EFFECTS OF CO_2 CAPTURE AND STORAGE ON OCEAN ACIDIFICATION

Peter M. Haugan
Geophysical Institute, University of Bergen,
Bergen Marine Research Cluster

- Introduction to Carbon Dioxide Capture and Storage (CCS) schemes – geological and ocean storage
- Possible effects
- Regulatory status
- Prospects for implementation
- Discussion

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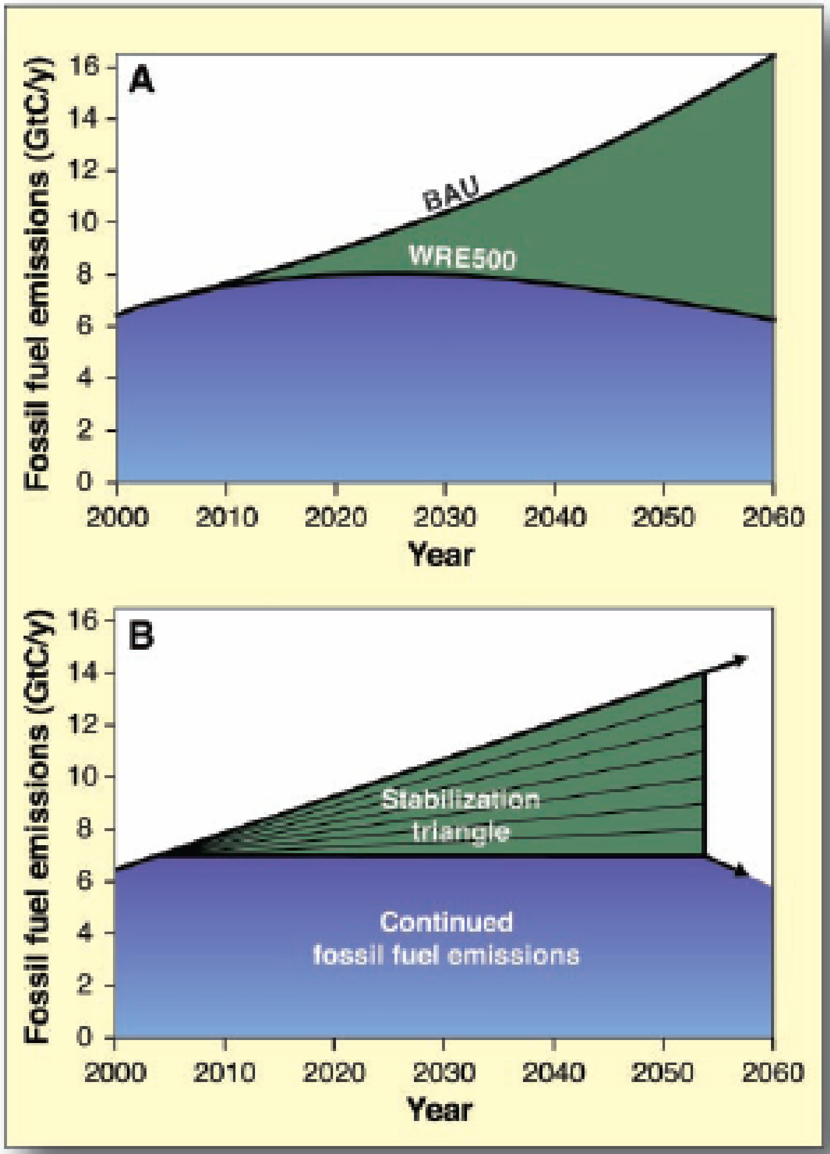
What to do with CO_2 ?

Pacala & Socolow (Science, 2004) introduced 14 potential 1 GtC/year wedges of which 7 are needed to achieve stabilization.

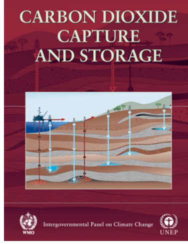
Three involve Carbon Capture and Storage (CCS):

- Baseload power plants (800 GW coal or 1600 GW gas)
- H_2 plant (250-500 Mt H_2 /year)
- Coal-to-synfuel plant (30 million barrels per day)

These would require 3500 storage facilities of the size of one presently existing and in use (Sleipner field - Utsira formation in the North Sea)



Options and obstacles



IPCC Special Report from December 2005:

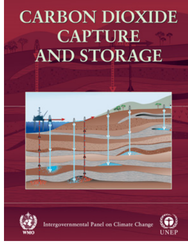
- *Sources, capture, transport, storage, costs, …*
- *Geological including subseabed storage, but also*
- *Ocean storage:*
  - *Dissolution at intermediate depths in the ocean*
  - *Storage in depressions on the deep sea floor ("lake")*
  - *Ocean options with $CaCO_3$ compensation*

General points:

Both geological and ocean storage options need to address permanence, costs, environmental issues, public perception, regulation, safety.

Leakage may occur from pipeline or well failure, faults, fractures or slow seepage.

Sources, capture, transport, costs



CCS applies primarily to large stationary sources – 40% of present emissions. Transport sector (25%) must first be decarbonized unless capture from air becomes viable (e.g. Keith et al).

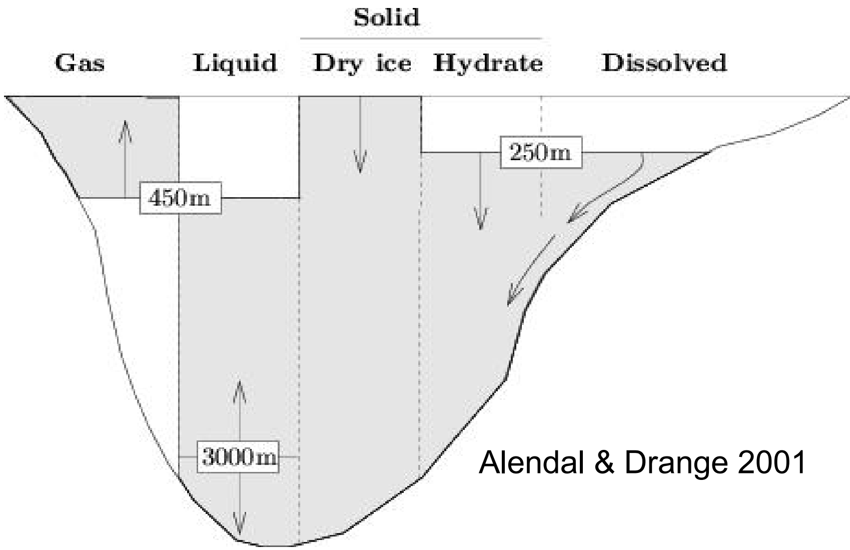
Range of technologies for capture depending on type of plant. Power plant life is around 30-50 years.

Energy penalty presently around 20%, i.e. 20% more fossil fuel must be burnt to operate CCS with same amount of electricity produced; may come down towards 5%.

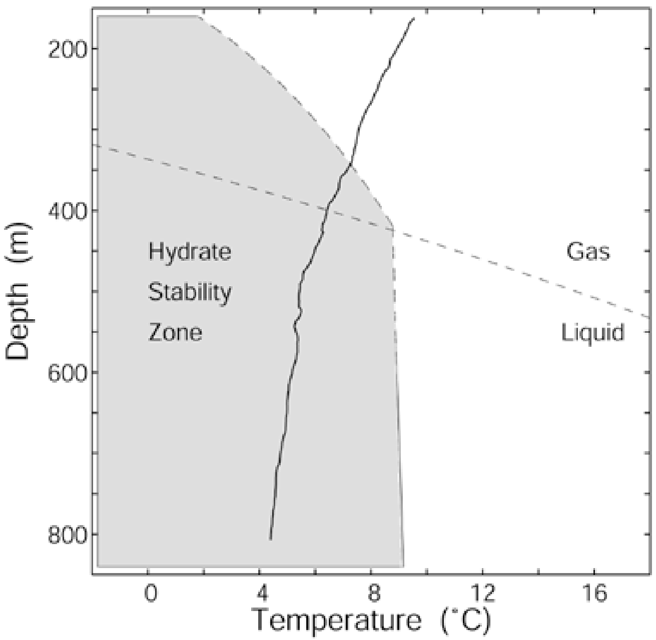
Reasonable geographical match between sources and perceived storage sites. Economy of scale in pipeline transport.

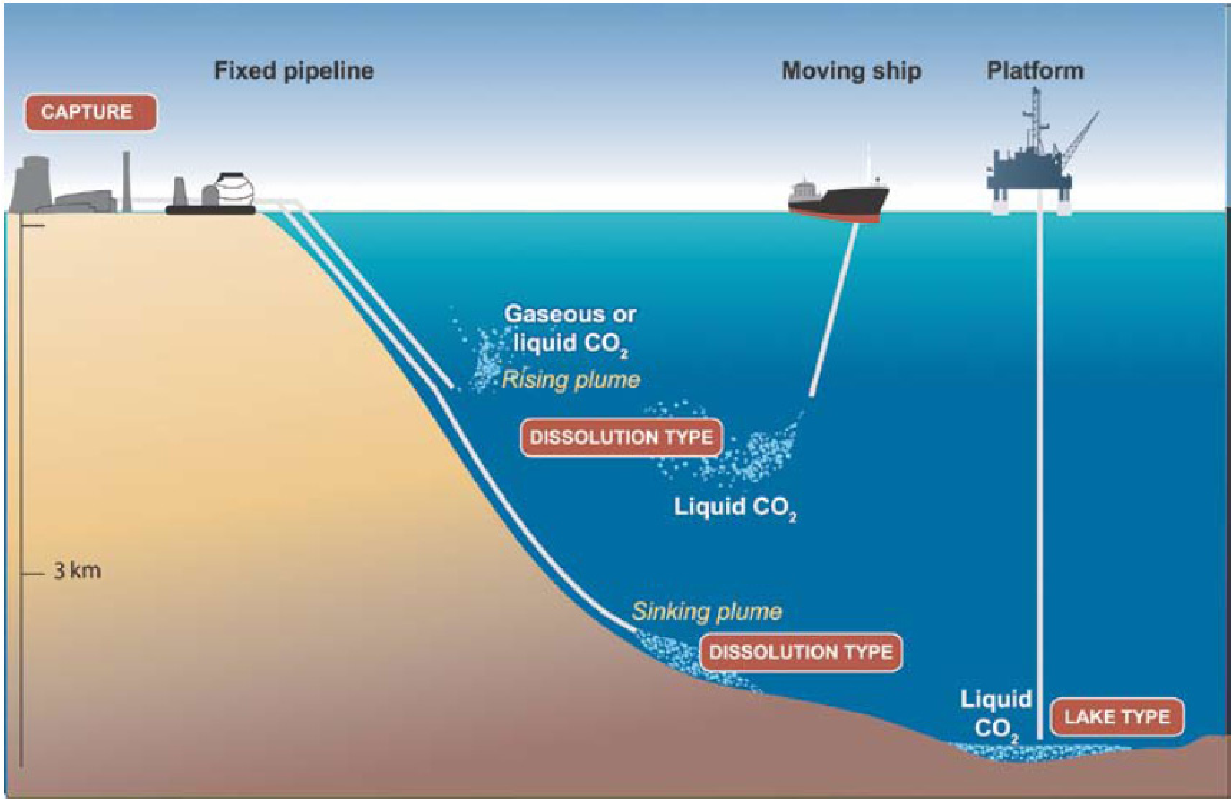
Expected costs are typically 20-70 USD/ton CO_2 avoided for coal fired plants, dominated by capture. This applies to both geological and ocean storage essentially neglecting monitoring costs.

CO_2 ocean storage options; relevant CO_2 properties

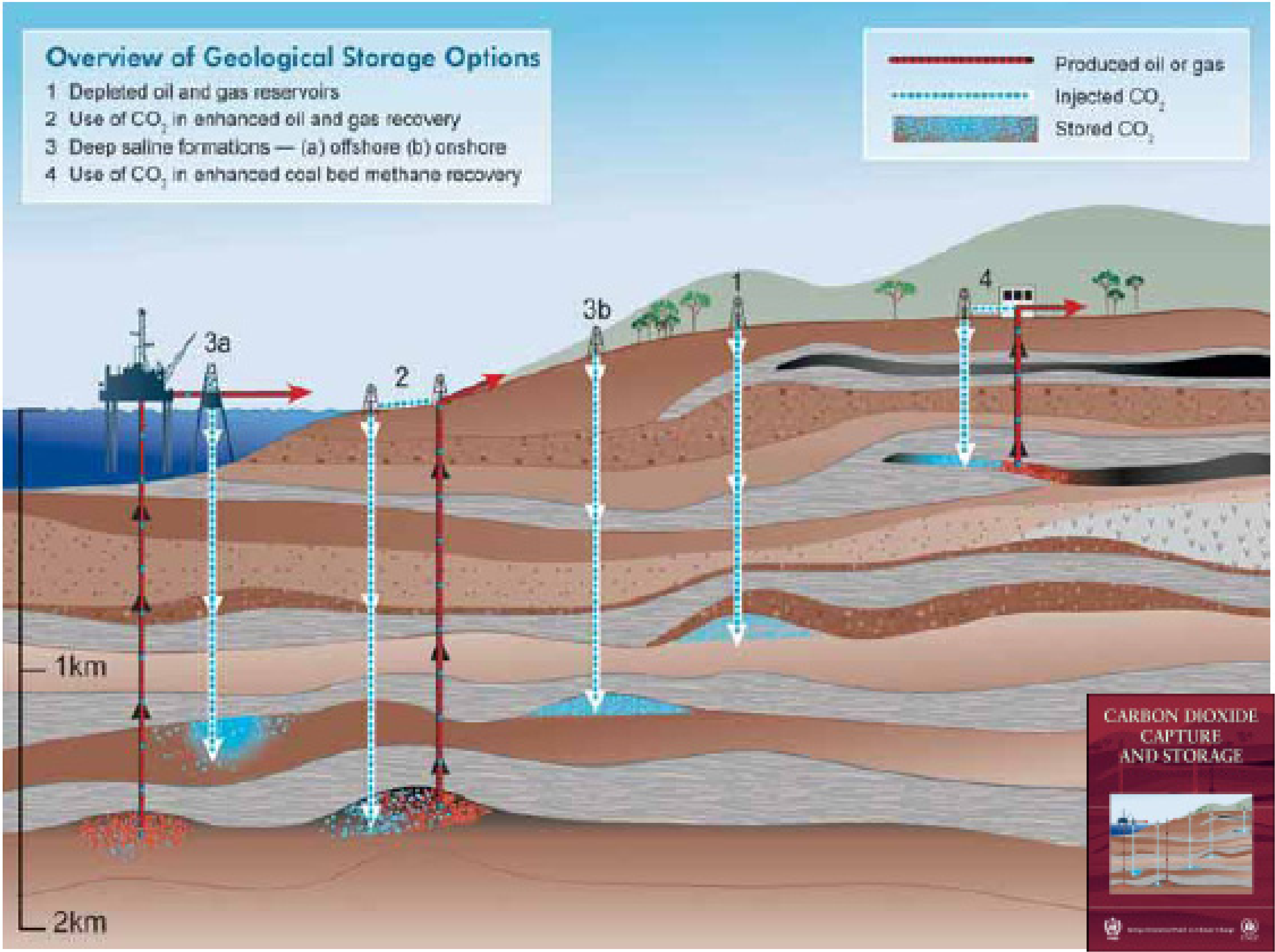


Alendal & Drange 2001

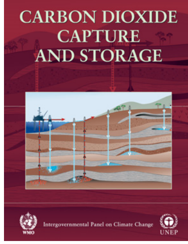




Hydrates are only metastable, but hydrate skin reduces dissolution rate


Overview of Geological Storage Options
1 Depleted oil and gas reservoirs
2 Use of CO_2 in enhanced oil and gas recovery
3 Deep saline formations — (a) offshore (b) onshore
4 Use of CO_2 in enhanced coal bed methane recovery
Produced oil or gas
Injected CO_2
Stored CO_2
3a
2
3b
1
4
1km
2km
CARBON DIOXIDE
CAPTURE
AND STORAGE

Geological storage



Depleted oil and gas reservoirs and enhanced oil recovery projects have estimated global volumetric capacity up to 1000 Gt CO_2.

Deep saline aquifers are widespread on continental shelves and on land, estimated to allow at least 1000 Gt CO_2, but capacity and properties much more uncertain.

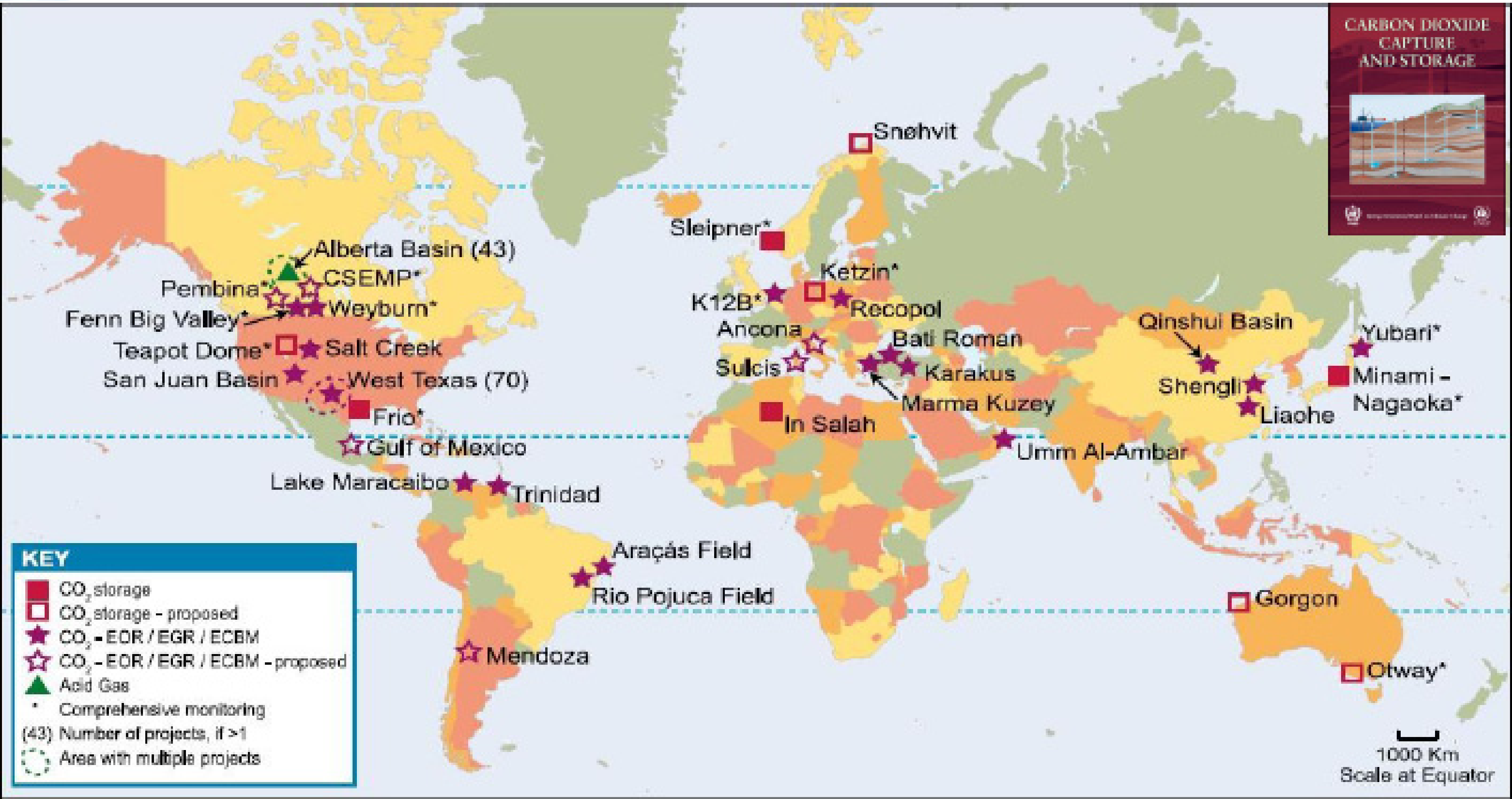
Much smaller expected contributions from unminable coal beds and largely unexplored options like basalts. *[But Broecker/Lackner et al propose capture from air + storage in basalt]*

Injectivity requires high permeability, overpressuring can compromise structural seal ("cap rock").

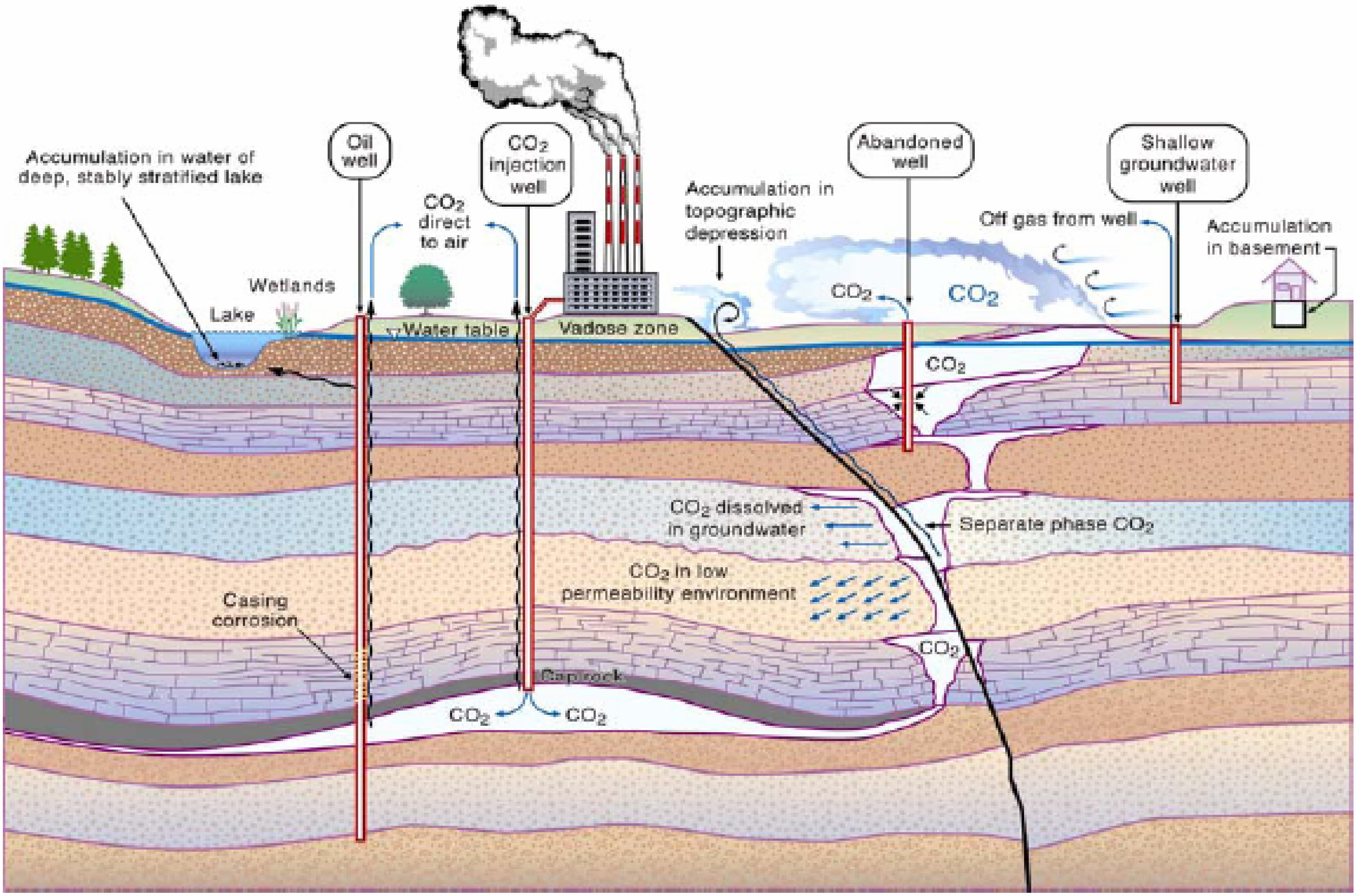
CO_2 is almost always less dense than in situ fluid because of high temperature, so tends to move upwards.

Dissolution in brine and mineralization can occur on longer time scales, but is hard to verify and depends on details of pore structure, contact area between phases etc.

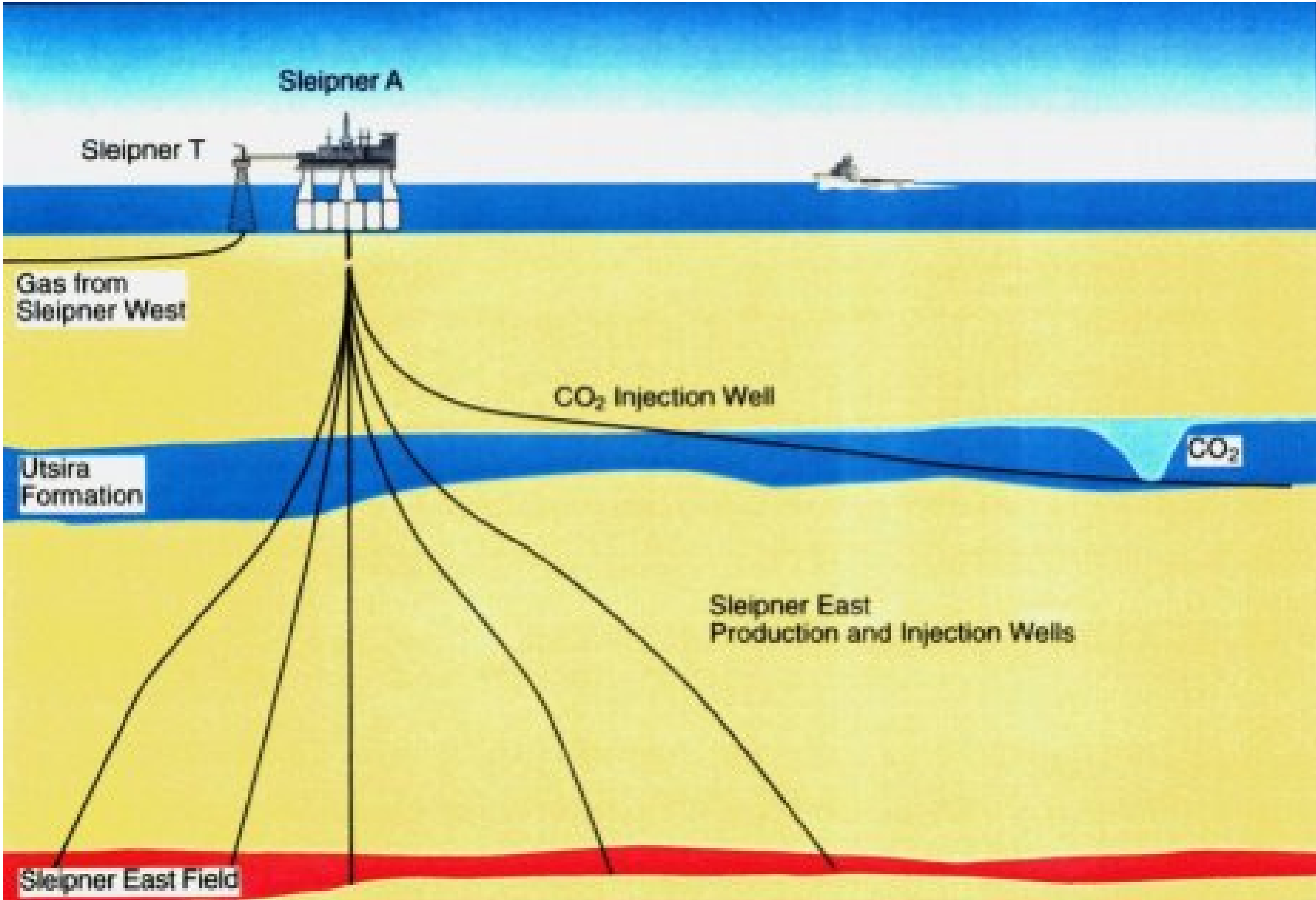
Ongoing and planned CO_2 storage, Enhanced Oil Recovery and Coal Bed Methane projects [Update: Otway on stream, new Svalbard site 2009]



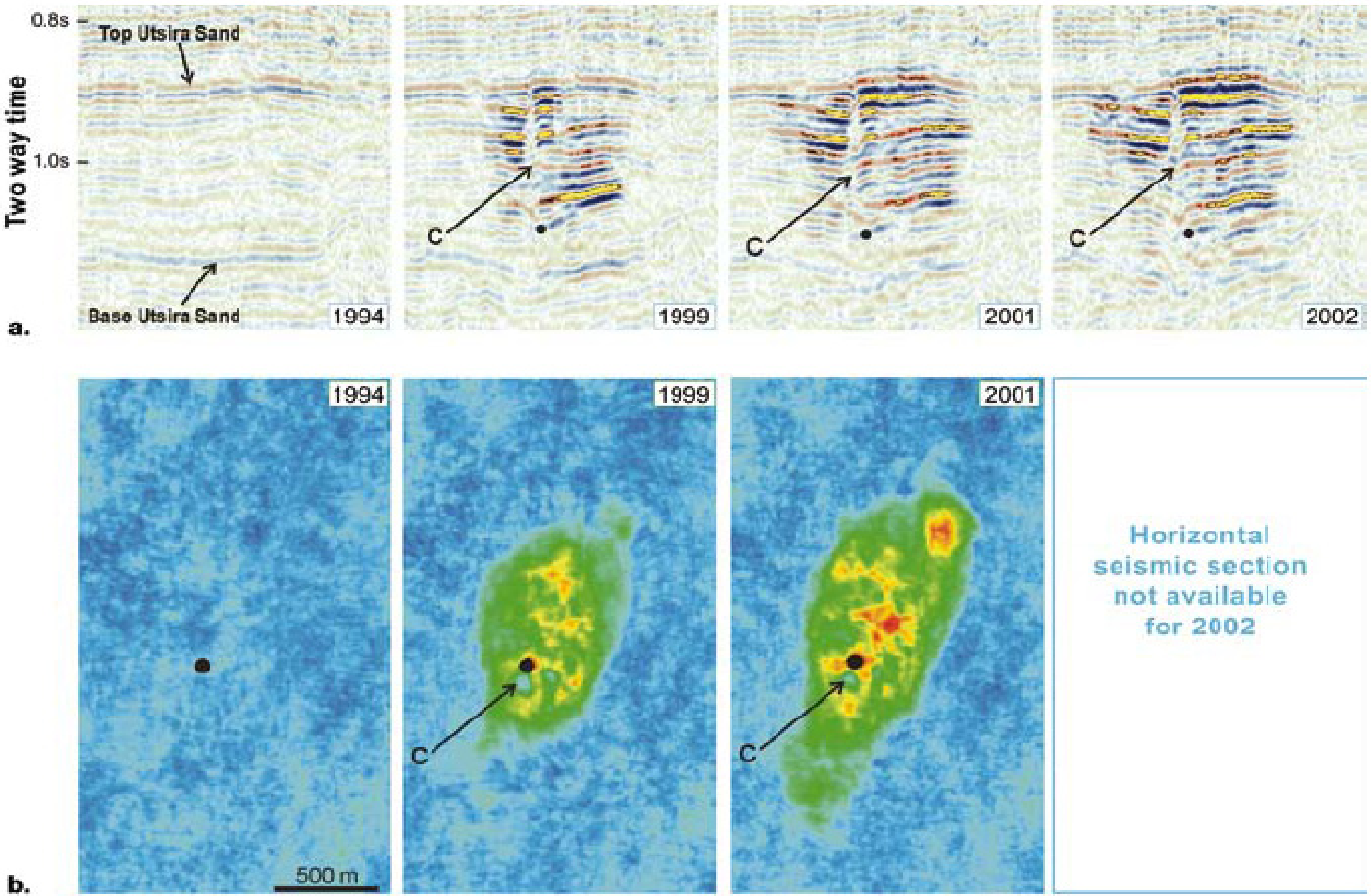
Conditions and processes affecting leakage



Norway ongoing: Injecting 1 Mt CO_2/y from natural gas production at Sleipner into Utsira formation in the North Sea since 1996



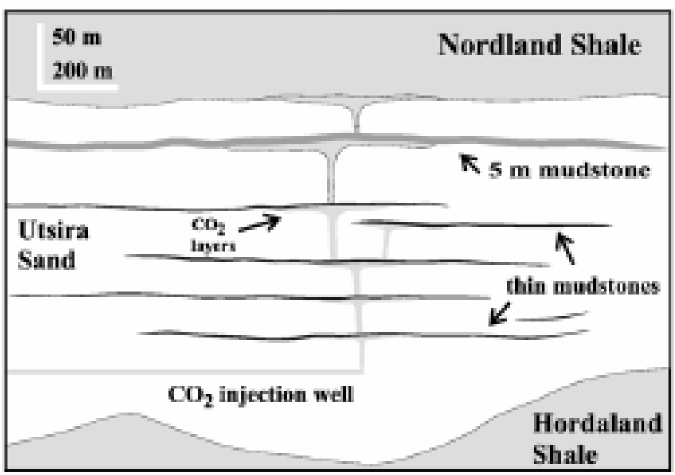
Vertical and horizontal seismic sections at Sleipner-Utsira

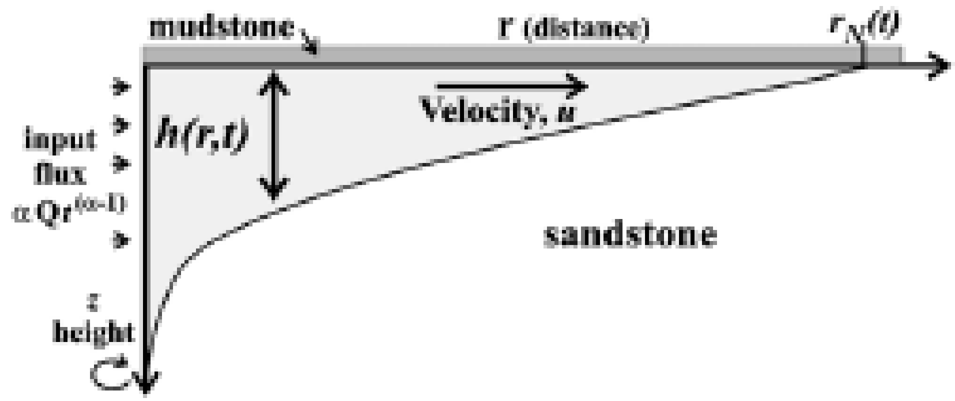


Central chimney conduit plus rapid leakage through 1-5 m shale layers

Recent modelling study of Sleipner - Utsira

Comparing observed (seismic sections) development of thickness versus radius in 9 distinct layers with analytical gravity current dynamics in porous and permeable media.





Layers have started filling gradually. Leaks occur through thin mudstones. Model-data consistency requires either CO_2 permeabilities order of magnitude lower than measured on core samples or CO_2 layer thickness from seismic are overestimated –> Possible that CO_2 saturation is small and CO_2 has escaped.

Bickle, Chadwick, Huppert, Hallworth and Lyle. Modelling carbon dioxide accumulation at Sleipner: Implications for underground carbon storage. Earth and Planetary Science Letters 255 (2007) 164-176.

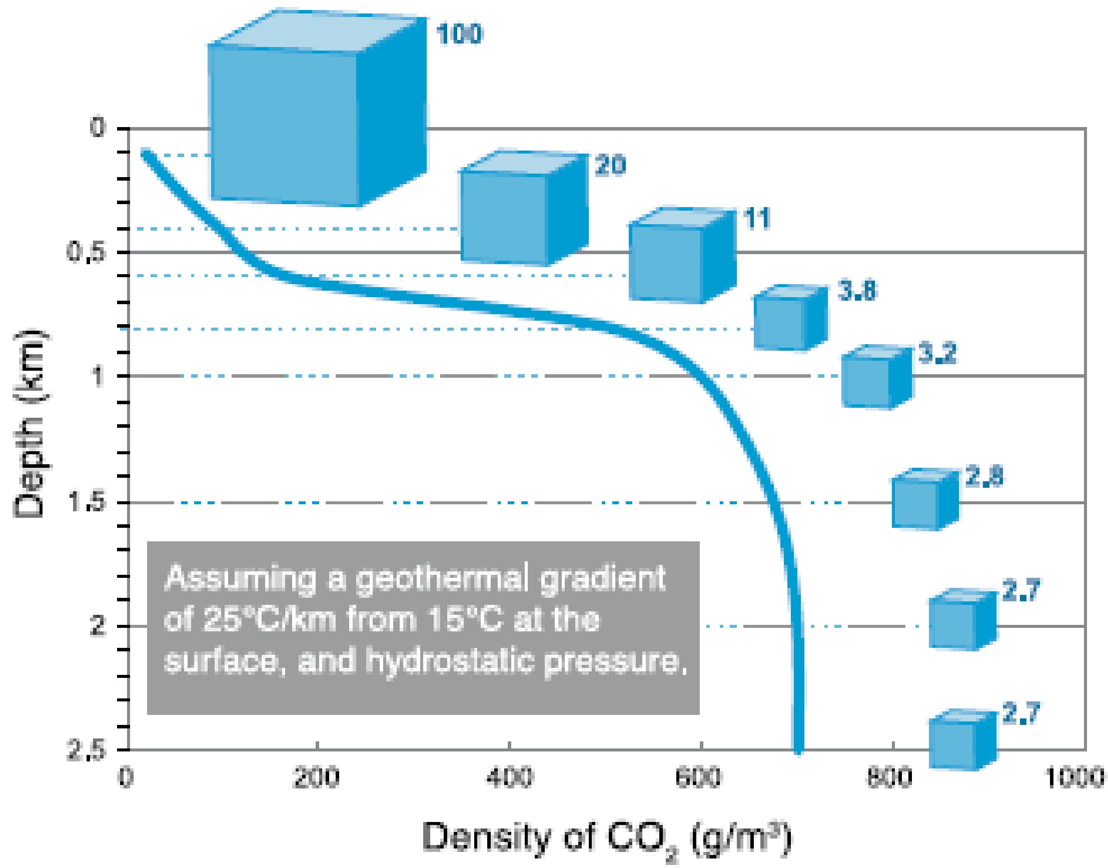
Depth of Utsira is close to CO_2 low density regime

+ high sensitivity to temperature

=>Hard to estimate CO_2 in place

Other parts of Utsira are quite clearly in CO_2 low density regime and should be avoided; previous capacities over-estimated.

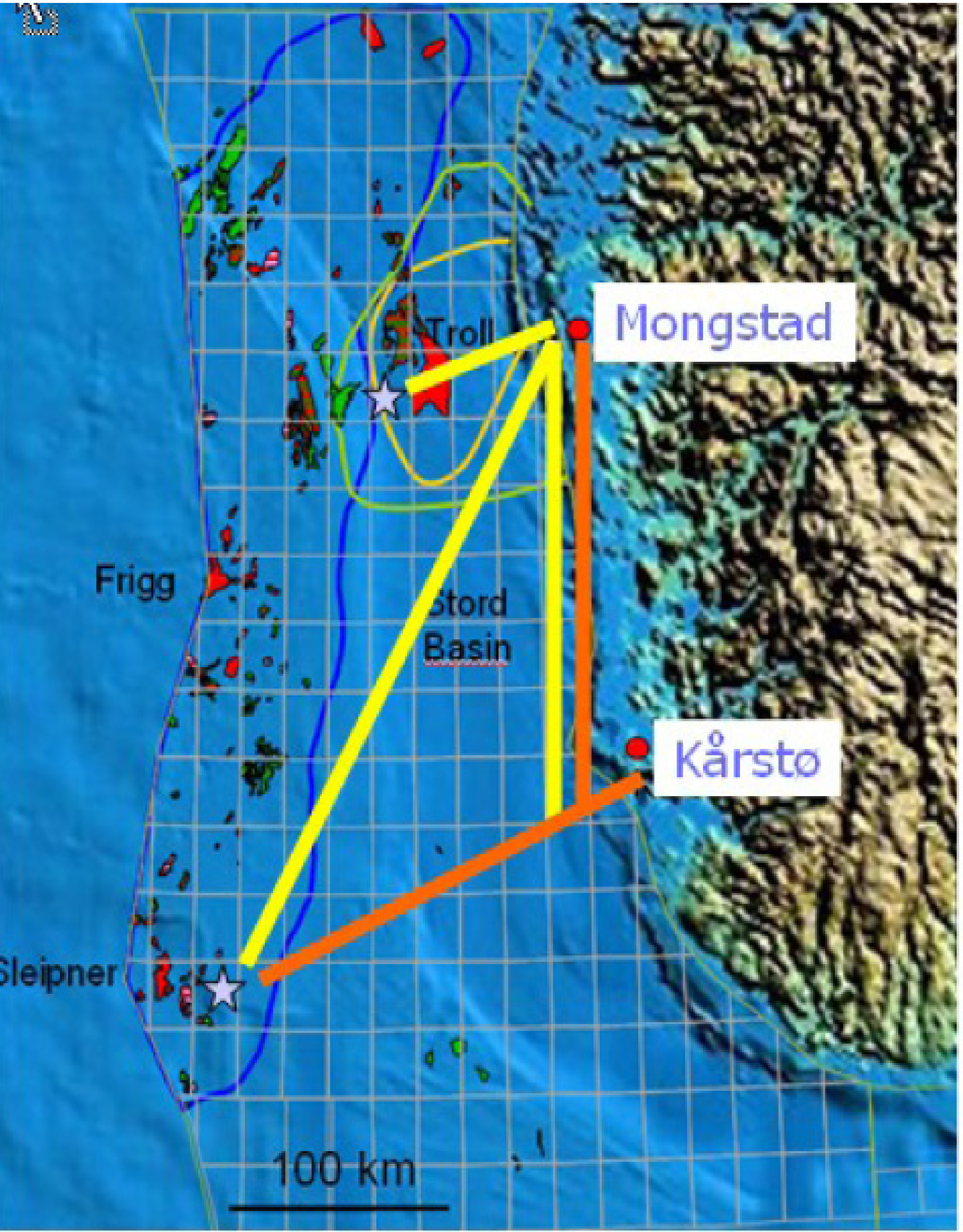
Still Utsira is probably the most suitable formation in the North Sea with high permeability and porosity.



Outreach material: No significant leakage

Truth: Large uncertainty on volumes, fluxes

Some current plans for offshore CO_2 storage in Europe



Gas power plants:
Kårstø and Mongstad:
Storage either Utsira above Sleipner or Johansen below Troll.
Mongstad: 1.1 to 3.3 M tons/year
Kårstø: 1.1 to 2.2 M tons/year
Concept decision December 2008.
Startup 2012 (K), 2014 (M).

Other plants further north along the Norwegian coast.
Emerging Skagerrak initiative.

Coal fired power plants:
Danish plans
UK plans
- North Sea

Norwegian at Svalbard (onshore)

Possible environmental consequences of large scale application

Capture: Emissions similar to standard power plant (N, S) plus amine if post-combustion separation

Transport: Land use, safety

Indirect effects: Trend towards larger plants, restructure of electricity grid system

Storage during operations (30 years): Local health and safety, induced seismicity

Storage after closure (10 000 years to indefinite):

- Degradation of subsurface biodiversity
- Prevention of other resource utilization
- Ground water salinification
- Mobilisation of methane, metals

If leakage (10 000 years to indefinite):

- Climate impact (global), ocean or soil acidification, impact on flora and fauna, limnic eruptions (local)

Relevant international regulations

- Kyoto Protocol and IPCC Greenhouse Gas Inventory
- London Protocol and OSPAR Guidelines
- EU and national regulations

EU directive from January 2008 on geological storage defines role and responsibility of national government, reporting and EU approval, open competition for exploration permits, transfer of responsibility from operator to ”competent auhority” [+ also bans direct ocean storage and requires new power plants to reserve space for future CC facilities].

Amendment to the OSPAR convention 2007
(Oslo – Paris Convention on the Protection of the Northeast Atlantic)

CO_2 streams from capture processes can be stored into a sub-soil geological formation[1] if:

- the streams consist overwhelmingly of carbon dioxide
- no wastes are added for the purpose of disposing
- they are intended to be retained permanently and will not lead to significant adverse consequences for the marine environment

The London protocol is being amended along a very similar path.

[1] The amendment applies only to shelf areas (not deep ocean) and only to storage several hundred meters below the seafloor.

Any show stoppers?

For capture and transport: None. Requires time and effort, but doable based on existing knowledge and similarities to other industrial operations.

For storage: Fundamental problems with demonstrating long term storage integrity [EU directive: ”permanent”, ”completely contained for the indefinite future”].

Much of the information about geological storage including environmental aspects comes from proponents. Few peer reviewed sicentific publications on the subject.

Socolow (2002): ”Uncertainties of permitting could dominate total sequestration costs”. Costs of obtaining data from aquifers and running monitoring could be significant.

[”Petroleumstilsynet” in Norway 2007: critical to health and safety of CCS operations; work needed.]

All of these could mean delay, but probably not stop the development. What remains is to cover the costs.

Some comments

Present proponents of subseabed geological storage assume a very low cost of monitoring compared to capture and transport.

Proper account has perhaps not been taken of effects of pressure buildup on enhanced natural (shallow) gas release, microbial conversion of CO_2 to CH_4, subsoil microbial biodiversity or effects of natural seismic events on millennial time scales.

Obtaining site specific data can be costly in particular offshore (drilling wells also themselves constitute leakage pathways), so decisions on whether to allow storage may be made on basis of untested models.

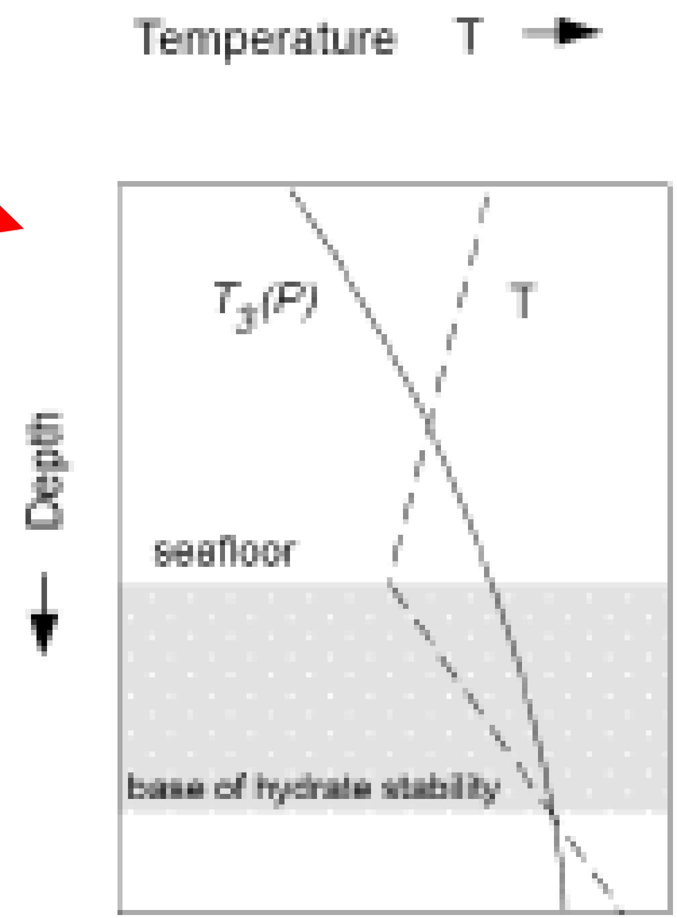
It would be easier if environmental impact assessment could be made more generic rather than site-specific. However geological formations are notoriously heterogeneous.

An option that may be better but is presently banned (1.2.3&4 in EU directive)

Only the deep ocean (> 3000m) provides cold temperatures and high pressure to make CO_2 negatively buoyant.

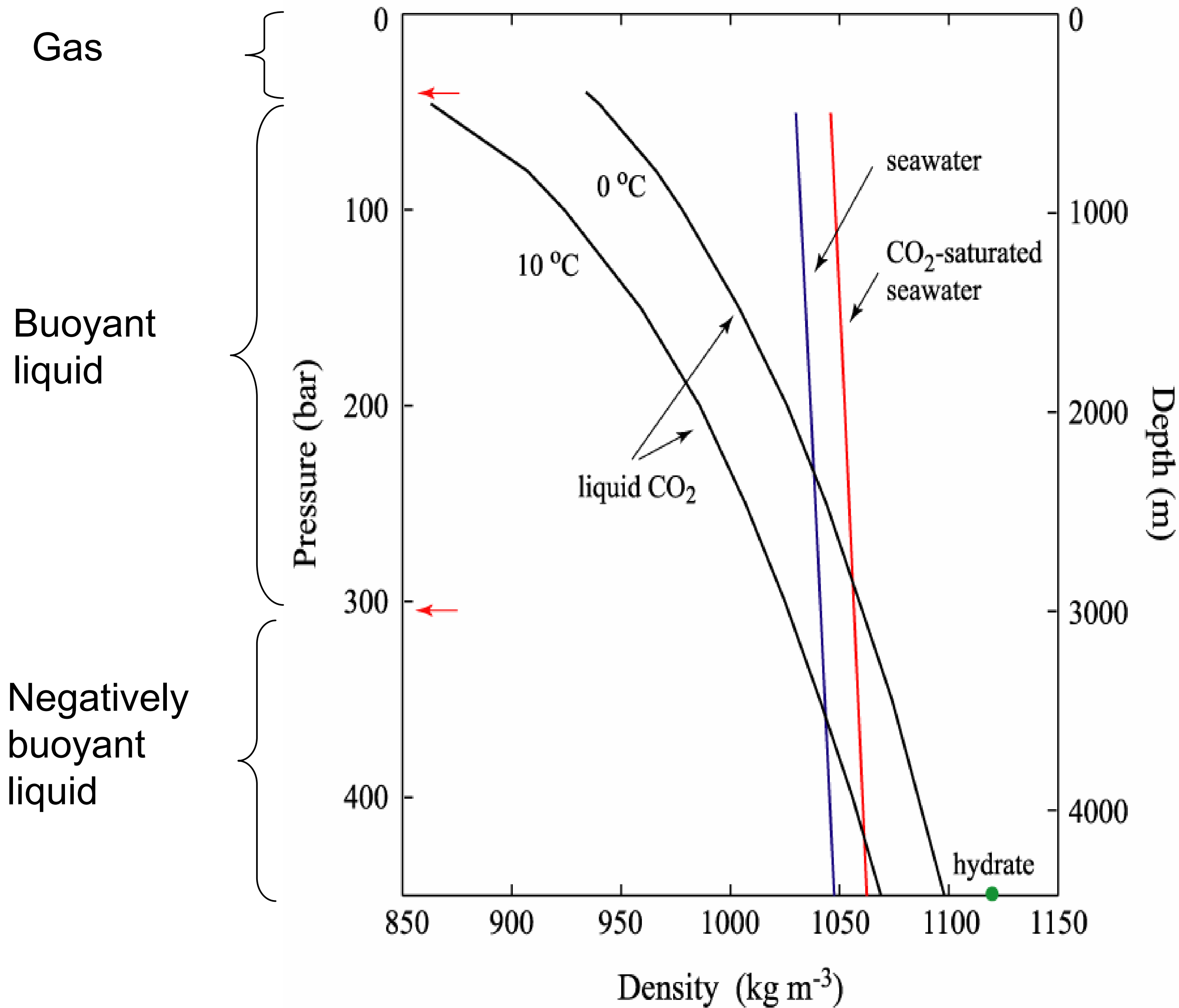
Favorable hydrate formation; possibly injection into deep sea sediments.

If geological storage falls out of favor for cost or environmental reasons, perhaps deep ocean will come back ?



House et al., 2006

Density of liquid CO_2, seawater, CO_2-enriched seawater and CO_2 hydrate



Ocean issues related to CCS

-> dissolution, spreading, acidification and potential biological damage, communication to atmosphere.

In addition to the options studied so far there are some yet unexplored versions:

- Inject into high salinity brine water in deep depressions, e.g. the Red Sea, or

- Inject into anoxic basins, e.g. the Black Sea.

- Inject in deep sea sediments in the negative buoyancy zone where dense phase CO_2 is denser than formation water and hydrates are stable (House et al., 2006)

+ Perhaps others will be found?

North Sea model study of leakage (Blackford et al, MPB 2008) using well tested hydrodynamic model with tides: Small impact relative to that of uptake scenarios

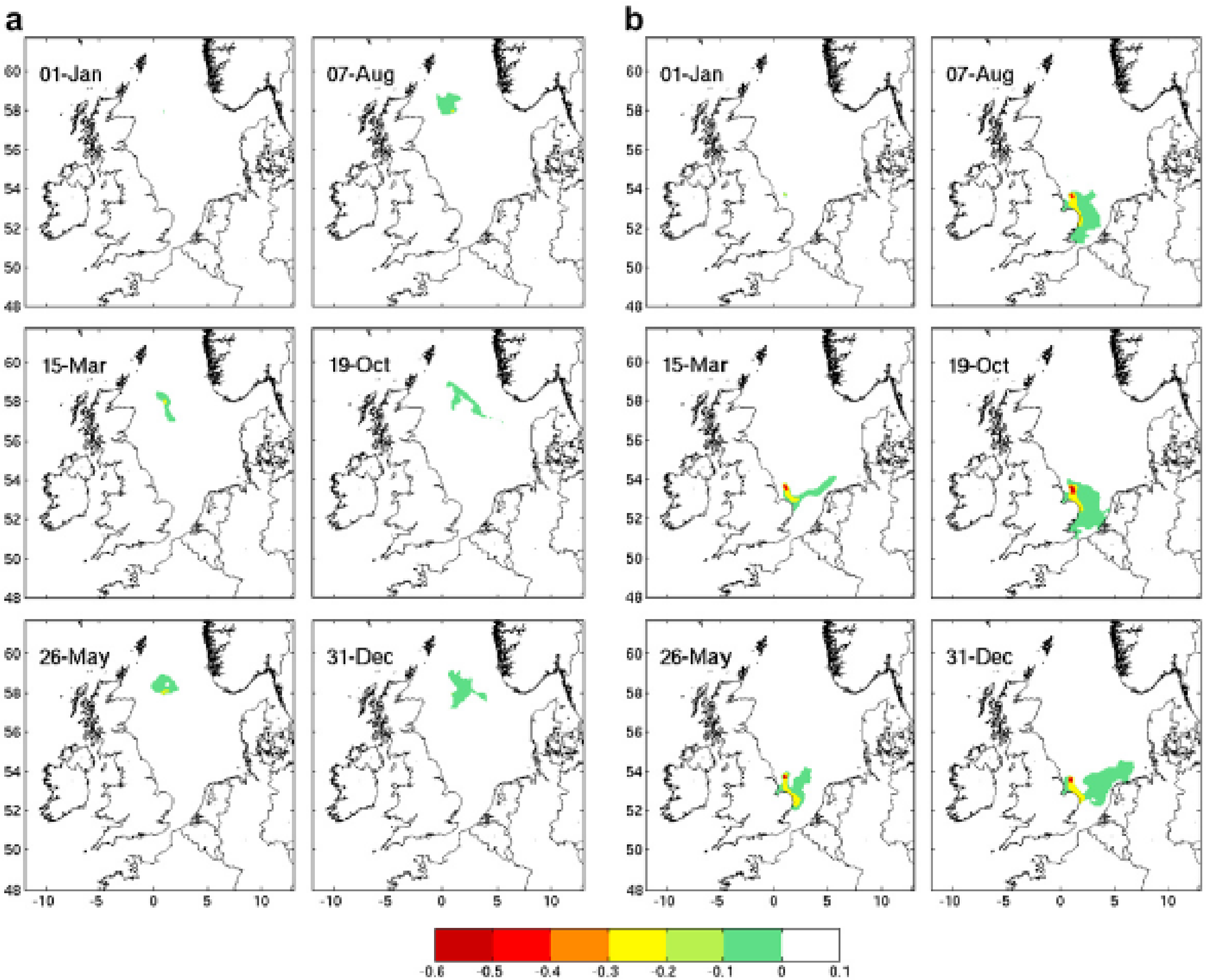


Fig. 4. Long-term leak evolution, (a) north site and (b) south site, times as stated. All perturbations below 0.01 pH unit have been masked for clarity.

<u>Model details:</u>

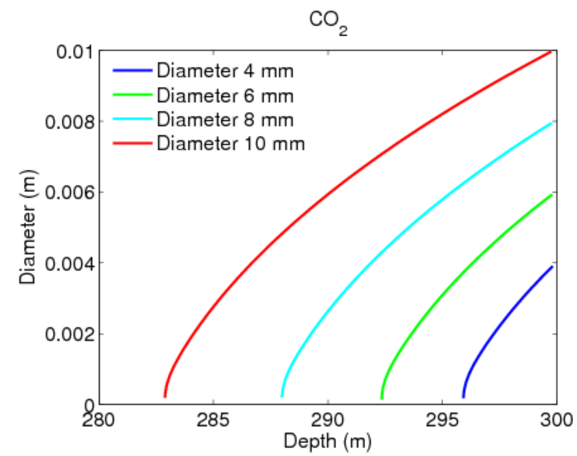
Leakage 5 times Sleipner injection

7x7 km grid
Dissolved CO_2

Highly local effects not resolved

Blackford, Jones, Proctor and Holt. MPB56 (2008), 1461-1468.

AND: CO_2 accumulation with increased water density near the seabed may occur in more quiescent areas with less tidal mixing than in the North Sea

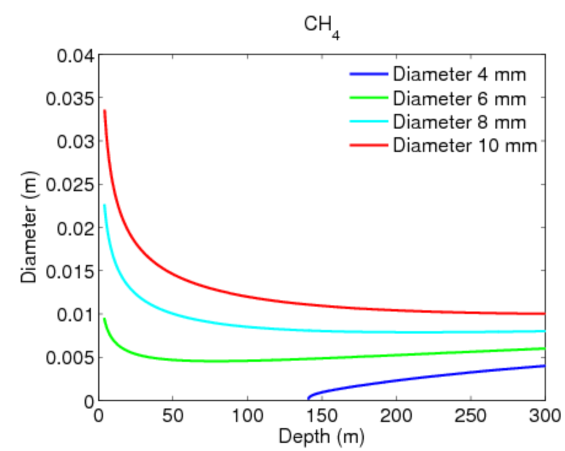


An evaluation of the properties of CO_2 and CH_4 in seawater shows that CO_2

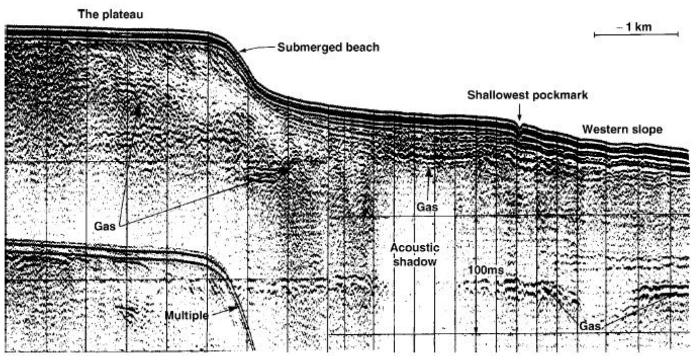
- is always heavier in the pure phase,
- dissolves faster than CH_4,
- imposes stable density stratification when dissolved in seawater.

Hence the leaking CO_2 will be dissolved and spread closer to the seafloor than CH_4.

(see poster M16 on near field modelling tools by Enstad/Haugan/Alendal)

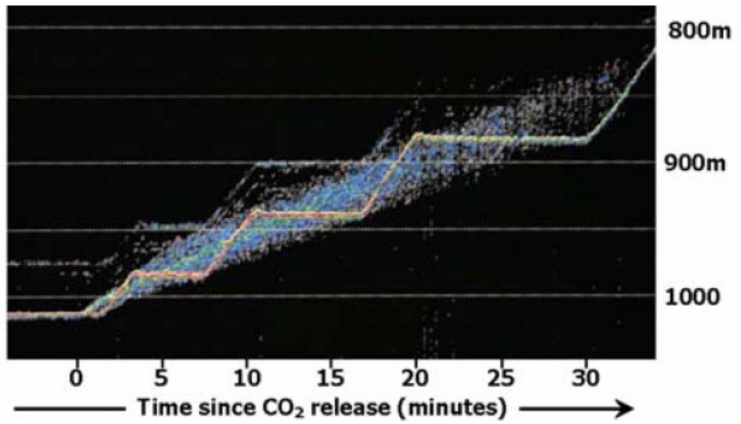


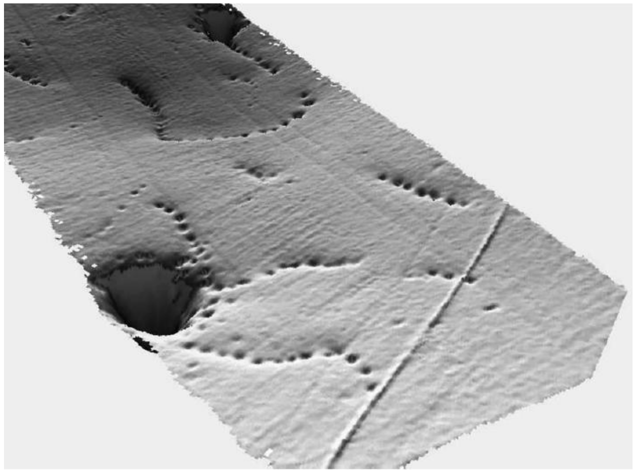
Some monitoring techniques



Above: Shallow seismic (sparker) profile across the Gullfaks field. Courtesy of M. Hovland, Statoil

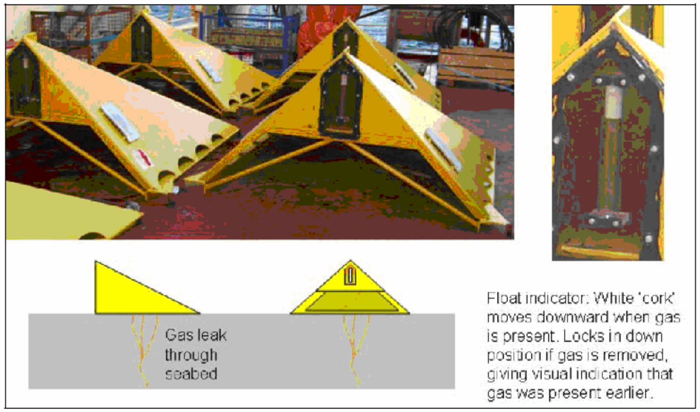
Below: CO_2 Experiment conducted by Brewer et al. (2006). (Geophysical Research Letters). Courtesy of P.G. Brewer, MBARI





Above: Model from high resolution multibeam echo sounder. (Vertical axis exaggerated five times). Haltenbanken pipeline down to the right. Courtesy of M. Hovland, Statoil

Below: Collection structure for shallow gas (CH_4) monitoring at Troll. Courtesy of NGI and IFE



Norwegian Climit-project 2007/2008 "Subsea Storage of CO_2; the marine component" (Alendal et al) literature survey http://www.cmu.uib.no/projects/CO2Marine

Will carbon sequestration be significant for 21st century CO_2 levels?

Present projects are only order 0.01 Gt C/year, but are increasing, so maybe useful in the intermediate to long term (not short term!)

OR

the projects may turn out to be environmentally unacceptable, unreliable or too slow to provide a bridge, in which case the net effect is probably higher emissions because of false beliefs.

Will carbon sequestration be significant for ocean acidification?

Some local effects from leakage – studies are needed.

Most important effect via the resulting net emissions to the atmosphere.

Summary and conclusions

Considerable political interest in separation of CO_2 from fossil fuel power plants and industry followed by long term storage in geological reservoirs. The North Sea is envisaged as storage site for 30% of emissions for Europe within 2050.

Present global storage projects are only order 0.01 Gt C/year, but are increasing rapidly.

Direct storage in the deep sea is still prohibited, but recent developments in legislation give openings for subseabed storage on continental shelves. Geological disposal modelling is poorly constrained.

There is a need to assess the risks of large scale CO_2 storage, to avoid environmentally unacceptable projects. Some leakage will occur.

A worst-case scenario is that the net effect may be higher emissions and more acidification because of false beliefs and lack of other efforts.

Technology developments such as capture from air and deep seabed disposal add uncertainty to future scenarios.

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