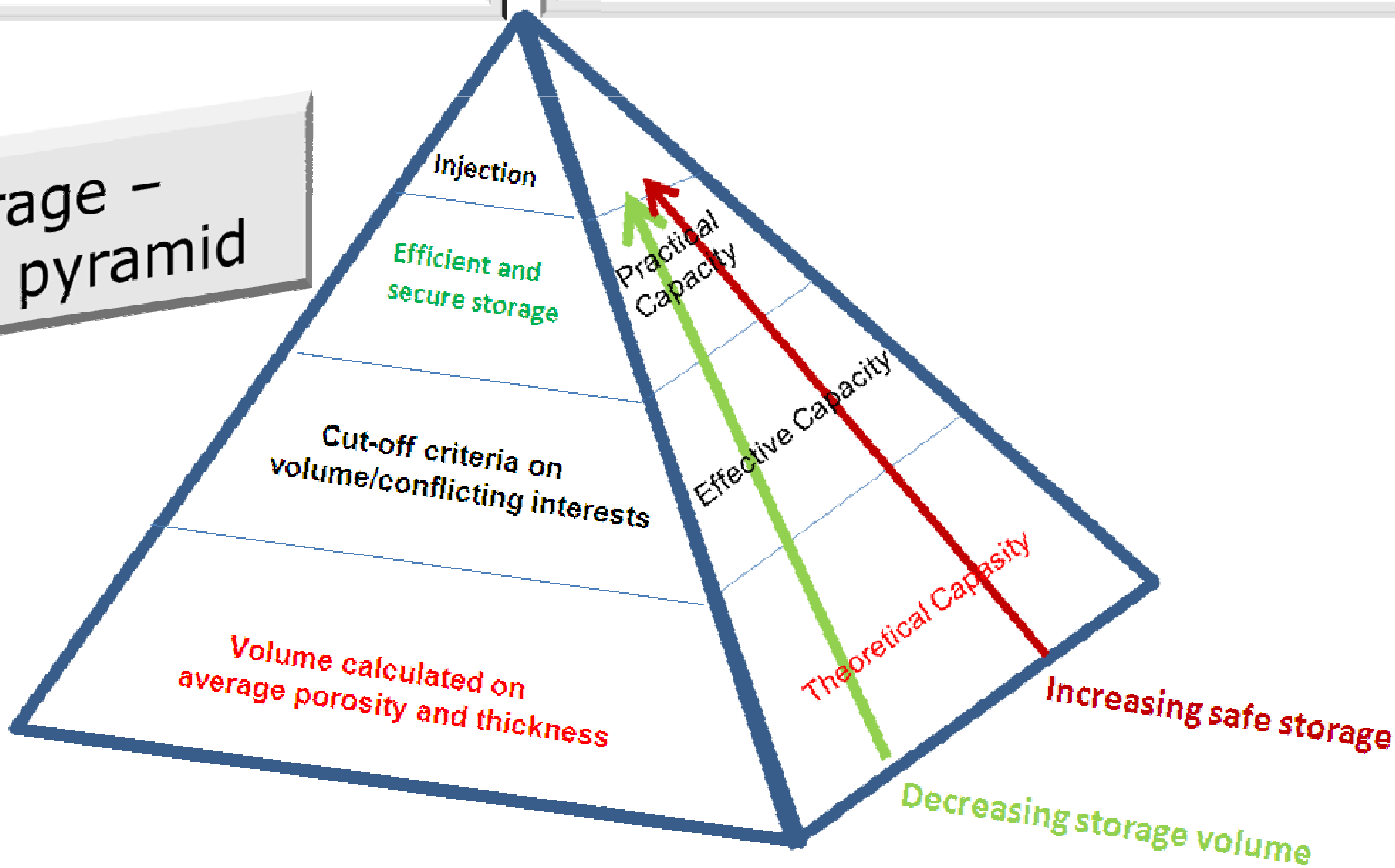
Scope

- Safe storage of CO_2
- Storage of CO_2 to be used in possible EHR projects

Type

- Saline aquiferes
- Defined geological structures
- Ceased hydrocarbon fields

CO_2 storage – maturation pyramid



Deep saline aquifers

$$M_{CO2e} = A \times h \times \phi \times \rho_{CO2r} \times S_{eff}$$

- M_{CO2e} : effective storage capacity
- A : area of trap or regional aquifer
- h : average height of aquifer × average net to gross rat
- ϕ : average reservoir porosity
- ρ_{CO2r} : CO_2 density at reservoir conditions
- S_{eff} : sweep efficiency (estimated)

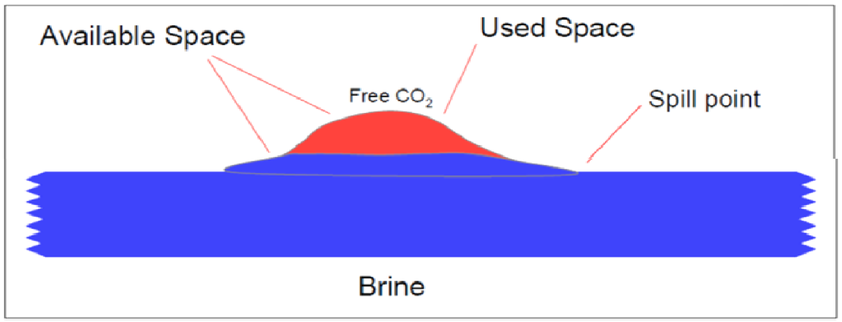
Typical S_{eff} ranges for structures: 5 – 40 %

Suggested S_{eff} for regional aquifers: 2 %

Estimation of CO_2 storage volume

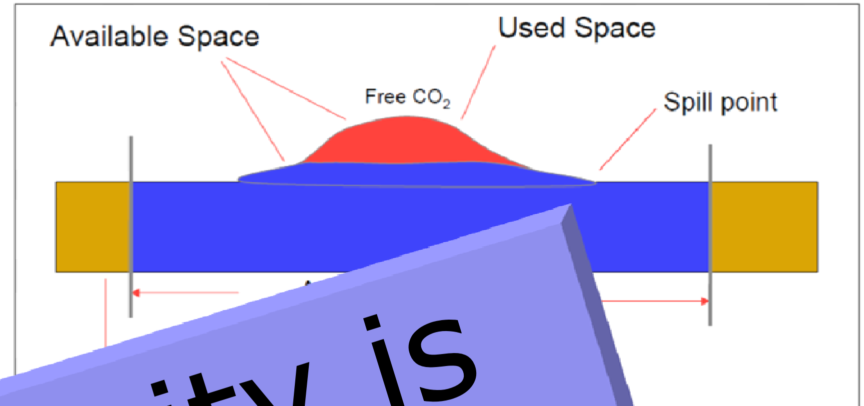
NPD

Conceptual model for open aquifers



- Storage space is generated by displacing existing fluids and distributing pressure increase in surrounding aquifer system
- Storage volume = A · height · N/G · ϕ · S_{eff}
- S_{eff} depends on connectivity to surrounding aquifer
- S_{eff} = Used space/Available space

Conceptual model for closed aquifers



• From Filip Neele, TNO

Storage capacity is site specific !

$M_{CO_2t} = A \times h$ …

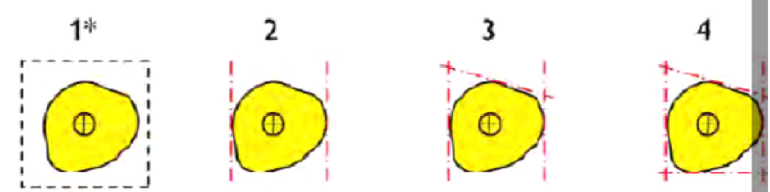
- M_{CO_2t}…
- A:
- h:
- ϕ:
- ρ_{CO_2r}: … conditions

$M_{CO_2e} = A \times$ … $\times \rho_{CO_2r} \times S_{eff}$

- M_{CO_2e}: effective storage capacity
- A: area of aquifer
- h: height × net to gross ratio
- ϕ: average reservoir porosity
- ρ_{CO_2r}: CO_2 density at reservoir conditions
- S_{eff}: storage efficiency factor

…oretical vs. effective capacity

Storage coefficient (by the rule-of-thumb) S_{eff}



	1*	2	3	4
High quality reservoir	40 %	20 %	10 %	3–5 %
Low quality reservoir	20 %	10 %	5 %	<3 %

*Volume of bulk reservoir shall be 5-10 times the volume of the reservoir

- · - Fault

CO_2 storage capacity offshore Norway (preliminary)

NPD

2008

Total conservative European storage capacity is 117 Gt CO_2

- 96 Gt in deep saline aquifers
- 20 Gt in hydrocarbon fields
- 1 Gt in unmineable coal beds

25 % is storage capacity offshore Norway

ONE NORTH SEA

A Norwegian- UK initiative 2009

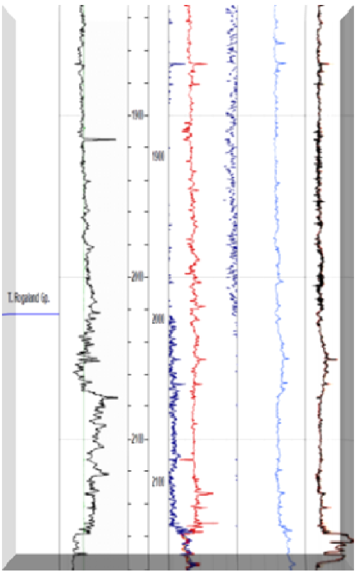
Modelled Mt CO_2 storage capacity in saline aquifers

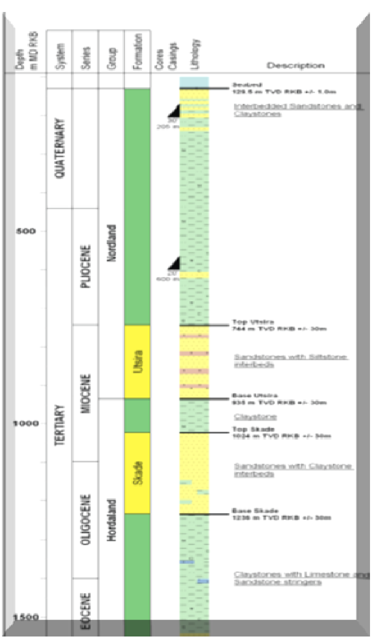
Country	2030 storage (Mt)	2050 storage (Mt)	Reference
Denmark	16,672		GeoCapacity
Germany	27,120		GeoCapacity
Netherlands	438		GeoCapacity
Norway[20]	48,488	97,059	NPD
United Kingdom	60,971		GeoCapacity and SCCS (2% efficiency)
Total	**153,689**	**202,260**	

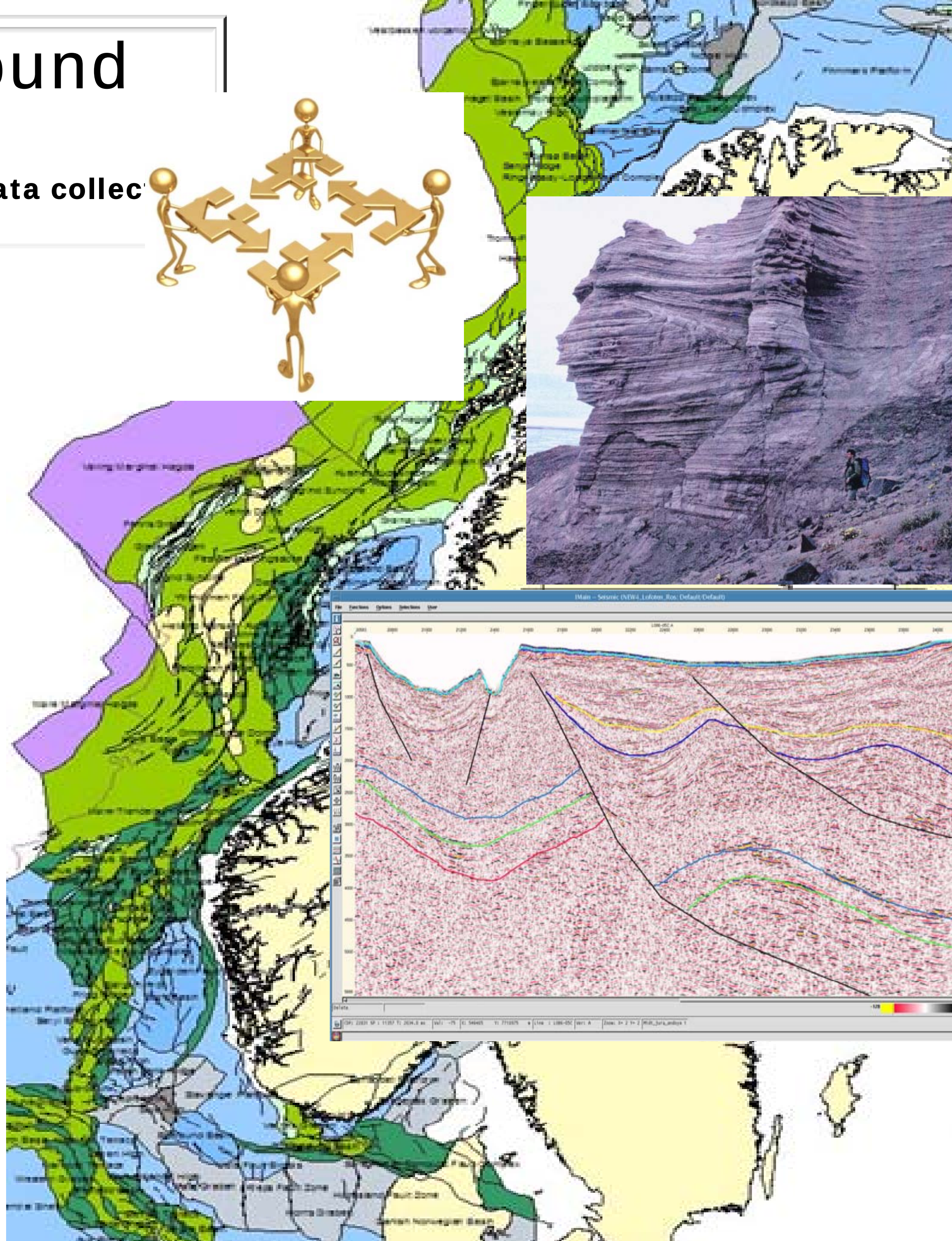
More detailed work in progress

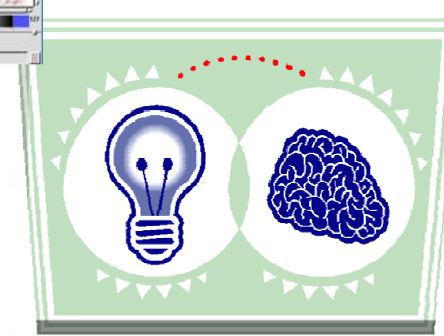
ur playground

has access to all data collec
hore Norway







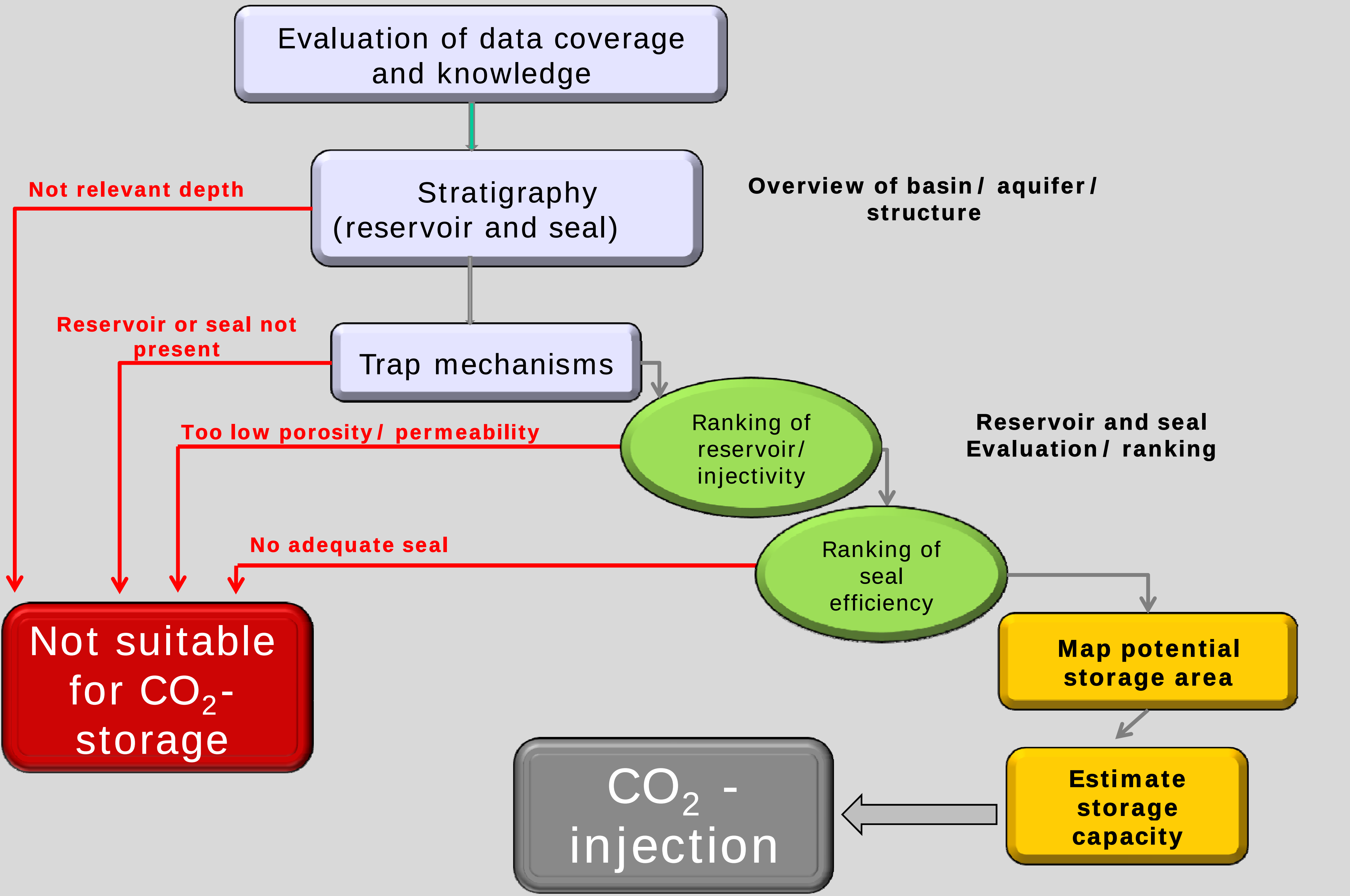


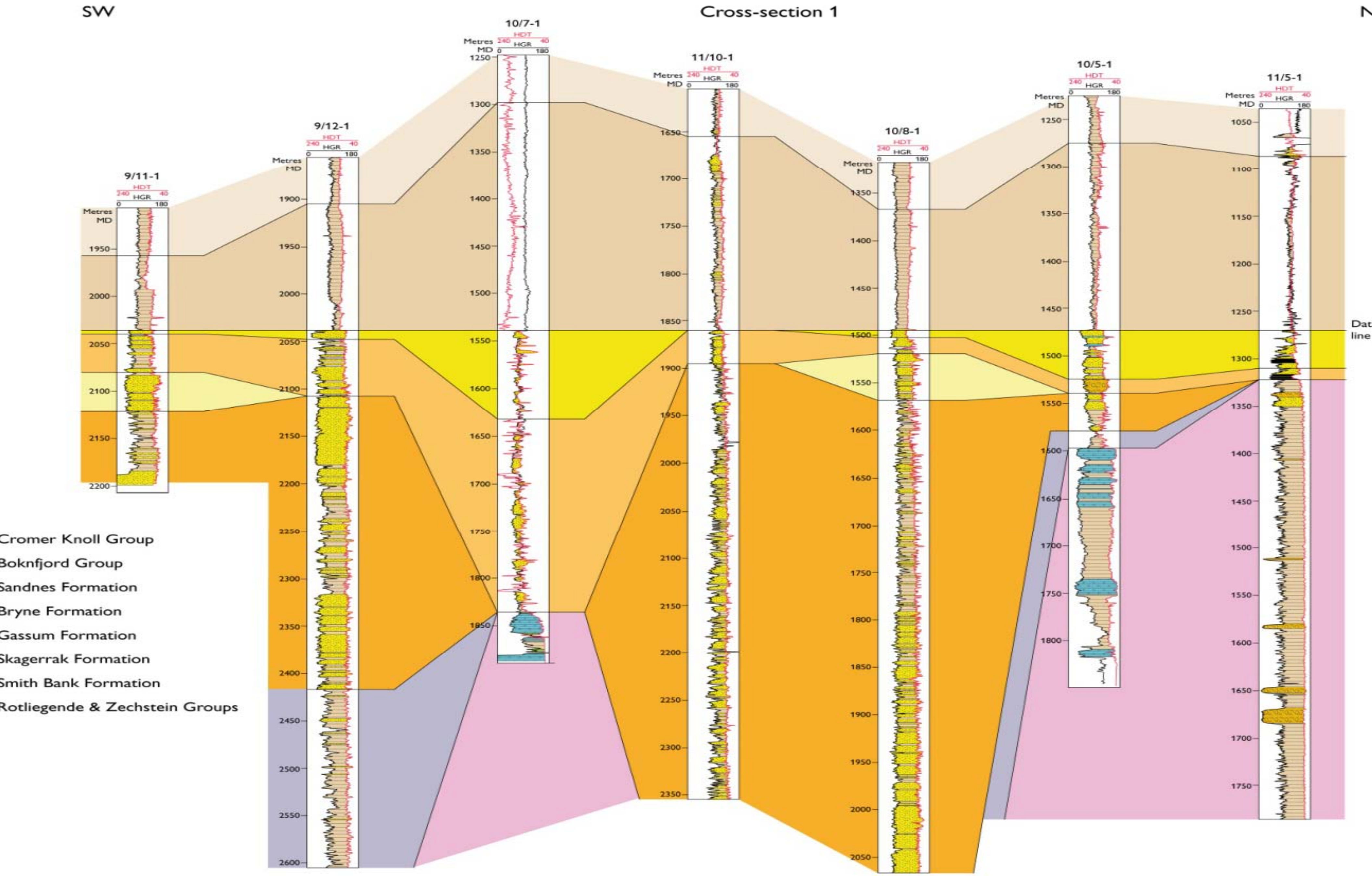
Ranking criteria

Ranking criteria				Choice	Definition/ comments
quality	Total trap efficiency	Defined trap	3	~~Effective seal~~	~~2 or more barriers, relevant thickness.~~
			2	Seal present	1 barrier
			1	Lack of seal	Barrier not present
		Undefined trap	3	Effective unconventional seal	2 or more barriers, relevant thickness. And extension
			2	Probable unconventional seal	e.g. well integrity
			1	Lack of seal	Not present
	Faults		3	No trough-going faults	No faults penetrates trough the seal
			2	Uncertainty of trough-going faults	Uncertain interpretation
			1	Trough-going faults	High risks of insufficient seal
quality	Porosity		3	Good porosity	Equal to or more x % or more
			2	Possible good porosity	Based on known information
			1	Insufficient/ no porosity	No proven effective porosity
	Permeability		3	Good permeability	Equal to or more than x mD.
			2	Possible good permeability	Based on known information
			1	Insufficient/ no permeability	No proven effective permeability
	Depth to top reservoir		3	> 800 m – 2500 m (3000 m)	800 m below surface due to CO_2 in supercritical fluid phase. 2500 m (3000) for technologicall reasons.
			2	> 600 m	Depending on pressure and temperature data from the area
			1	shallower	Unsuitable for storage, CO_2 in gas phase

(green)	Good data /quality	(yellow)	Limited data/ quality	(red)	Poor data /qualit

CO_2 storage - NPDs evaluation process




SW
Cross-section 1
9/11-1
9/12-1
10/7-1
11/10-1
10/8-1
10/5-1
11/5-1
HDT
HGR
Metres MD
Cromer Knoll Group
Boknfjord Group
Sandnes Formation
Bryne Formation
Gassum Formation
Skagerrak Formation
Smith Bank Formation
Rotliegende & Zechstein Groups

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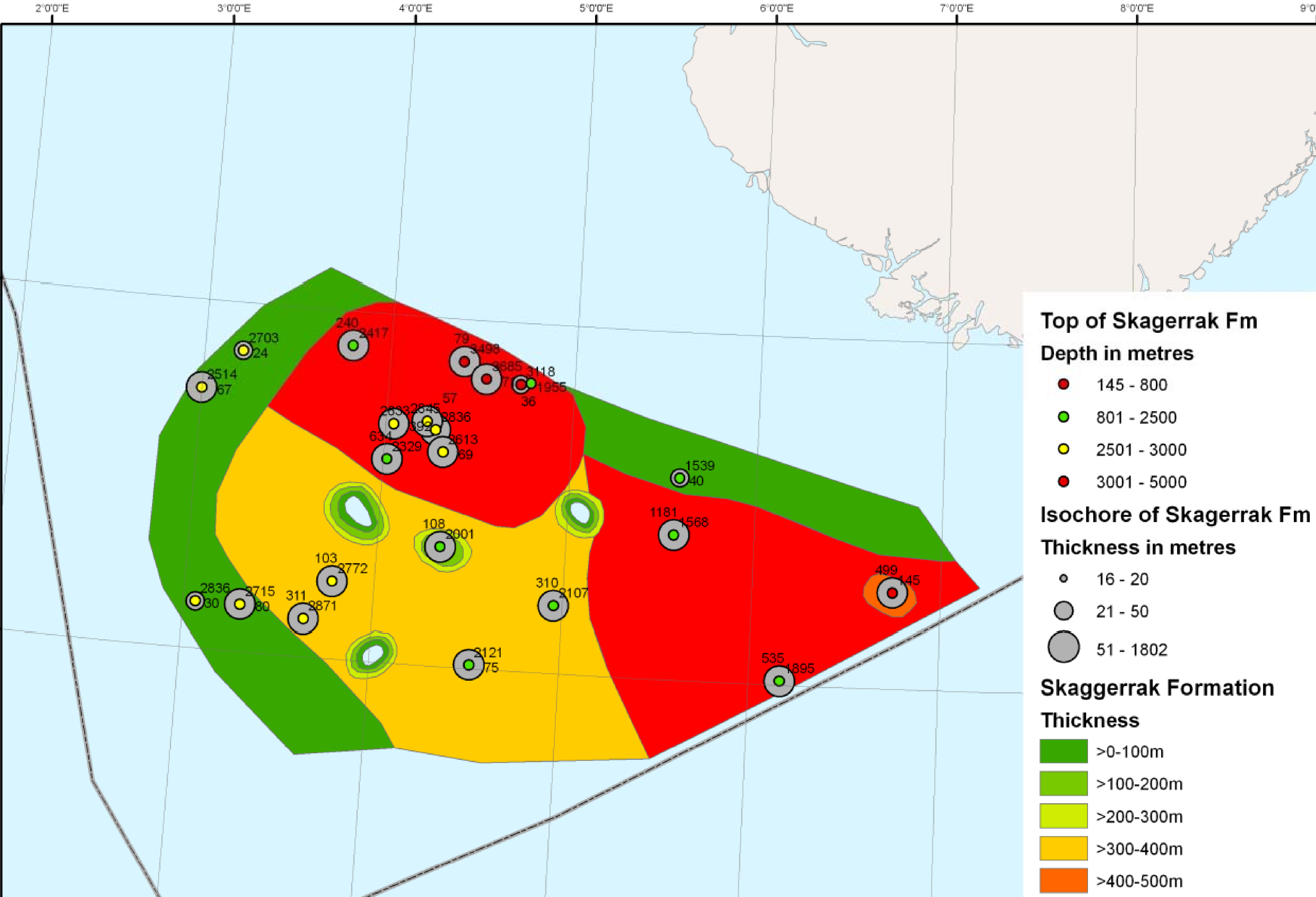
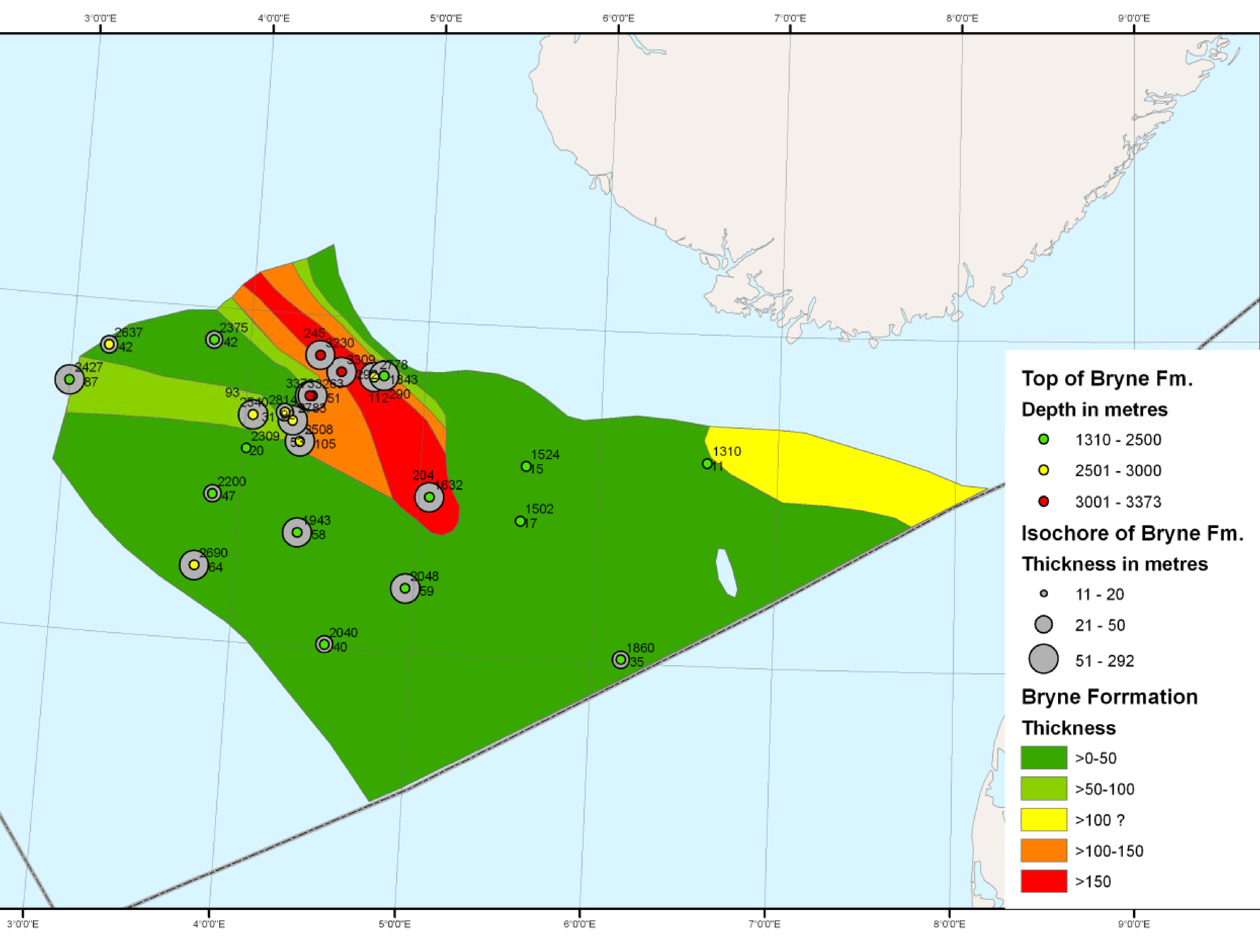
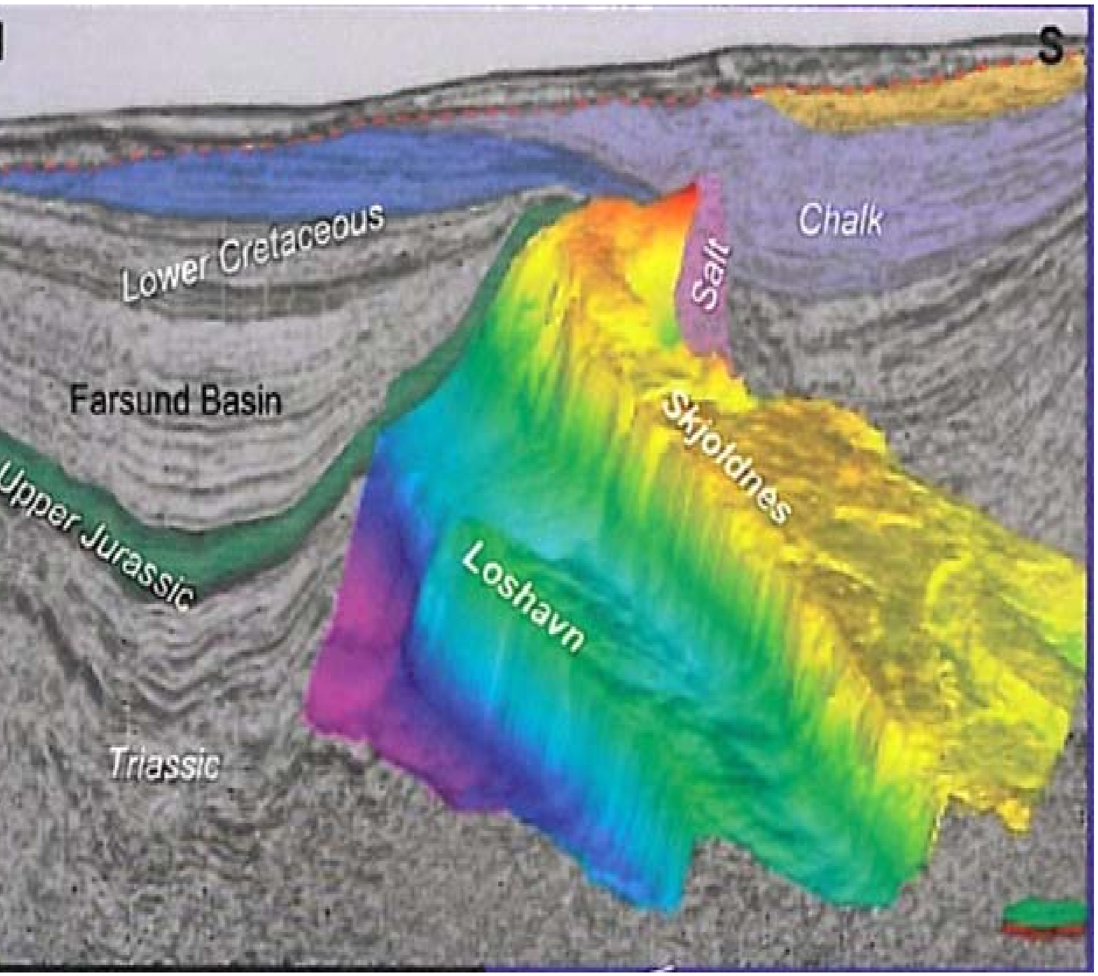


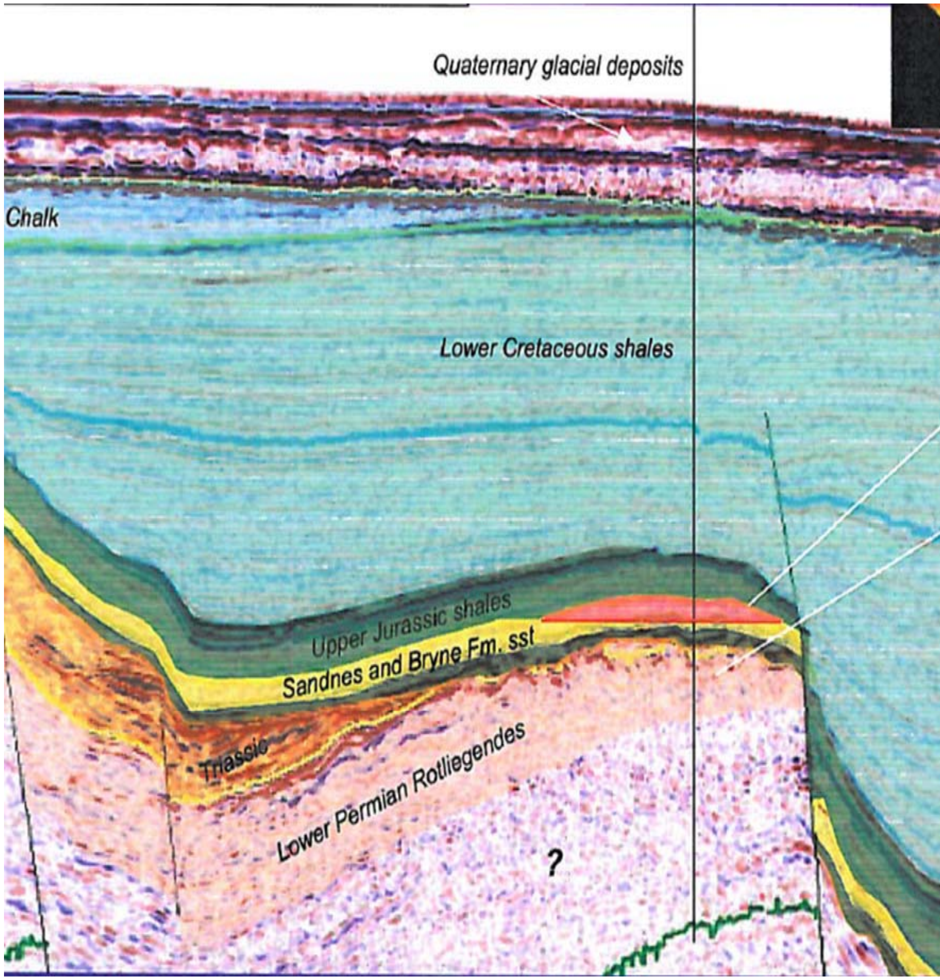
2°0'0"E
3°0'0"E
4°0'0"E
5°0'0"E
6°0'0"E
7°0'0"E
8°0'0"E
Top of Skagerrak Fm
Depth in metres
145 - 800
801 - 2500
2501 - 3000
3001 - 5000
Isochore of Skagerrak Fm
Thickness in metres
16 - 20
21 - 50
51 - 1802
Skaggerrak Formation
Thickness
>0-100m
>100-200m
>200-300m
>300-400m
>400-500m



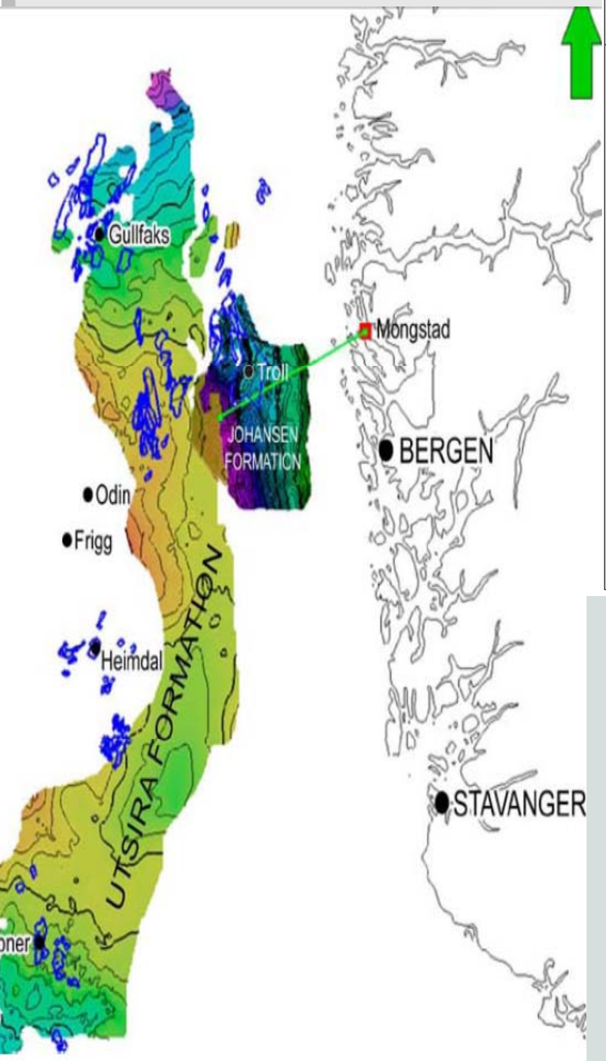
3°0'0"E
4°0'0"E
5°0'0"E
6°0'0"E
7°0'0"E
8°0'0"E
9°0'0"E
Top of Bryne Fm.
Depth in metres
1310 - 2500
2501 - 3000
3001 - 3373
Isochore of Bryne Fm.
Thickness in metres
11 - 20
21 - 50
51 - 292
Bryne Forrmation
Thickness
>0-50
>50-100
>100 ?
>100-150
>150

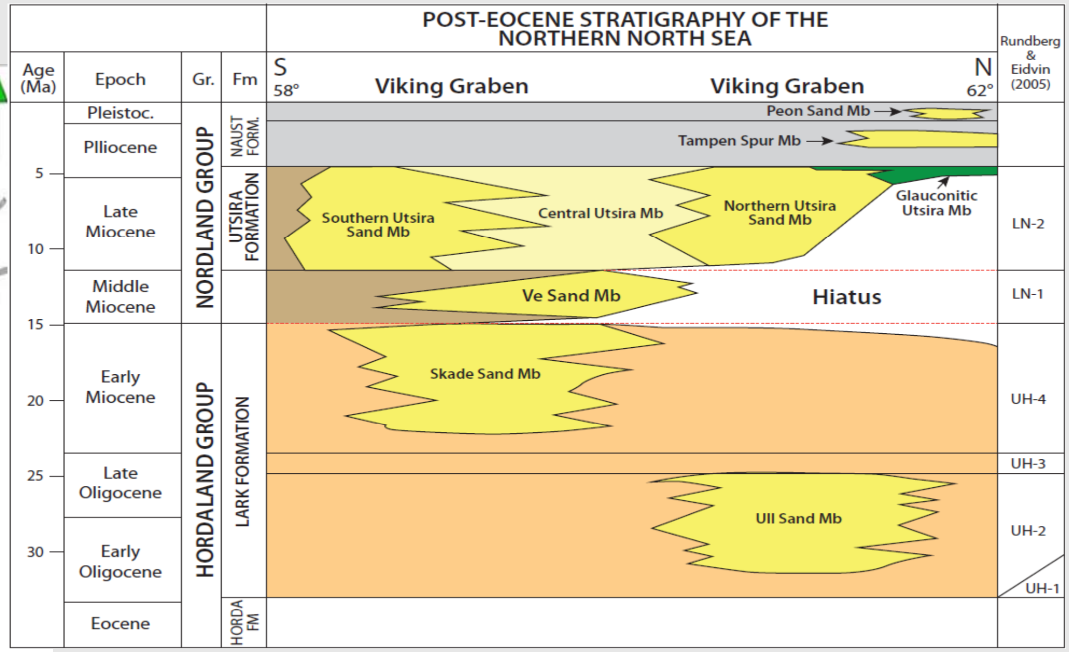
Dry-drilled geological structures

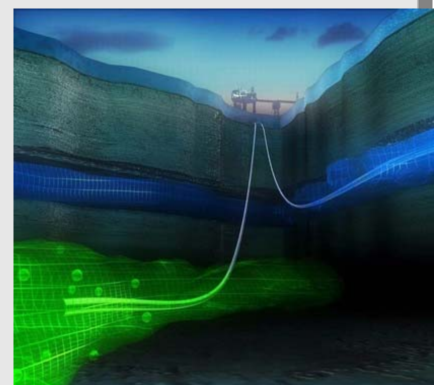


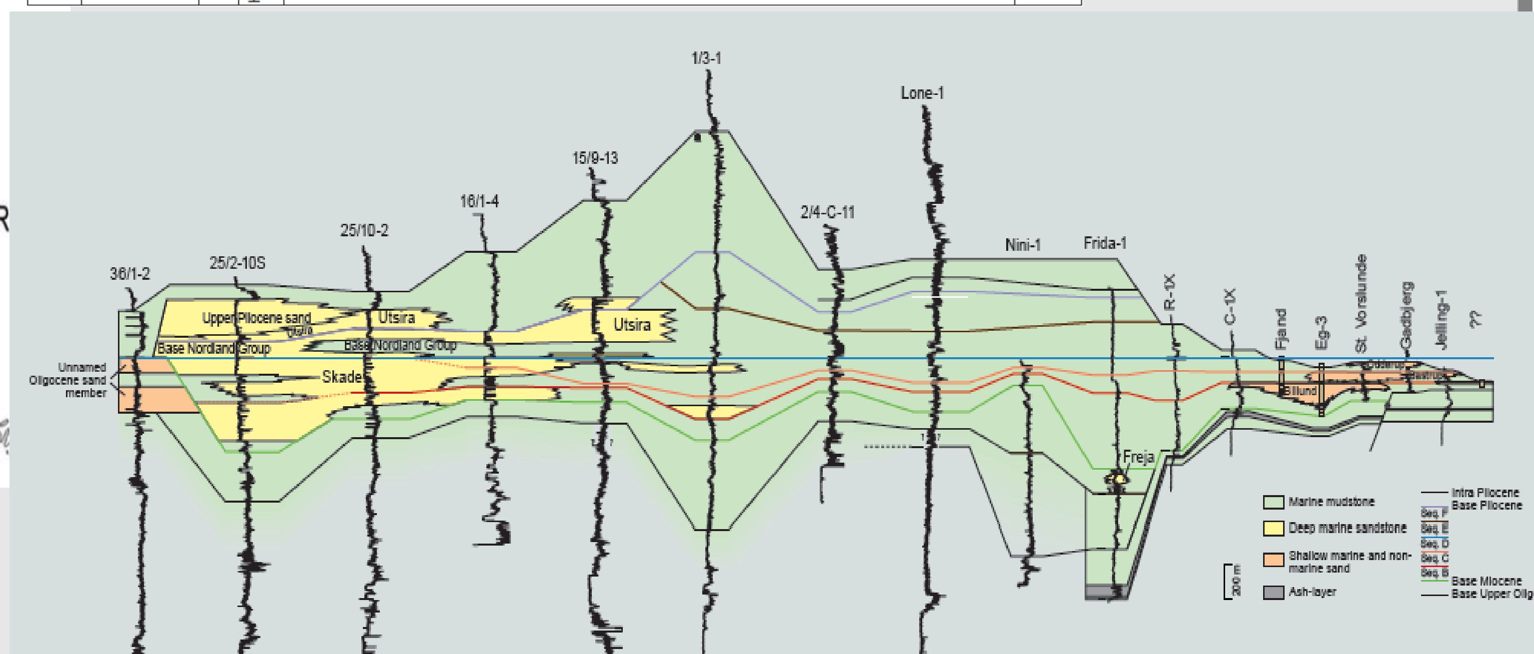


Utsira Formation

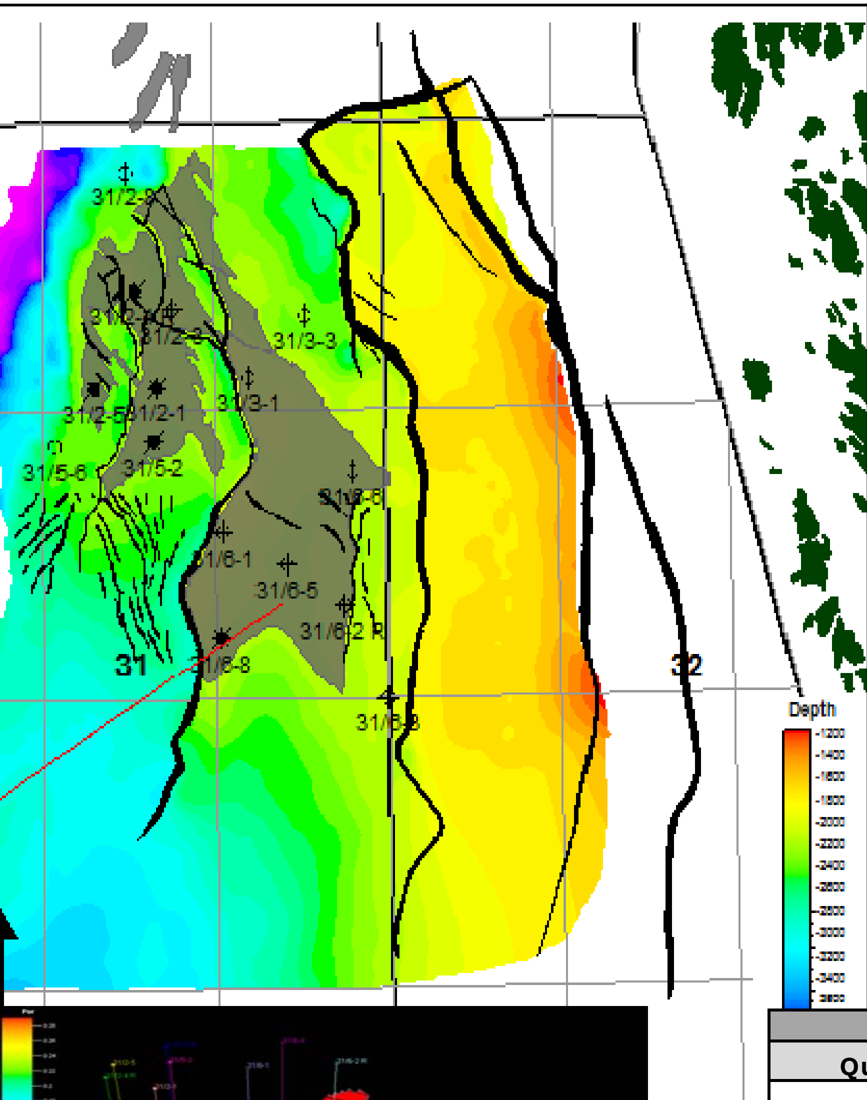


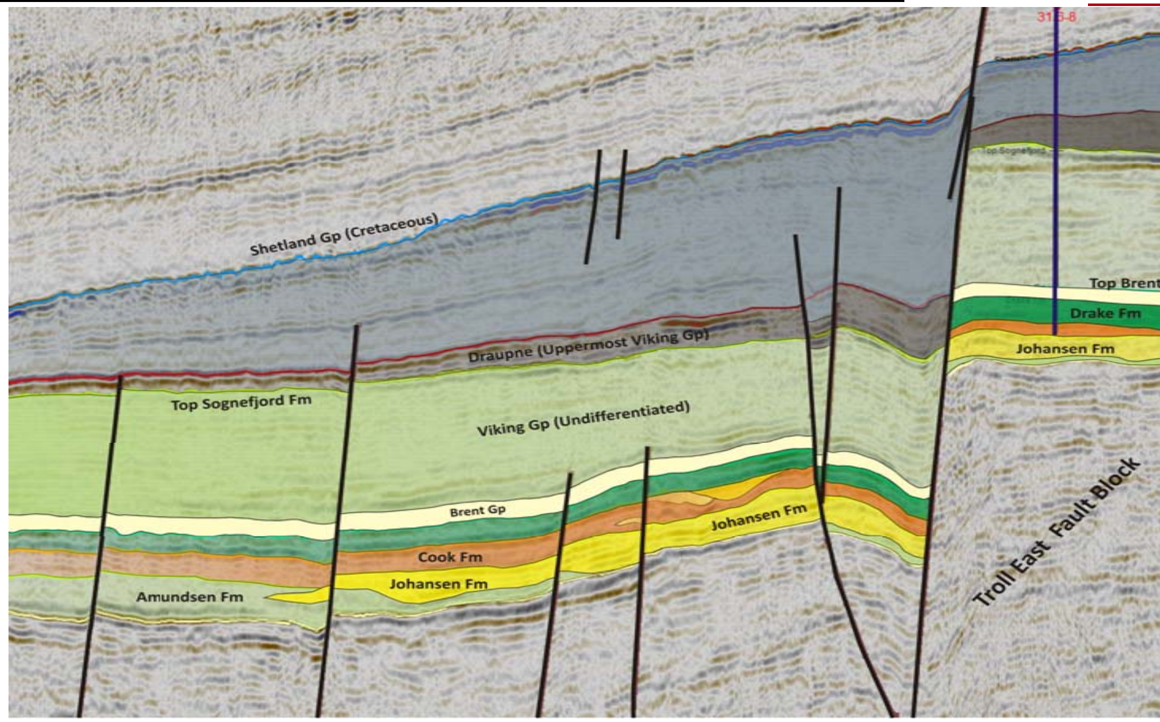


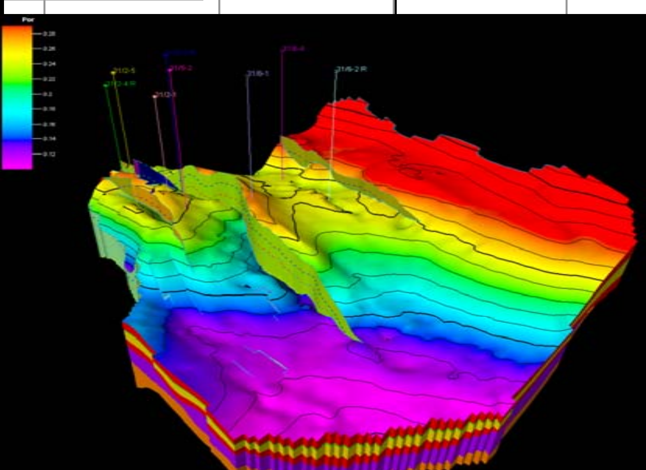




Johansen Formation







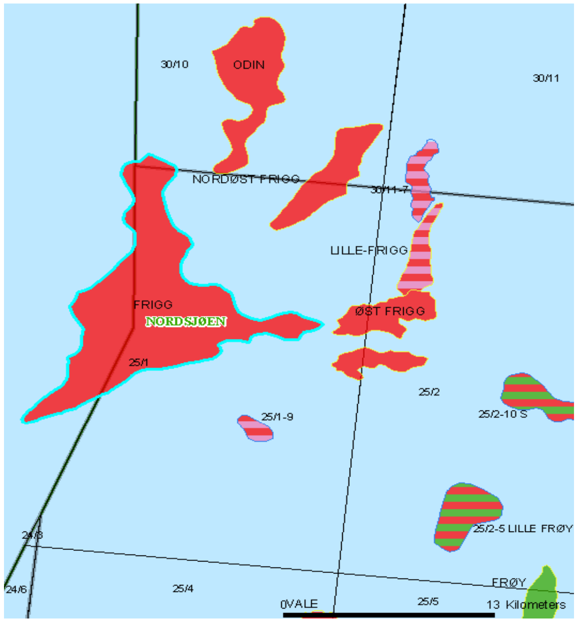
Formation summary

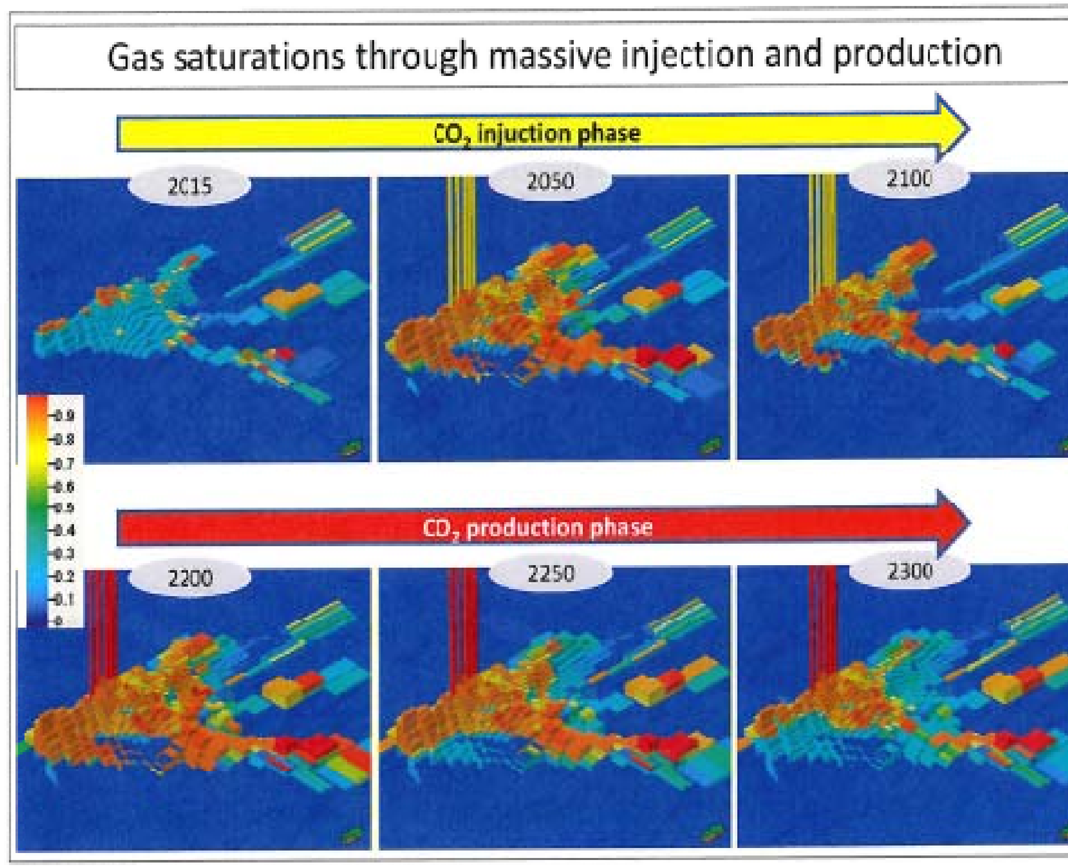
Quadrant	Max thickness	Porø.	Perm.	Seal	trap
31/32	Ca 80 m	20-30 %	500- 6000 mD (Well 31/2-3)	Dunlin Gruppen (1) 500 m sand/ shale (2)	Stratigraphy 2200-3500 m dyp

Seal Ranking			Reservoar ranking			Conclusio
Type	Effectivness	Faults	Porosity	Permeability	Depth	
K	3	2	3	3	3	Suitabl

Storagecapasity	Theoretical	Effective
	X...	X...

Evaluation of CO_2 sequestration in the Frigg Field

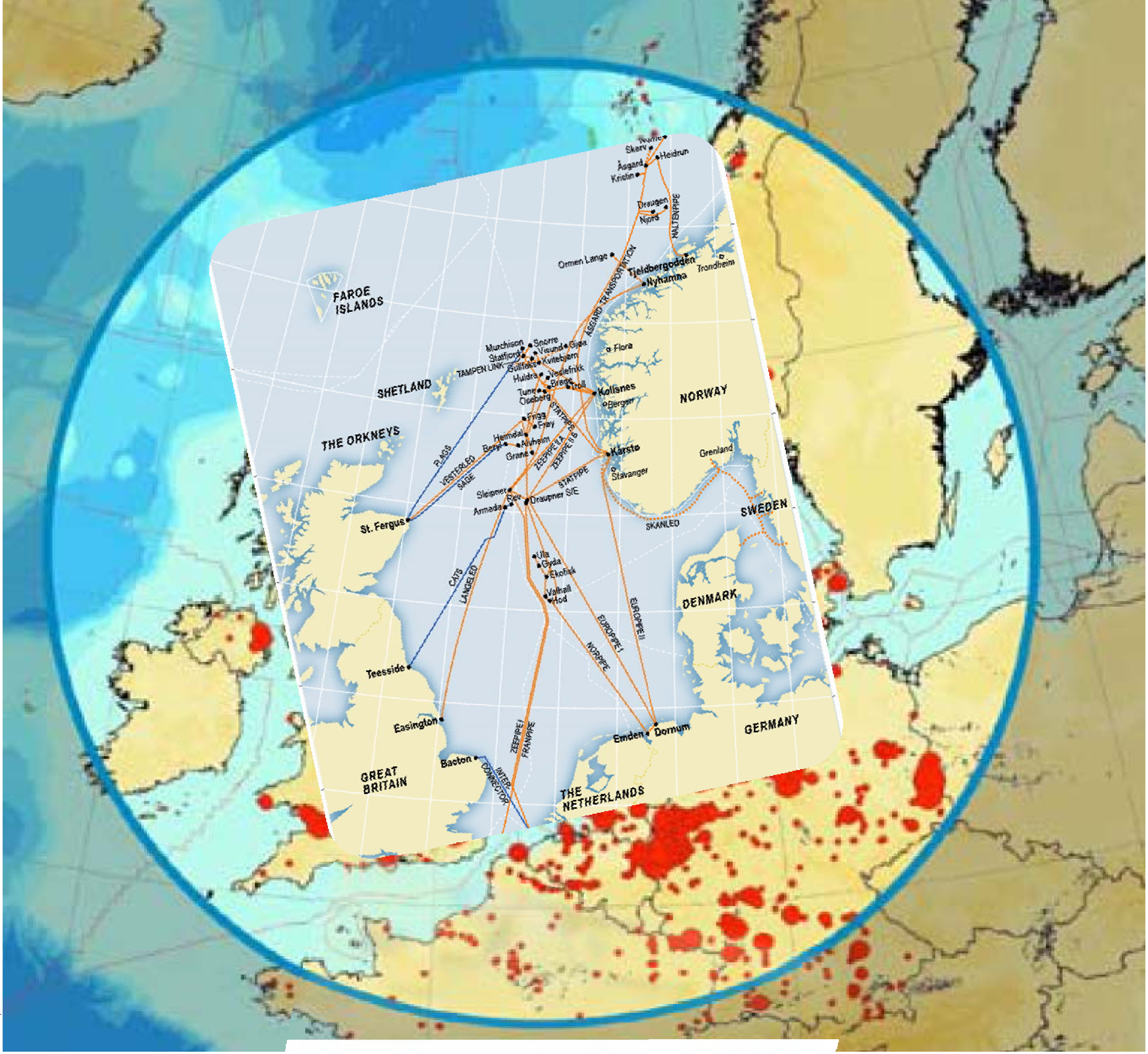




10 Million Sm3/day: 8 Million tonns of CO_2 for 55 years

50 Million Sm3/day: 3 Gtonns of CO2 for 85 years

NPD



FAROE ISLANDS
SHETLAND
THE ORKNEYS
NORWAY
SWEDEN
DENMARK
GERMANY
THE NETHERLANDS
GREAT BRITAIN
Norne
Skarv
Heidrun
Åsgard
Kristin
Draugen
Njord
HALTENPIPE
Ormen Lange
ÅSGARD TRANSPORTATION
Tjeldbergodden
Nyhamna
Trondheim
Murchison
Statfjord
Snorre
Visund
Gjøa
Gullfaks
Kvitebjørn
TAMPEN LINK
Huldra
Veslefrikk
Brage
Troll
Tune
Oseberg
Florø
Kollsnes
Bergen
Frigg
Frøy
Heimdal
Alvheim
Bergi
Grane
FLAGS
VESTERLED
SAGE
STATPIPE
ZEEPIPE II A
ZEEPIPE II B
Kårstø
Stavanger
Grenland
Sleipner
Rev
Armada
Draupner S/E
St. Fergus
SKANLED
CATS
LANGELED
Ula
Gyda
Ekofisk
Valhall
Hod
EUROPIPE II
EUROPIPE I
NORPIPE
Teesside
Easington
Bacton
INTERCONNECTOR
ZEEPIPE I
FRANPIPE
Emden
Dornum

NORTH SEA BASIN TASK FORCE

OLJE- OG ENERGIDEPARTEMENTET
Norwegian Ministry of Petroleum and Energy

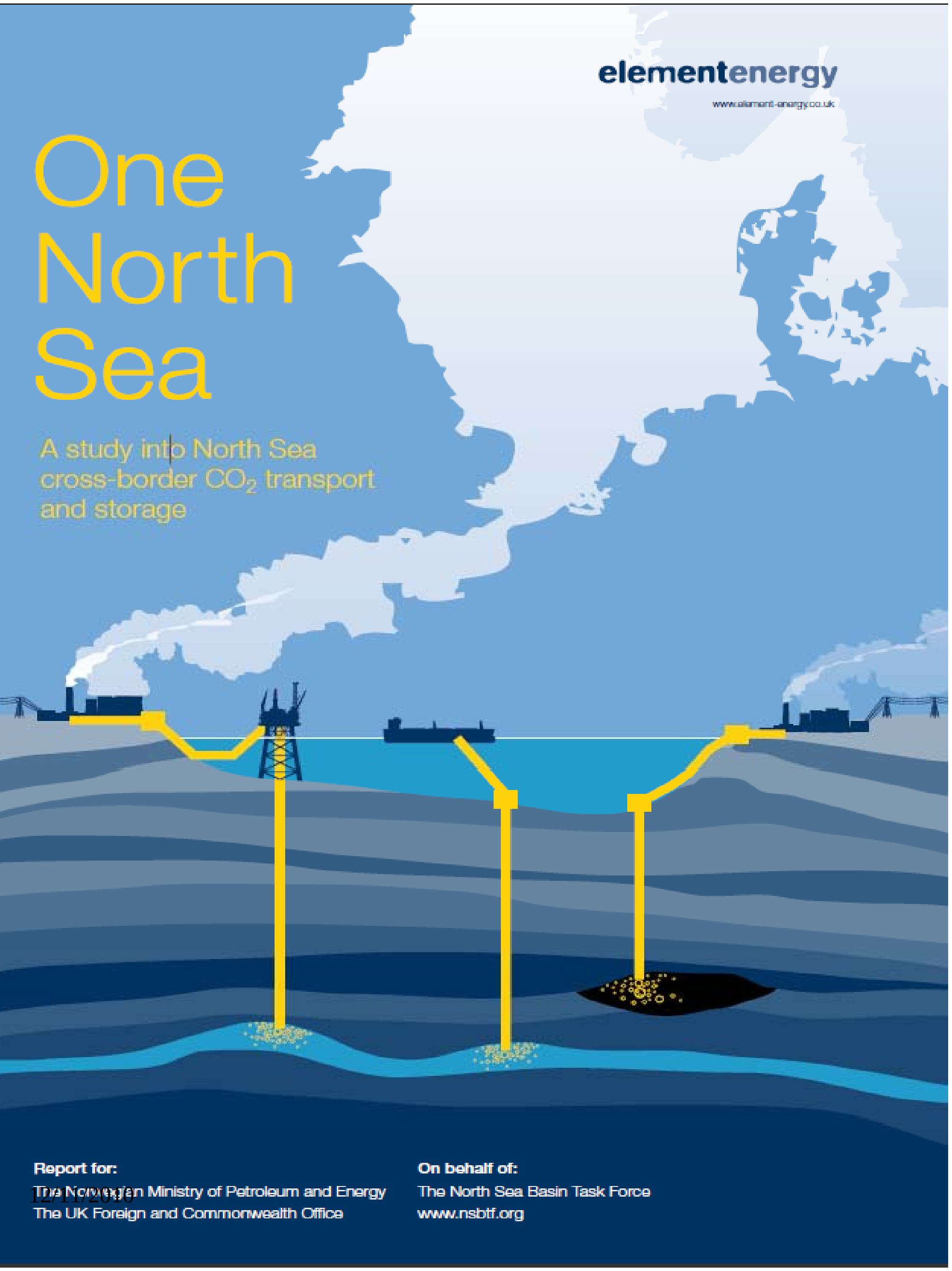
Bundesministerium für Wirtschaft und Technologie

Rijksoverheid

DEPARTMENT OF ENERGY & CLIMATE CHANGE

The aims of the North Sea Basin Task Force are to develop broad, common principles that could form a basis for regulating the storage of CO_2 under the North Sea and to provide a consistent basis for managing this activity.

cooperation with the North Sea countries

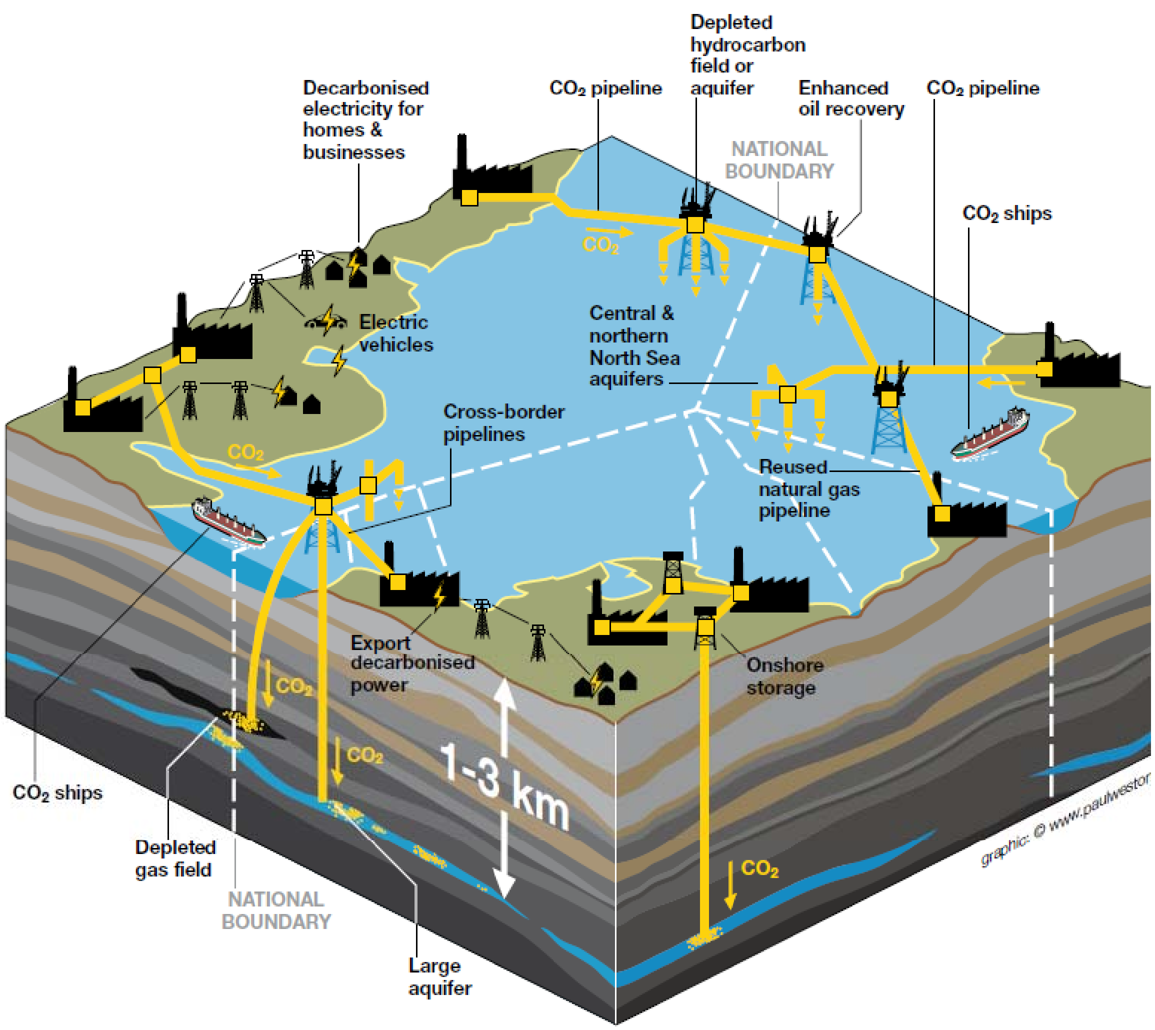


Initiated by the Norwegian and UK Energy Ministers in May 2009

- **Identify** the storage potential for CO_2 in the North Sea
- **Estimate** a likely CO_2 storage need for Europe
- **Identify** plausible matches of sources and sinks
- **Identify** challenges with regard to transport of CO_2 across countries
- **Optimize** CO_2 transportation infrastructure

One North Sea – objective

A ‘One North Sea’ vision



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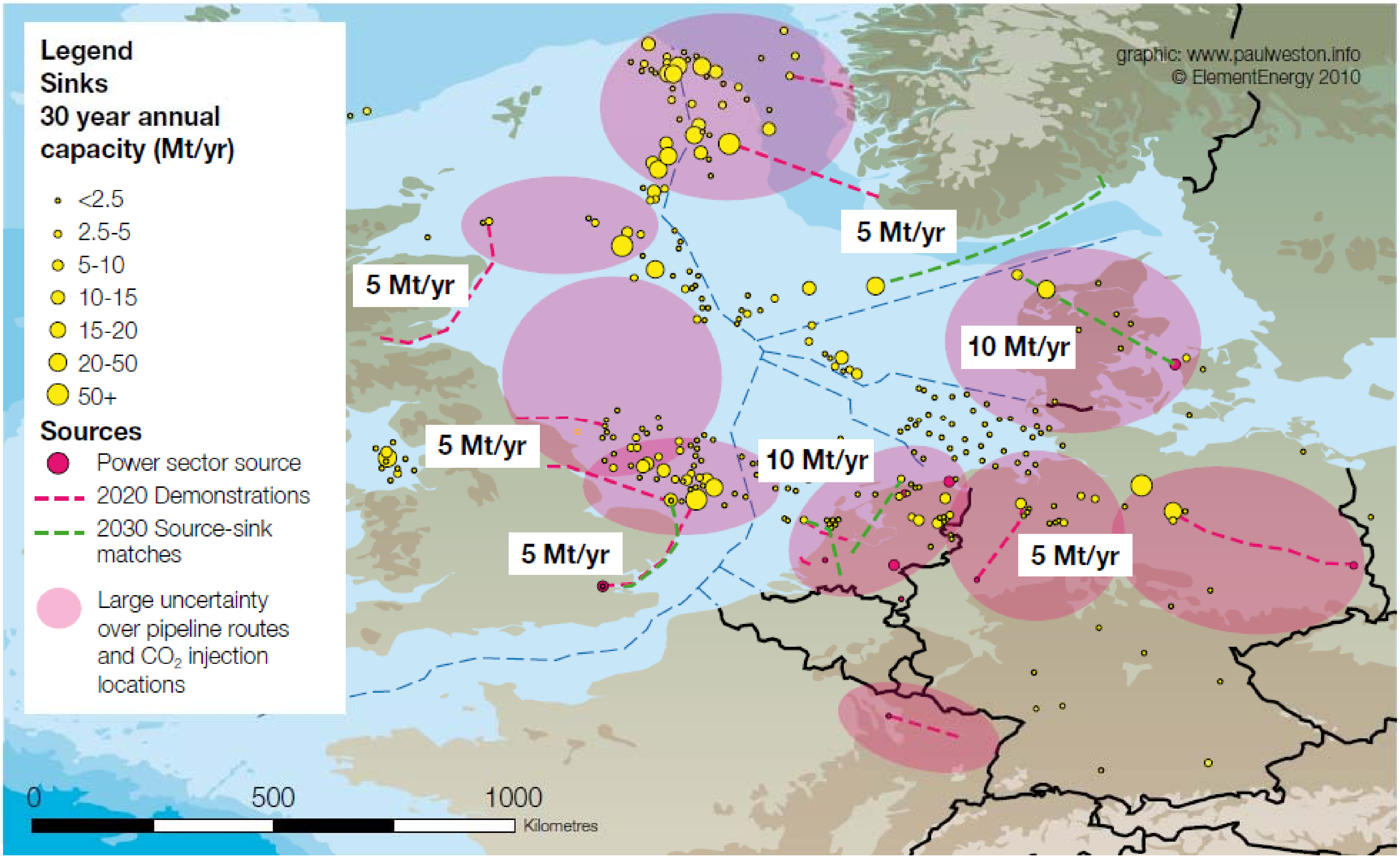
”One North Sea” database

- Storage capacity: based upon Geocapacity project and data from Norwegian Petroleum Directorate
- Policies and initiatives to support CCS at EU level and within Norway, UK, the Netherlands and Germany
- Economic modelling of CCS demand
- Analysis of legal and regulatory barriers
- Scenarios of investment in capture, transport and storage in 2030 and 2050
- CO_2 transport and storage scenarios and network
- Several stakeholder meetings

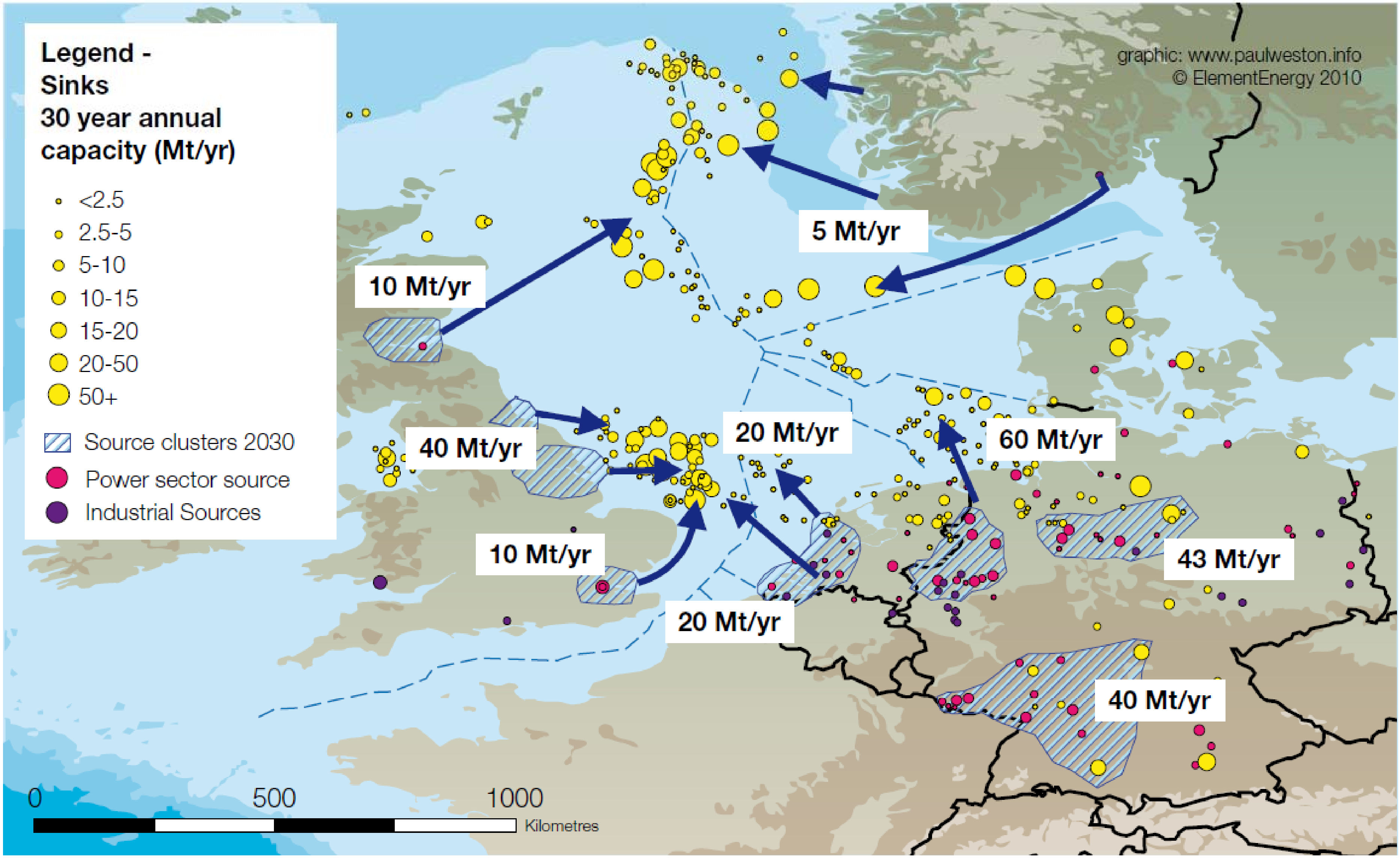
Summary of the market and policy combinations in 2030 used as inputs for the Classic Carbon model

Driving force	Mandatory	Competitive	Fragile
Power demand	High	Business as usual	Business as usual
Renewables	90% of 2020 target	90% of 2020 target	100% of 2020 target
CO_2 cap	30% reduction relative to 1990	40% reduction relative to 1990	25% reduction relative to 1990
CCS costs	35% reduction relative to 2008	25% reduction relative to 2008	20% reduction relative to 2008
CCS efficiency penalty	6% gas, 8% coal	8% gas, 10% coal	8% gas, 10% coal
Gas prices	$19/MWh	$22MWh	$27/MWh
Coal prices	$70/tonne	$70/tonne	$70/tonne
Nuclear	Known investments only	Known and new investments	Known investments only
Mandatory CCS	New investments from 2020	None	None

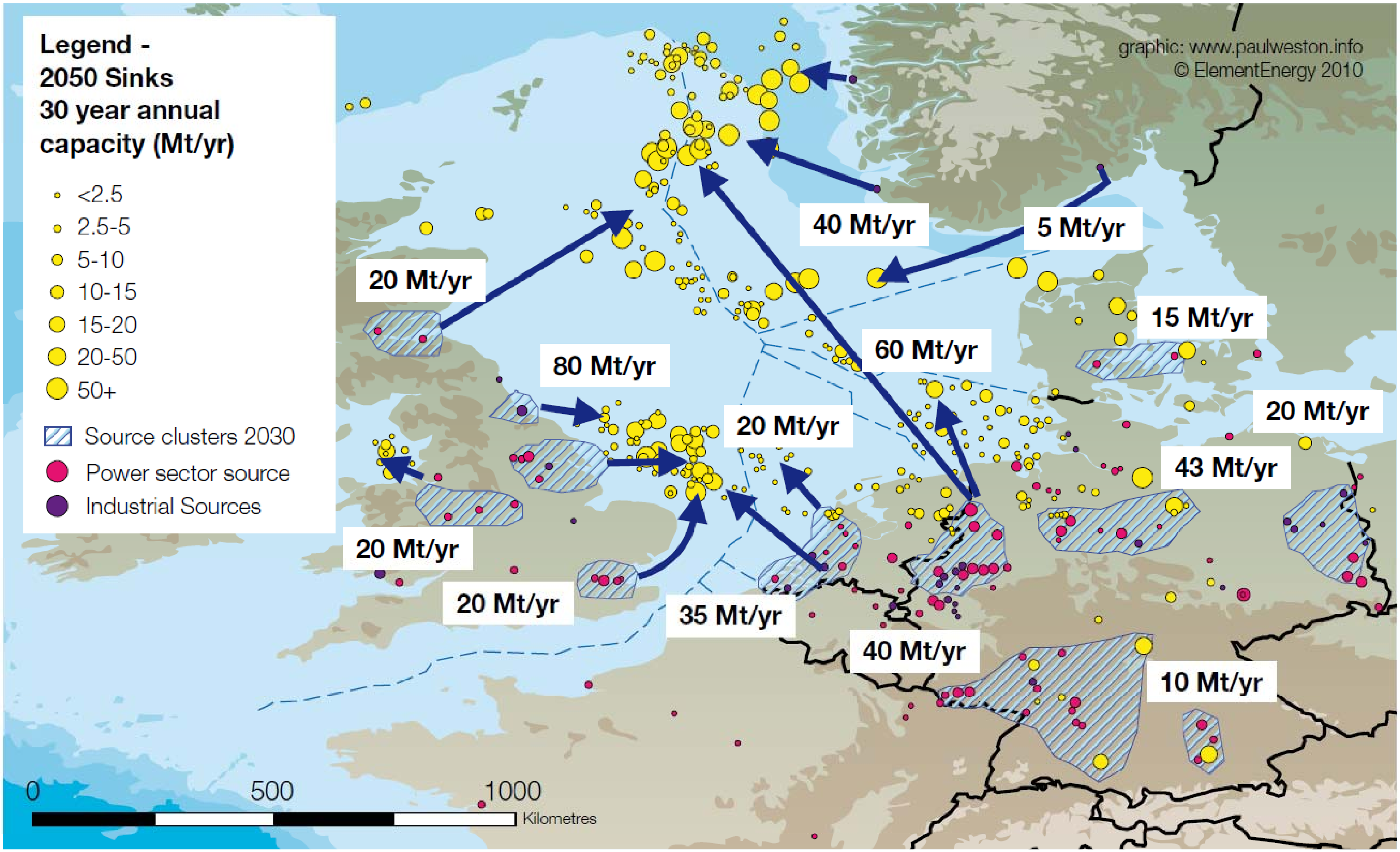
Map of source-sink connections in 2030 – 'Medium' Scenario



Map of CCS transport and storage in 2030 – 'Very high' scenario

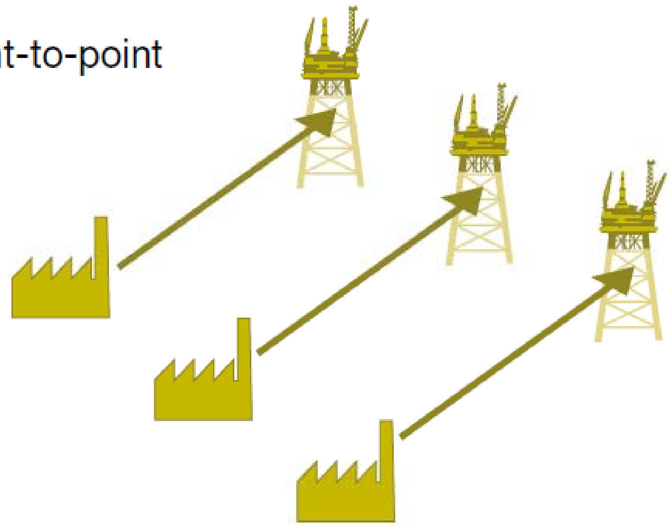


CO_2 transport in 2050 – Very High Scenario. (No restrictions on transport or storage)

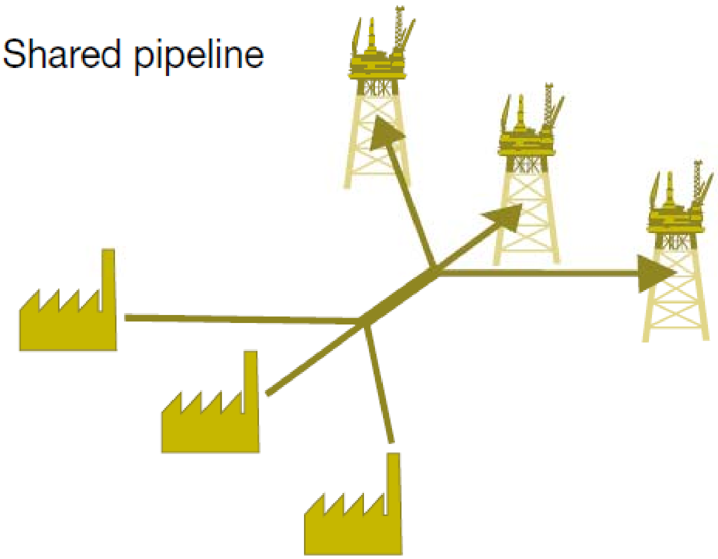


Transport network topologies

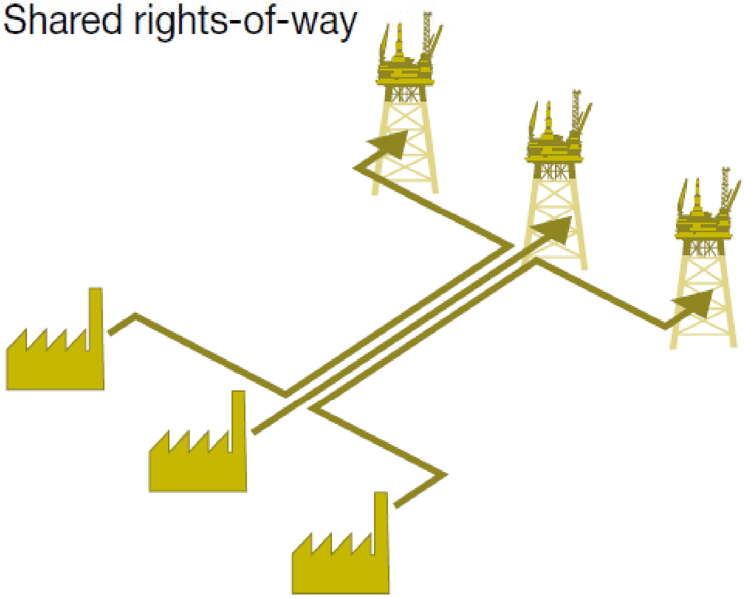
A) Point-to-point



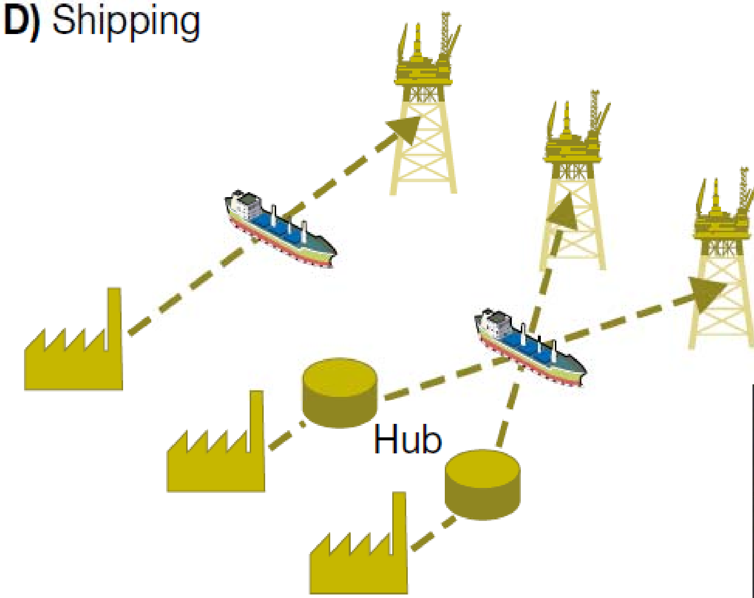
B) Shared pipeline



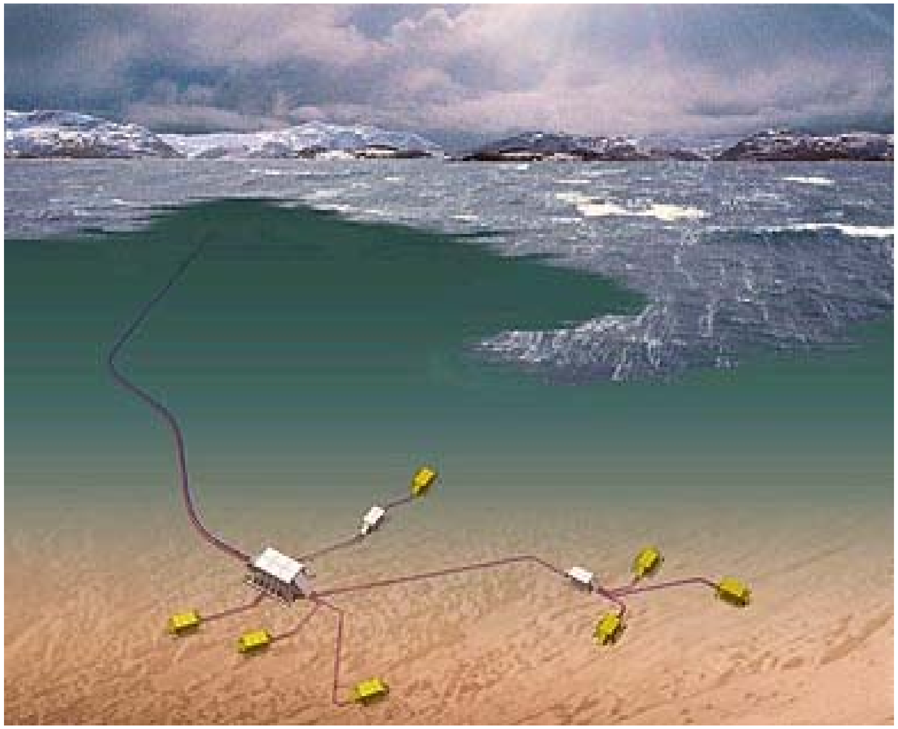
C) Shared rights-of-way



D) Shipping



CO_2 - transport (rørledning)



<u>USA</u>

Over 30 års erfaring med transport av CO_2

<u>Snøhvitfeltet</u>

143 km lang rørledning på havbunnen for transport og injeksjon av CO_2

CO_2 - transport (ship ?)

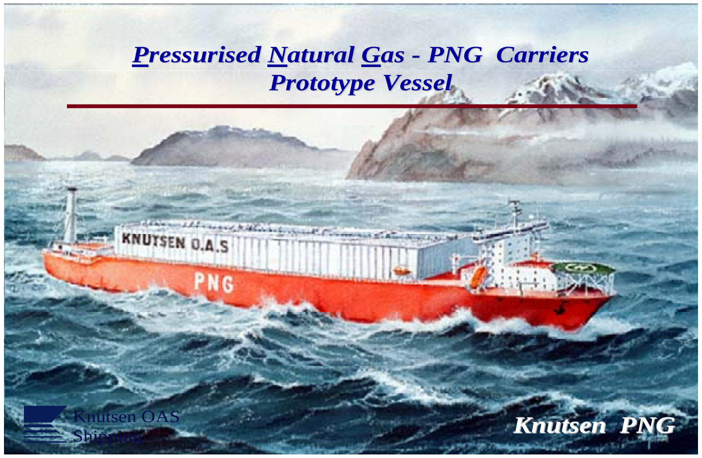
Existing technology

Available ship technology is not sufficient for transport of large volumes of CO_2

(0,5 tonnes CO_2 per m^3)

New technology

Cold liquefied CO_2



Pressurised liquefied CO_2

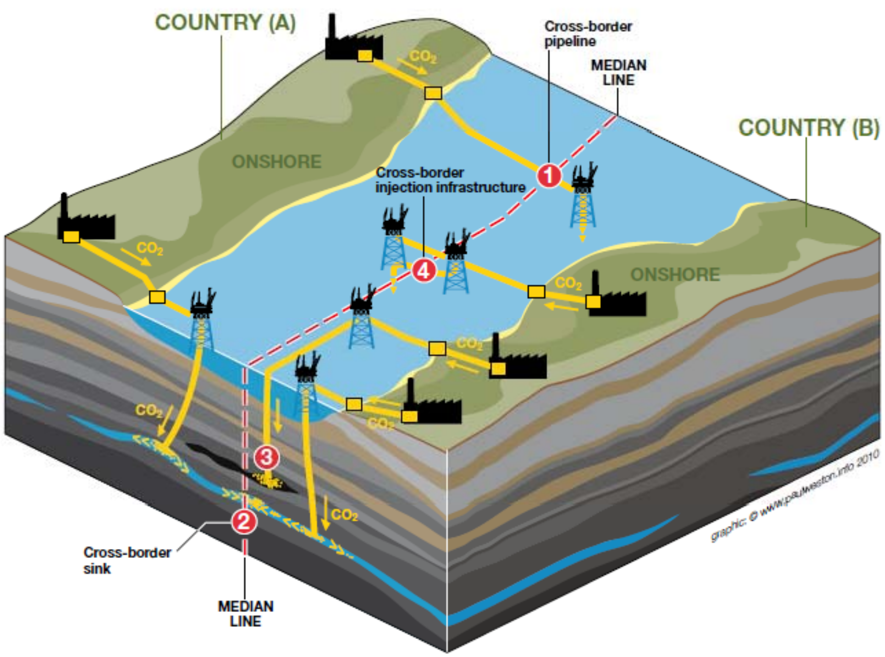
Legal and reulatory issues

EU CCS Directive

National regulations

Cross-border challenges

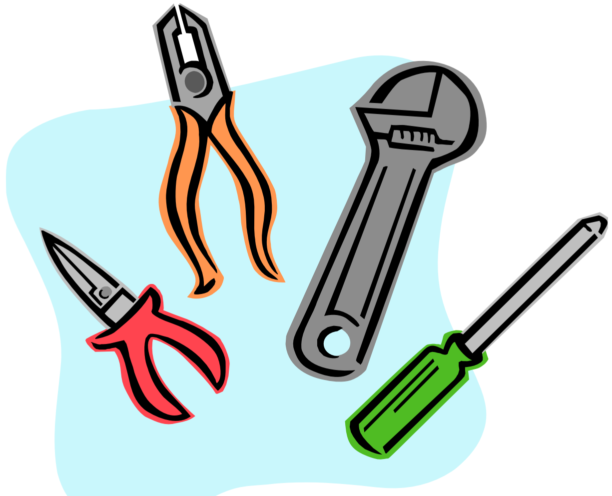
- Legal rights to transport CO2 across borders
- Regulation of cross-border transport of captured CO2
- Storage complex spanning national boundaries
- Cross border impacts from storage operation
- Emissions accounting
- Mechanism to facilitate cross-border project development



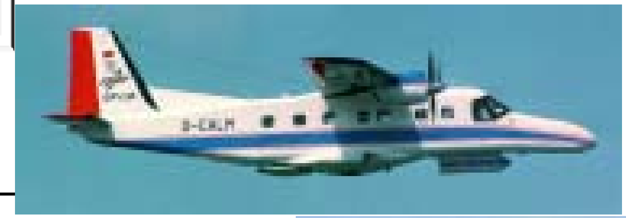
Before CO_2 injection

- Do risk assessment
- Have a good monitoring programme
- Have a clear remediation and mitigation plan

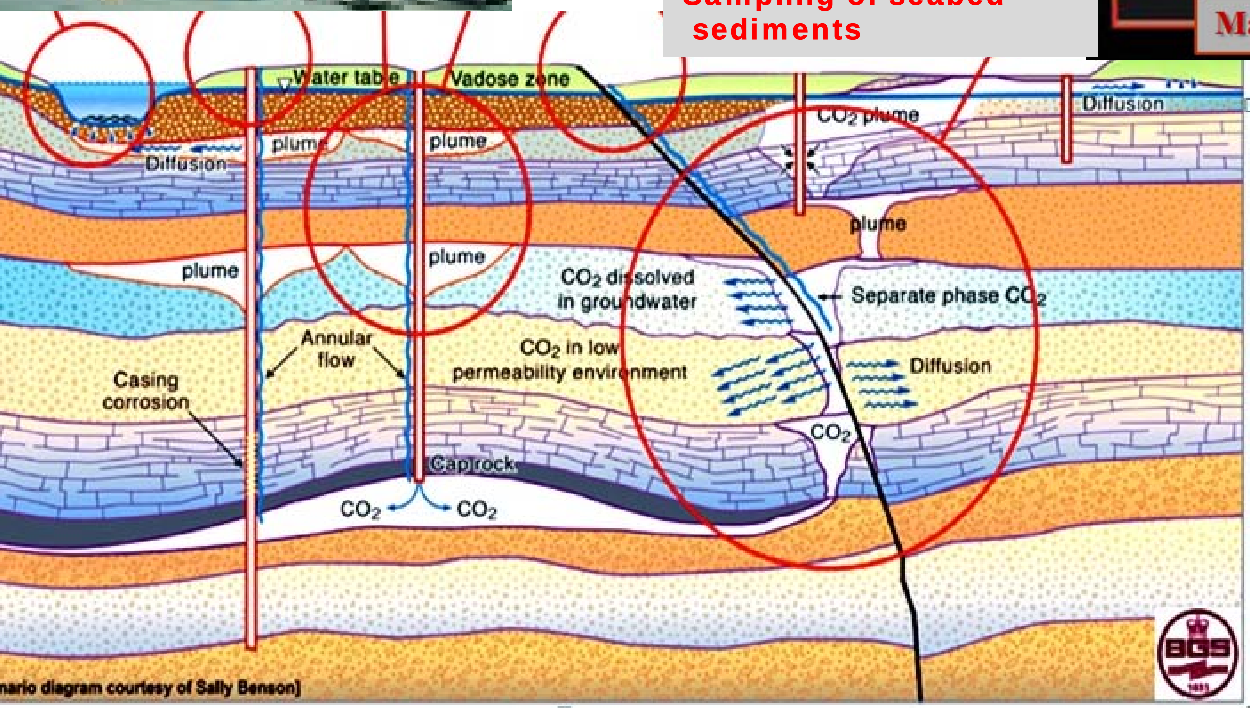
And do a baseline inspection

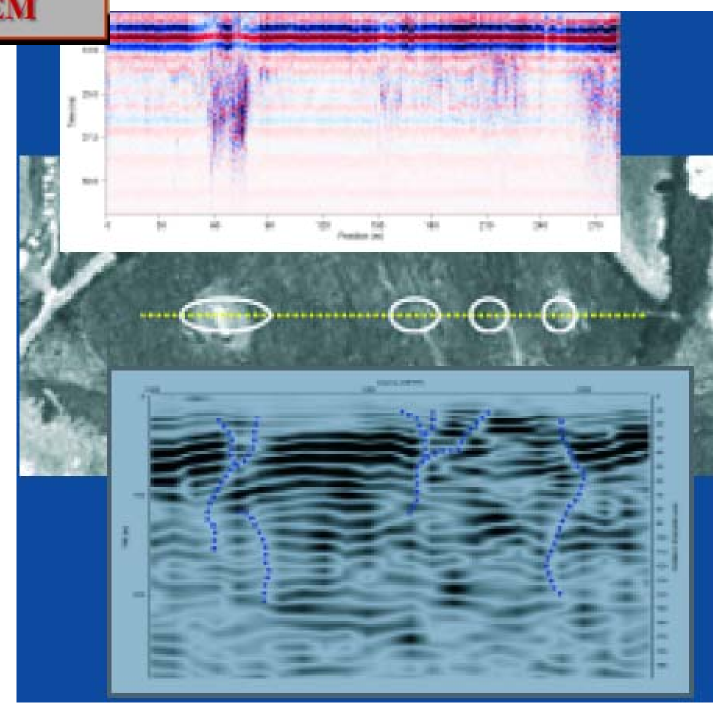


Monitoring tools

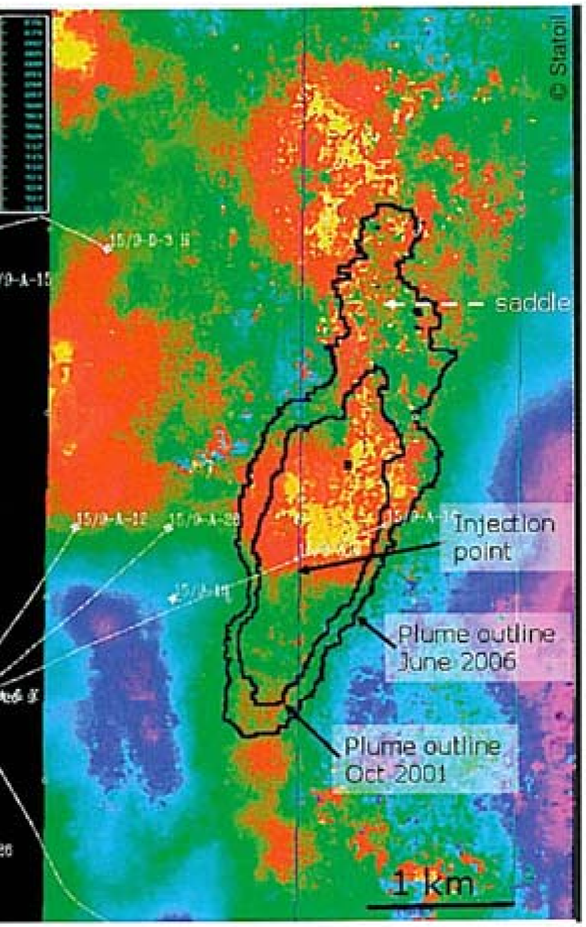


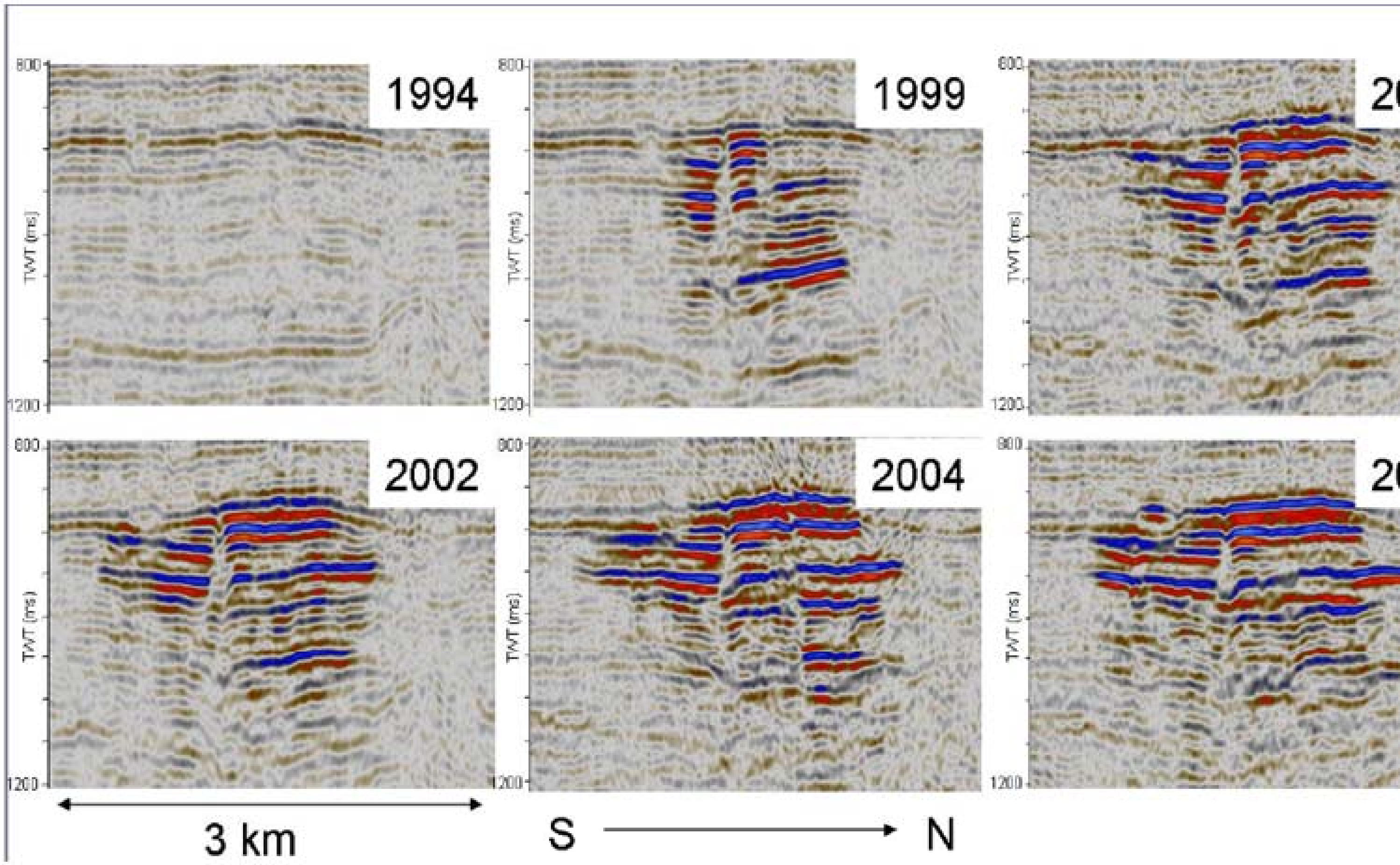
Sampling of seabed sediments



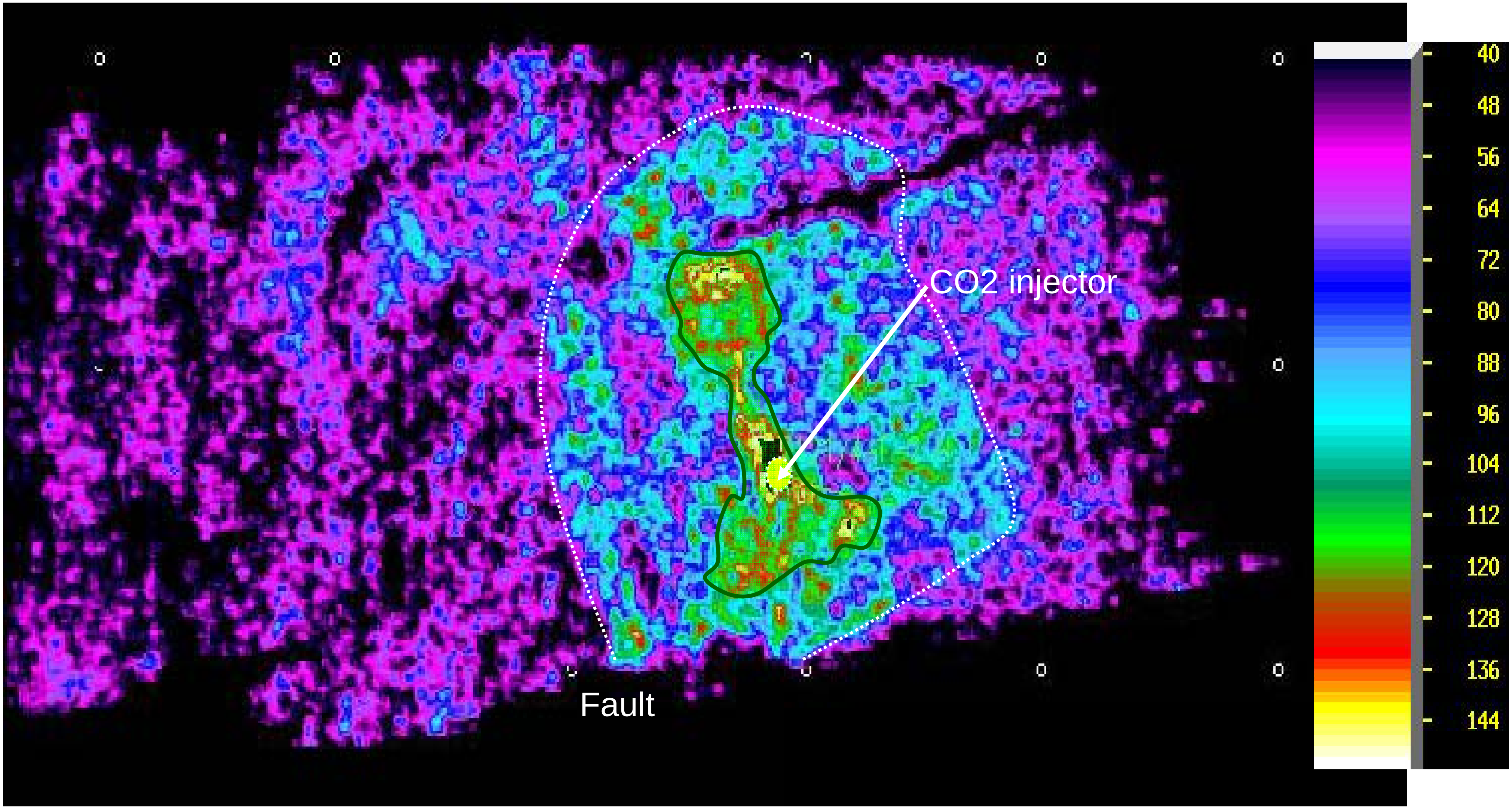


Monitoring of injected CO_2 in the Utsira Formation

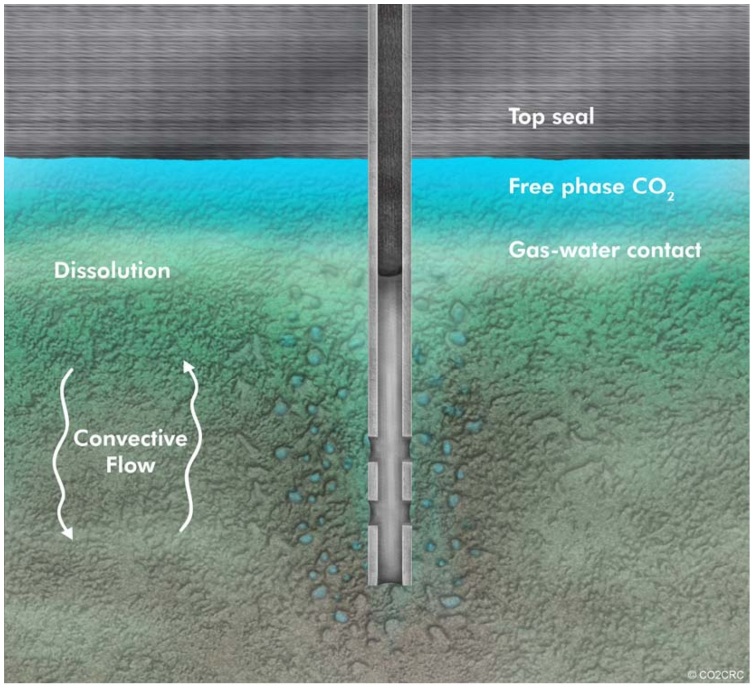


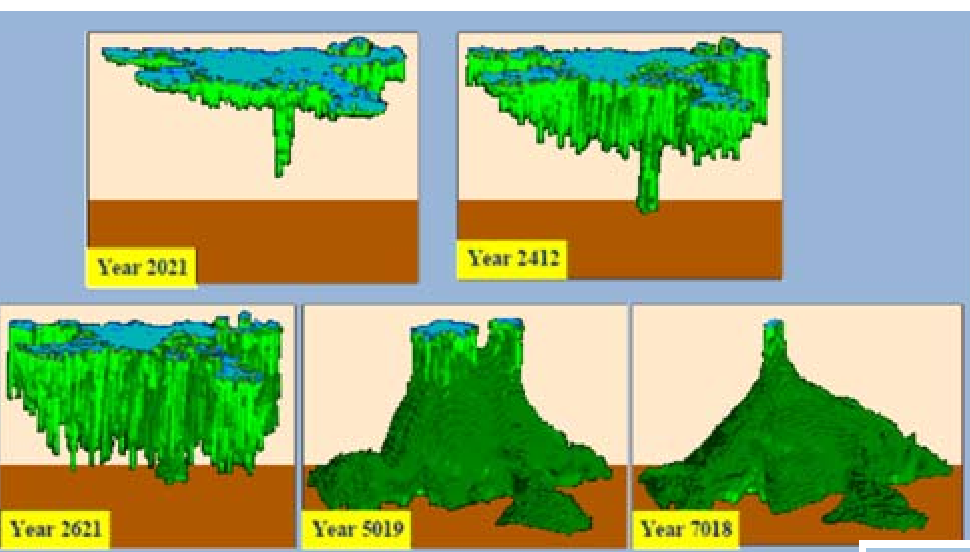


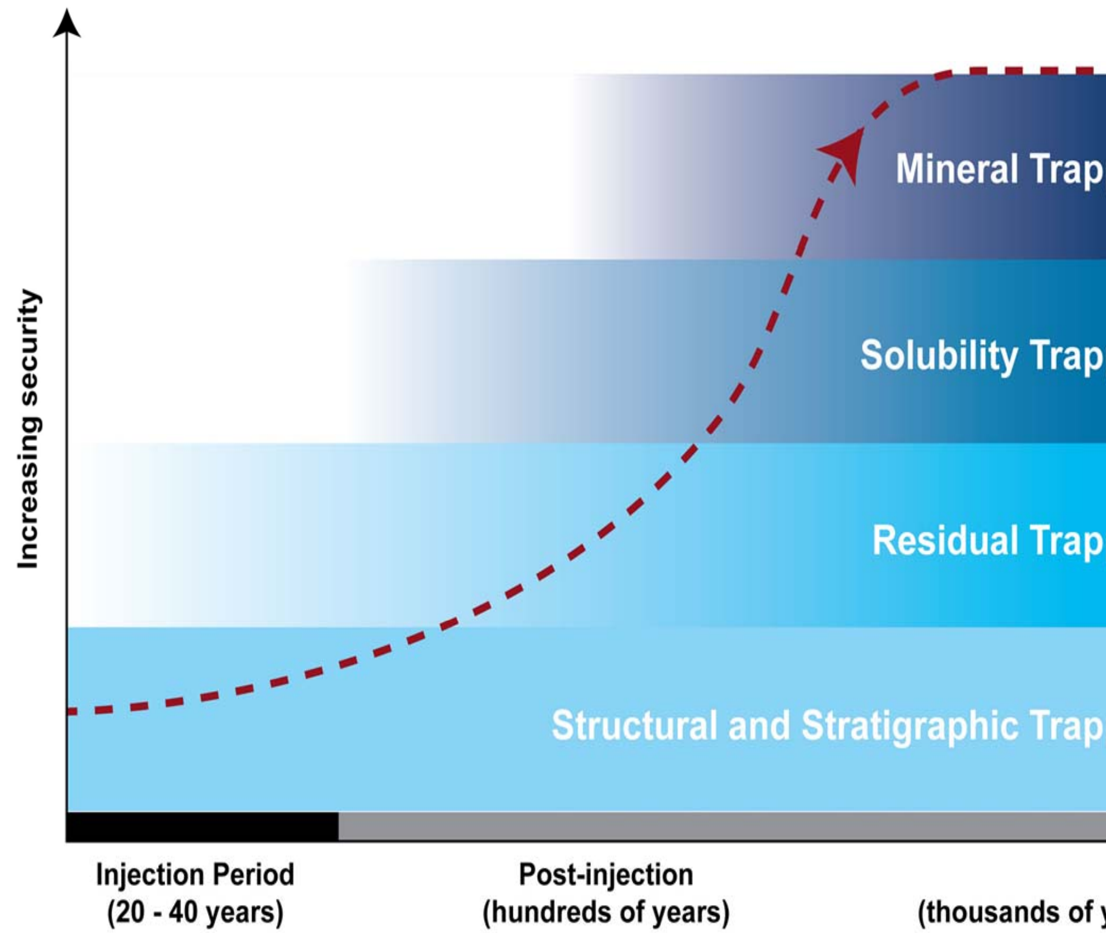
Pressure affected area



..and after termination of CO_2- injection

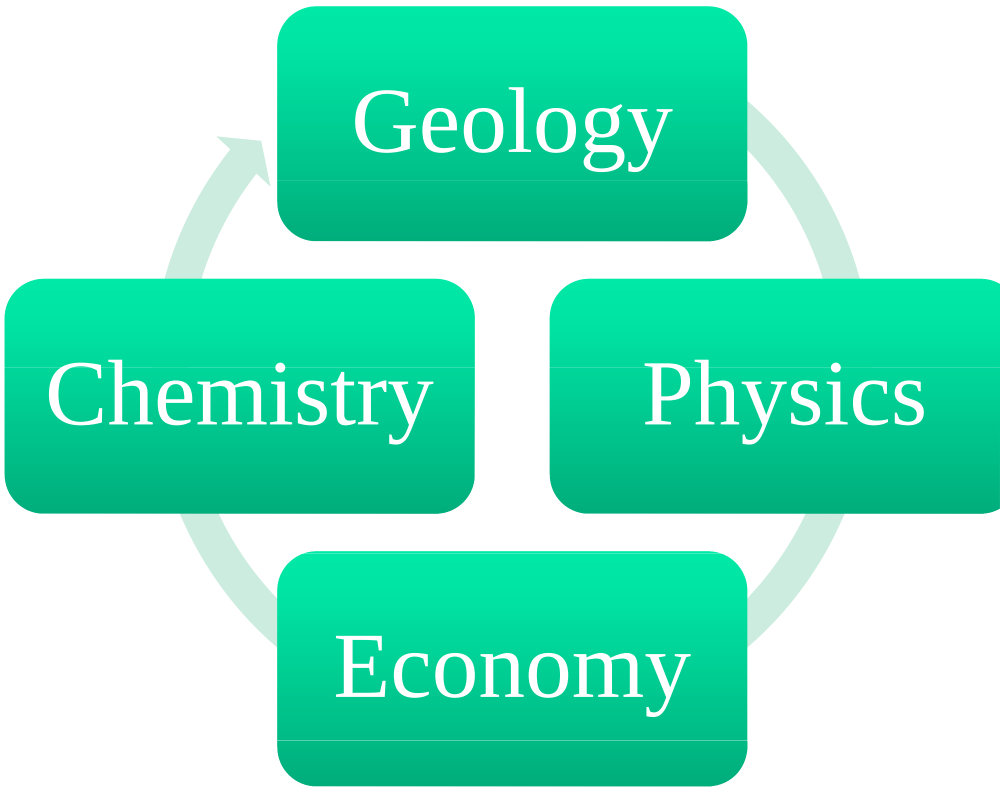






Role(s) of geosciences

- Know your geology
- Trap types
- Trapping mechanisms
- Geological risk
- Leakage rates
- Operational risk
- HSE risk



Geologists in action

Thanks for your attentio

NPD