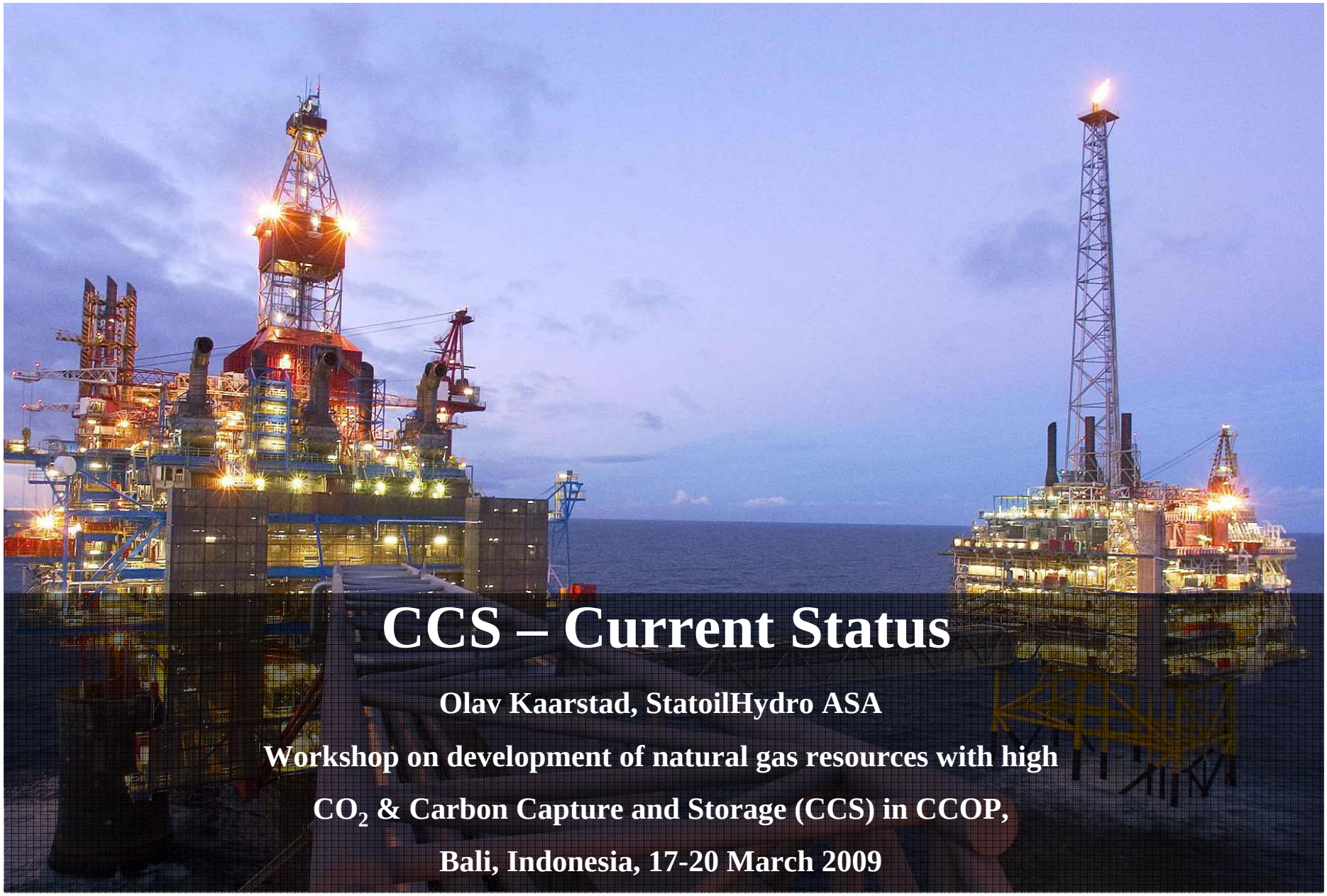

CCS – Current Status

Olav Kaarstad, StatoilHydro ASA

Workshop on development of natural gas resources with high CO_2 & Carbon Capture and Storage (CCS) in CCOP,

Bali, Indonesia, 17-20 March 2009

StatoilHydro

Topics covered

- Some CCS background
- What is CCS?
- Some elementary physics of CO_2
- Challenges & opportunities
- Transportation and capture of CO_2
  - where are we now?
  - What is in store for the future?
- Roles for government & industry
  - How can we work together?

Background → climate change
- The 5 tools of greenhouse gas emissions reduction

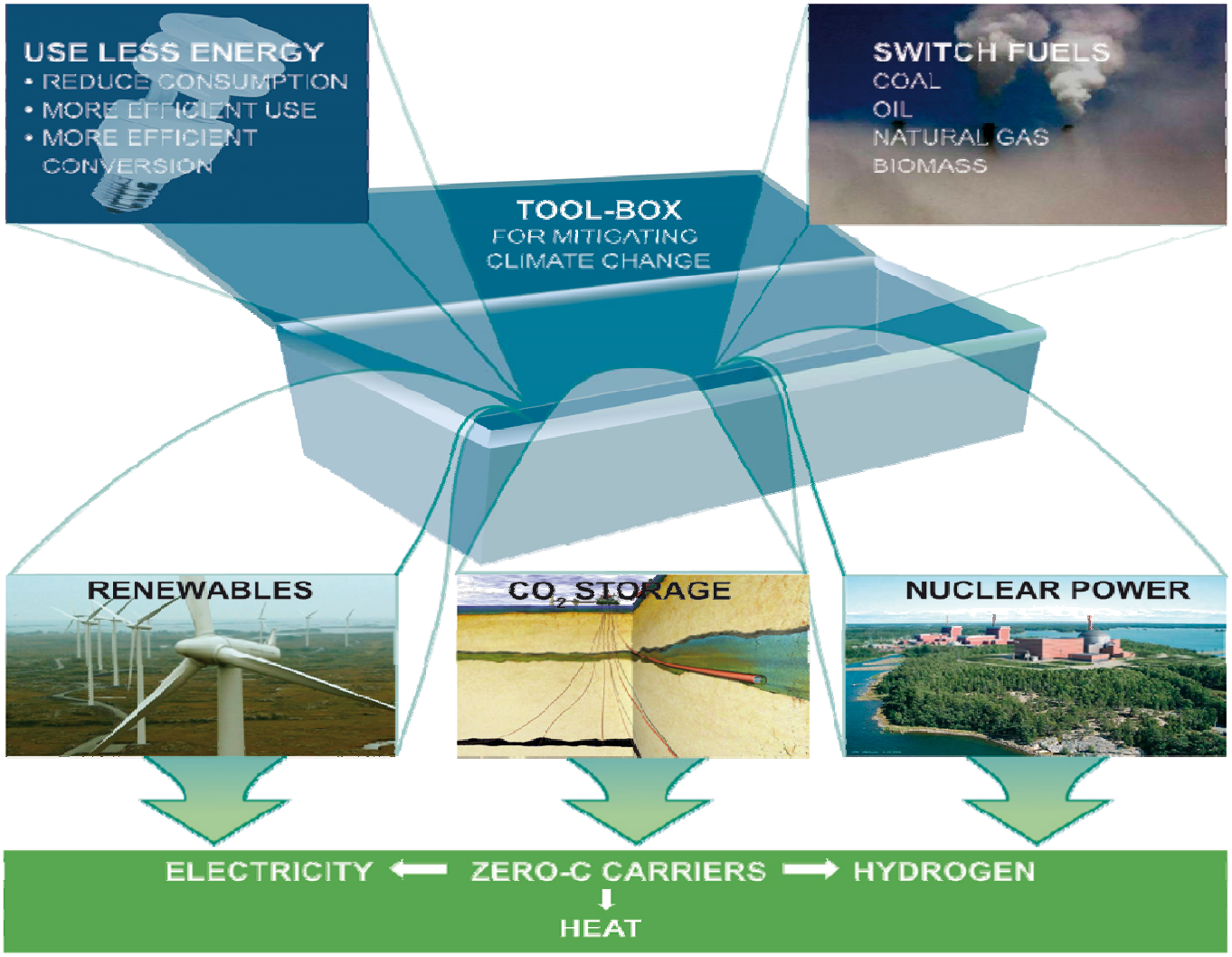

Illustration source: Freund, Kaarstad “Keeping the Lights on”, Universitetsforlaget, 2007

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Background → climate change

- 193 countries of the world
- Ten countries presently emit nearly 2/3 of the total

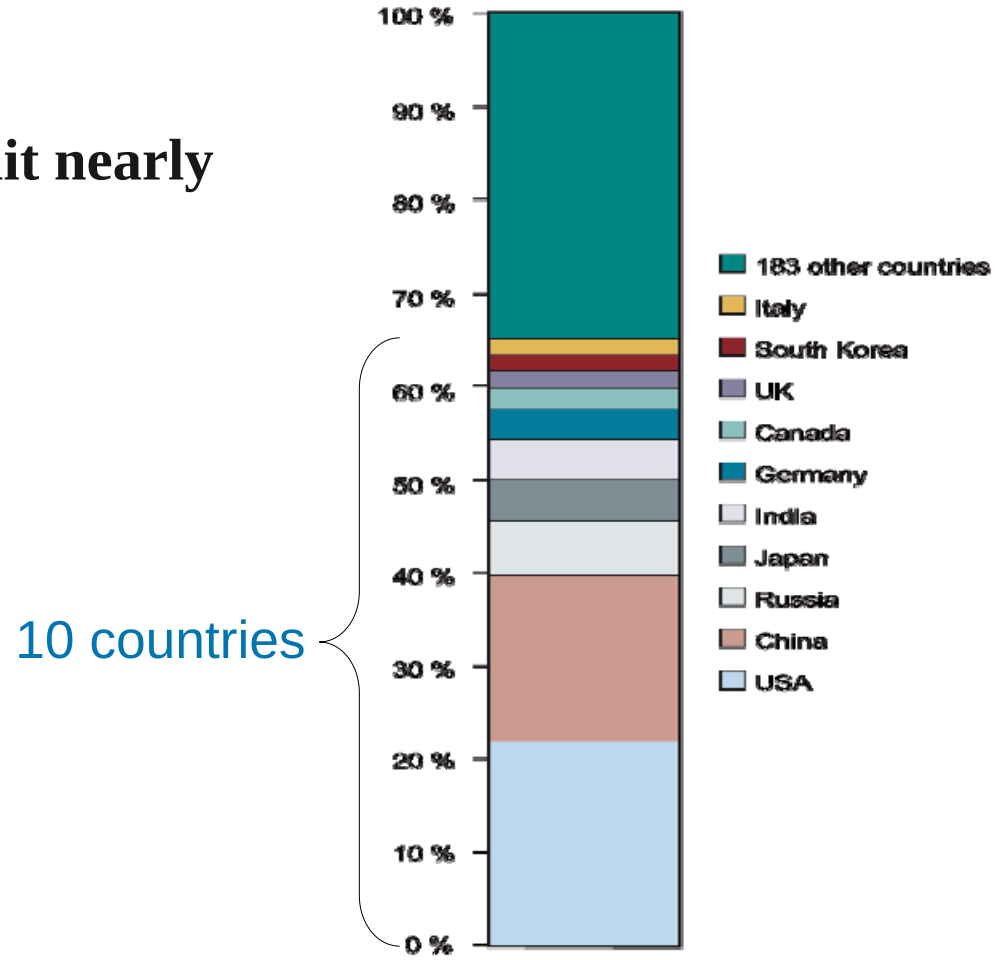

Illustration source: Freund, Kaarstad "Keeping the Lights on", Universitetsforlaget, 2007

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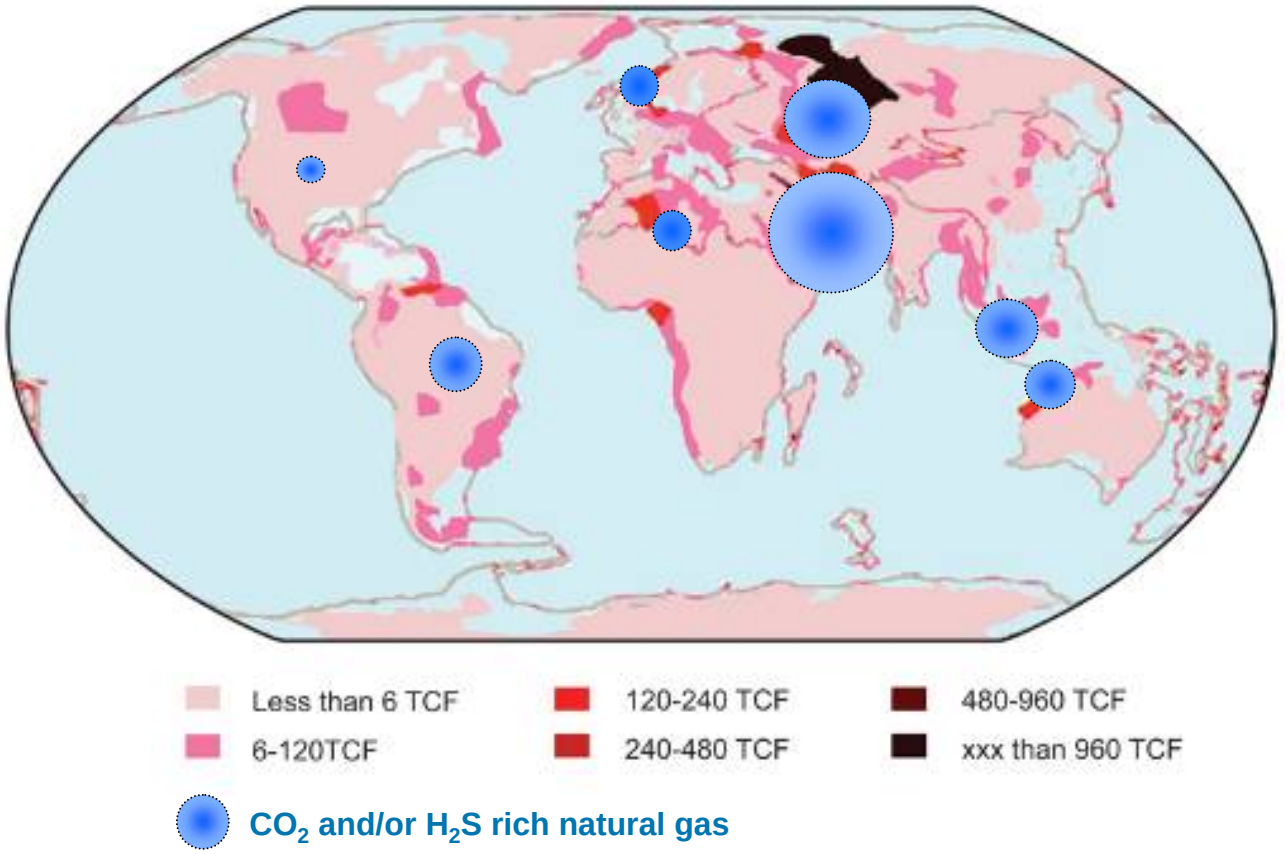
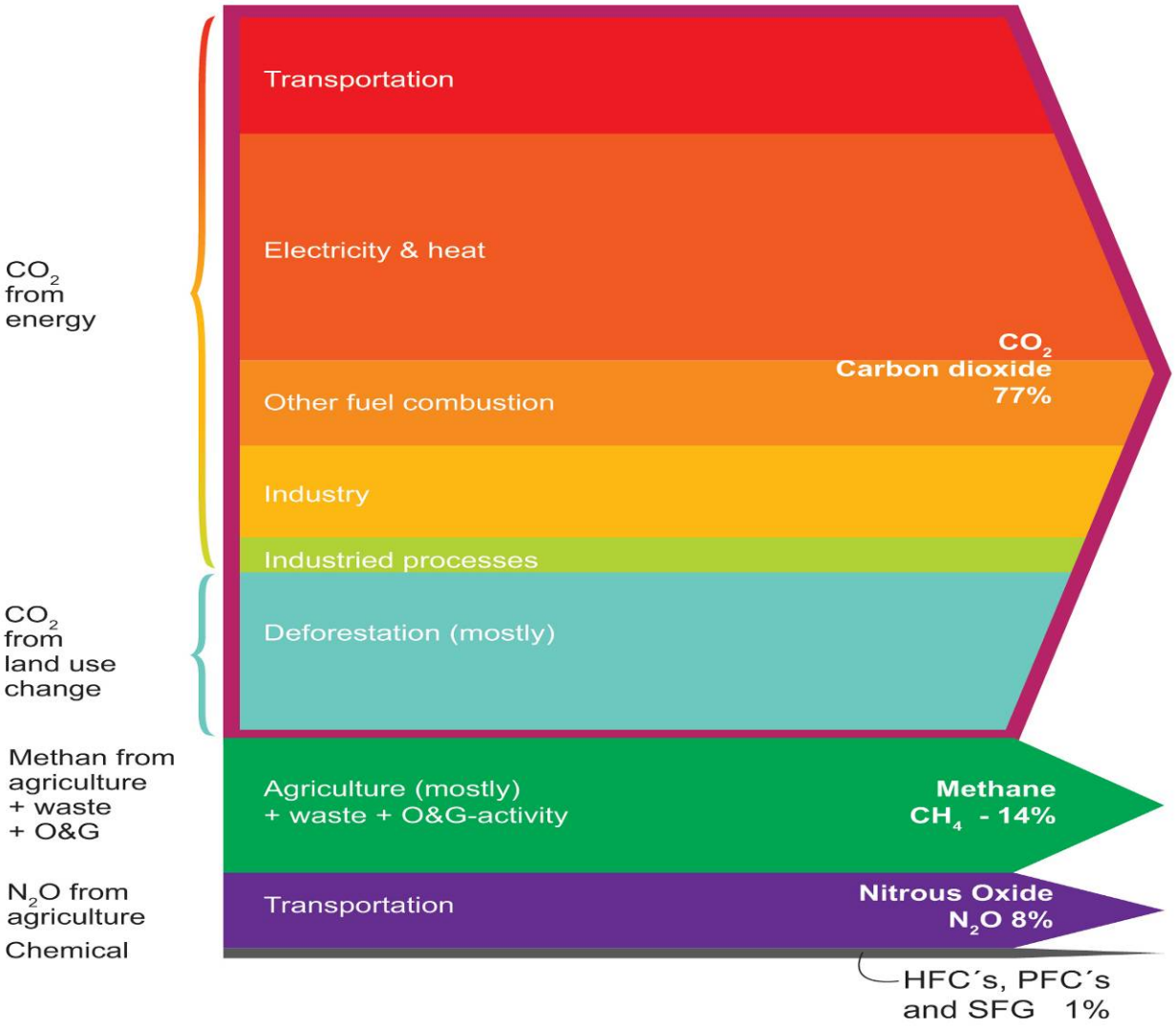
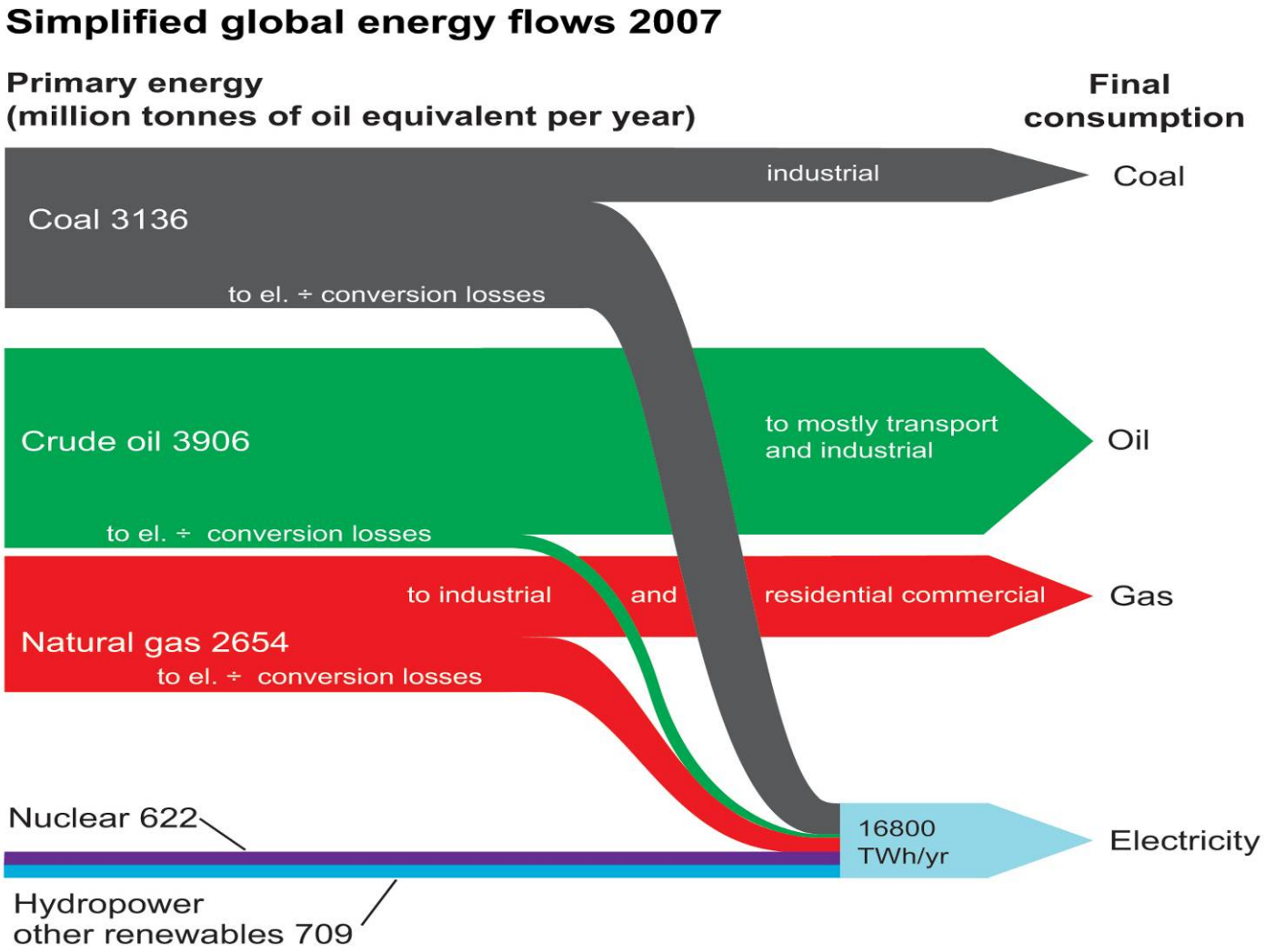
Background → bringing CO_2-rich natural gas to market
- Perhaps 40-50 % of remaining gas reserves have too high content of CO_2/H_2S



Simplified World GHG Emission Flow Chart

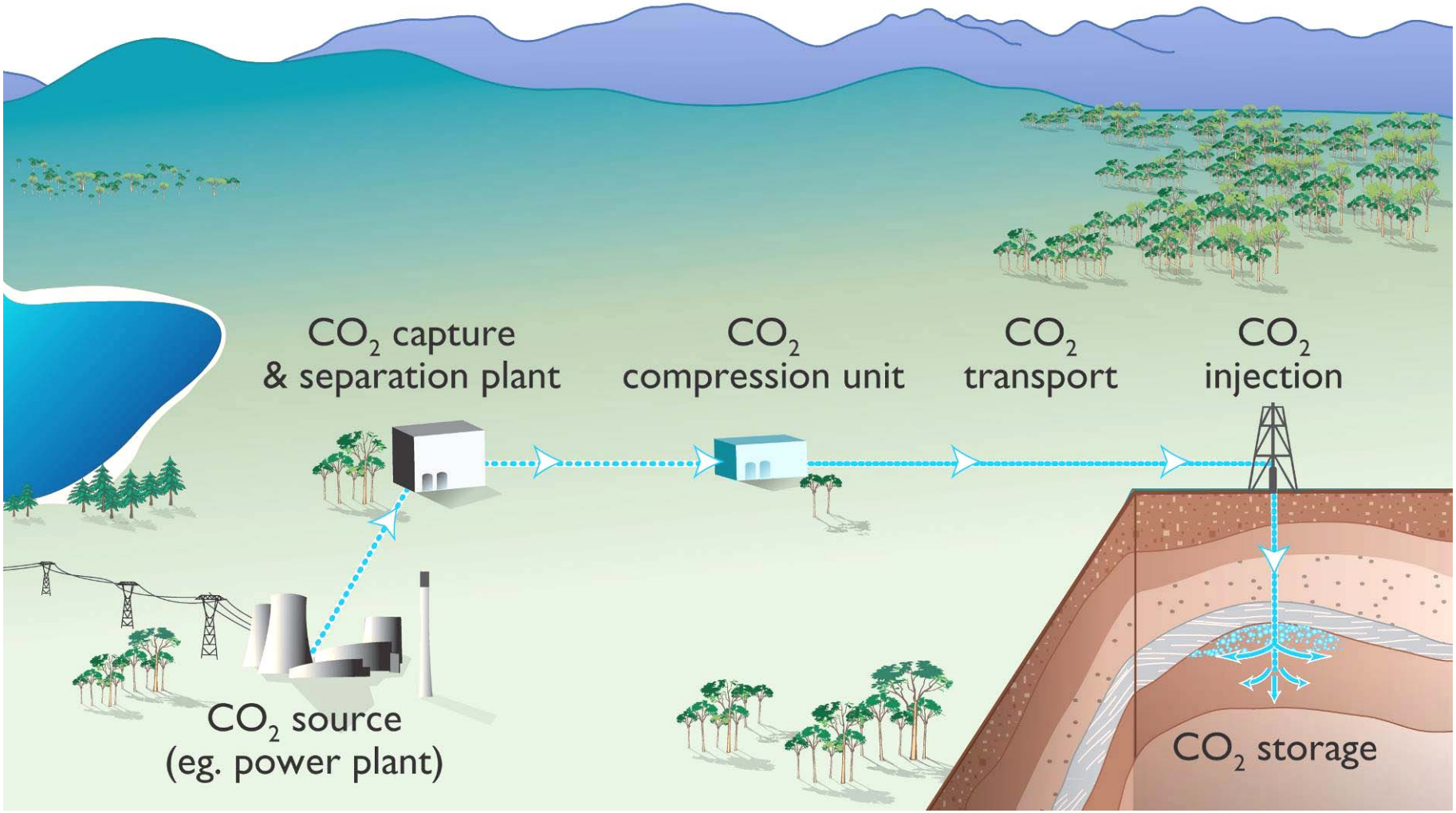


Not only coal, but also oil and gas to be seen as candidates for CCS



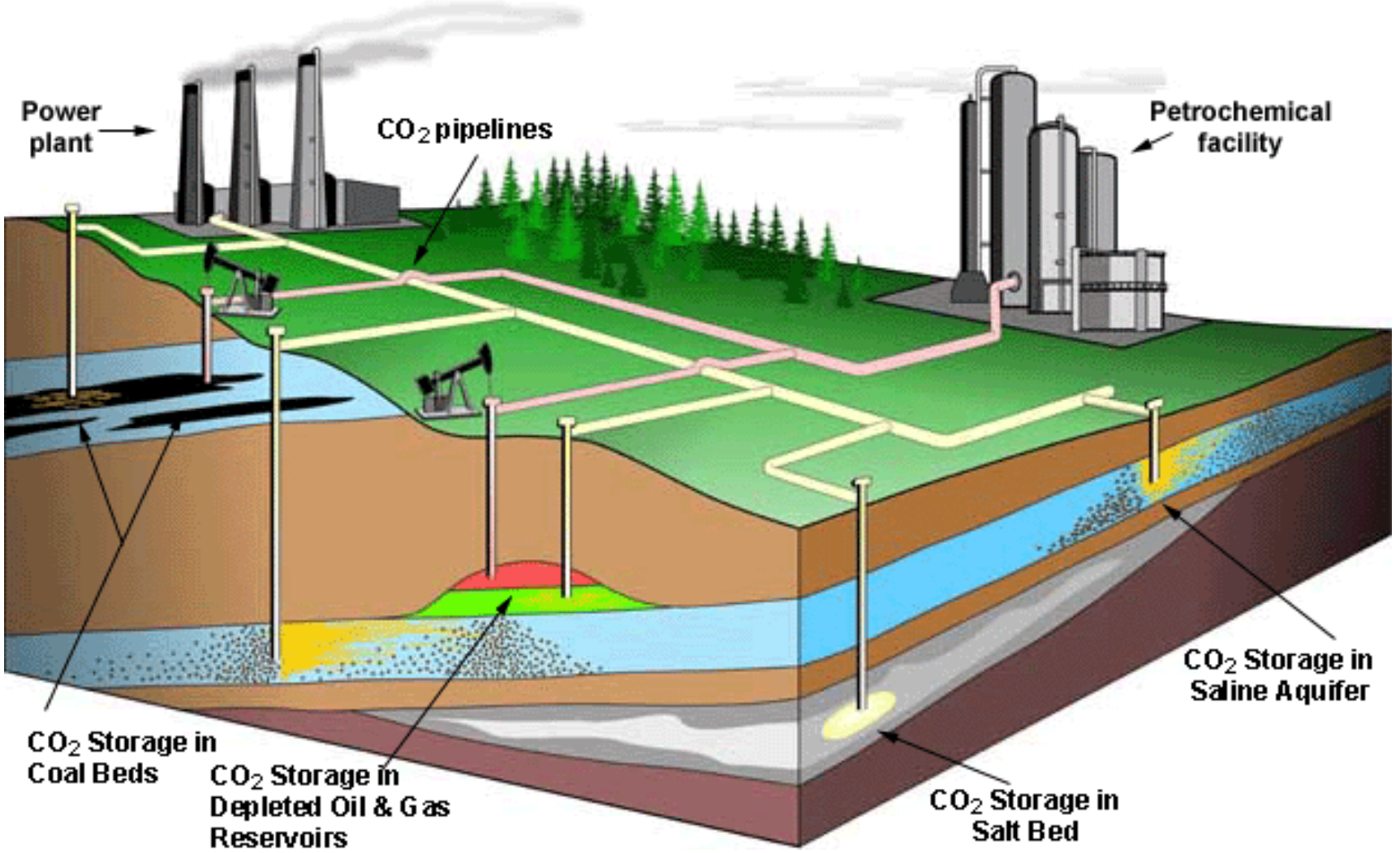
What is CCS?

What is carbon capture and storage?



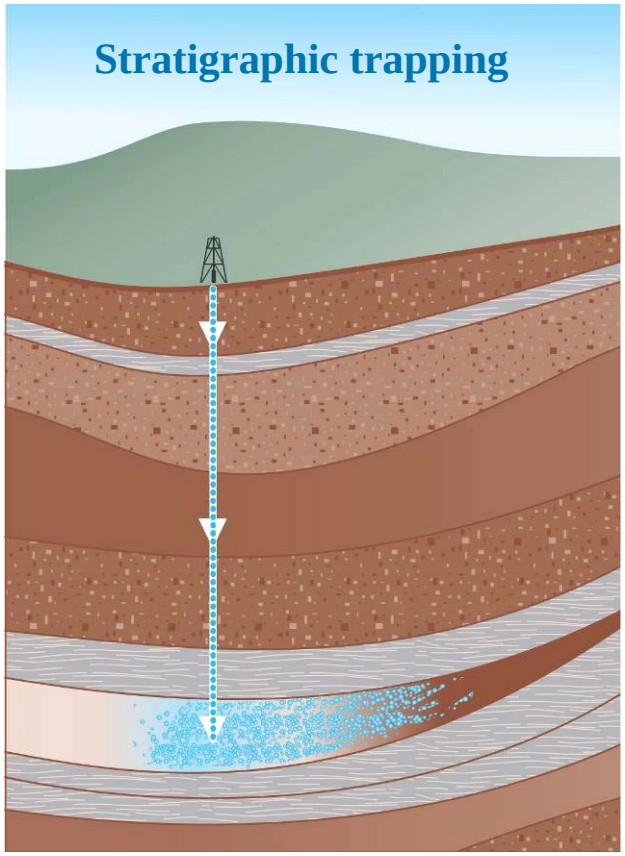
Source: CO2CRC, Australia

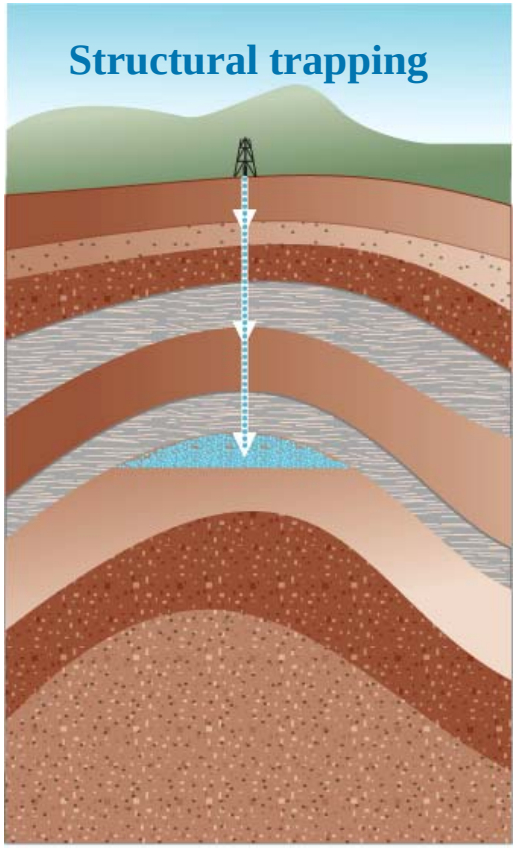
Types of storage reservoirs for CO_2 (1)



Source: Natural Resources, Canada

Types of storage reservoirs for CO_2 (2)





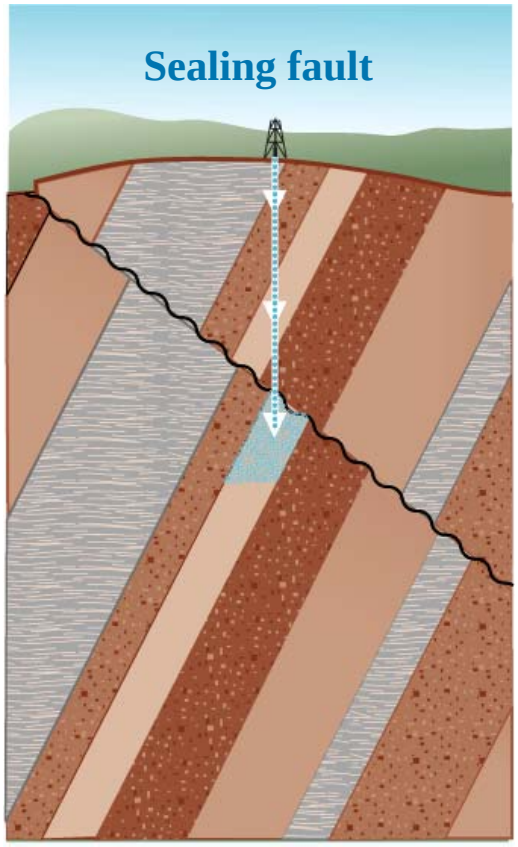
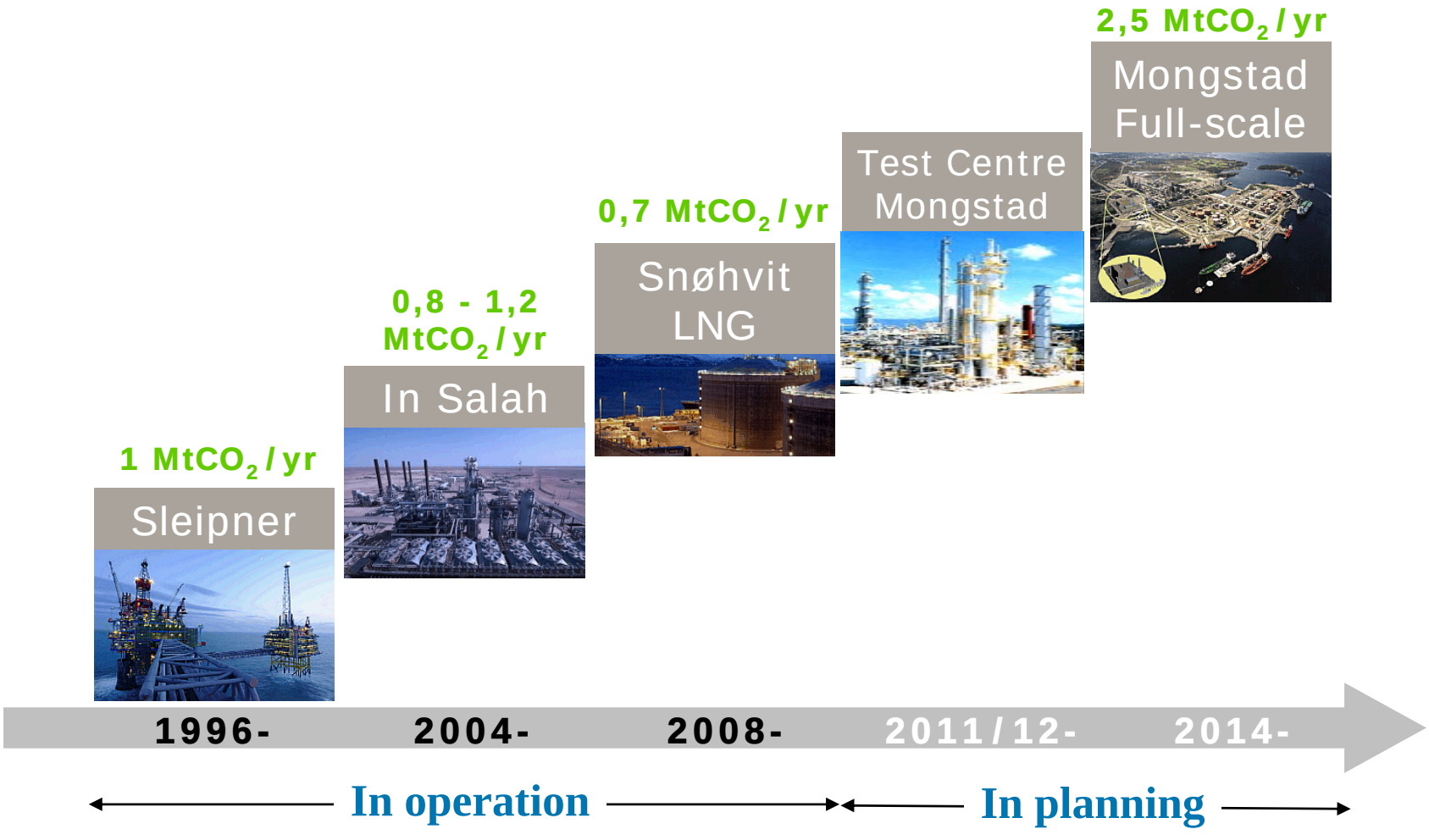


Image source: CO2CRC, Australia

StatoilHydro and CCS;
– operating and cooperating 3 out of 4 of the world large CCS projects



Natural analogues for underground storage of CO_2; - pure CO_2-reservoirs & CO_2-rich natural gas reservoirs

Source: IPCC SRCCS, 2005

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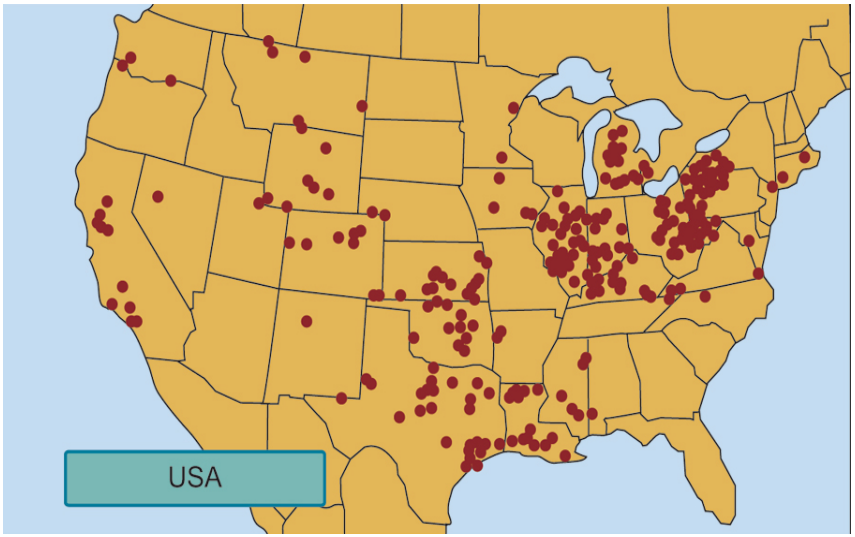
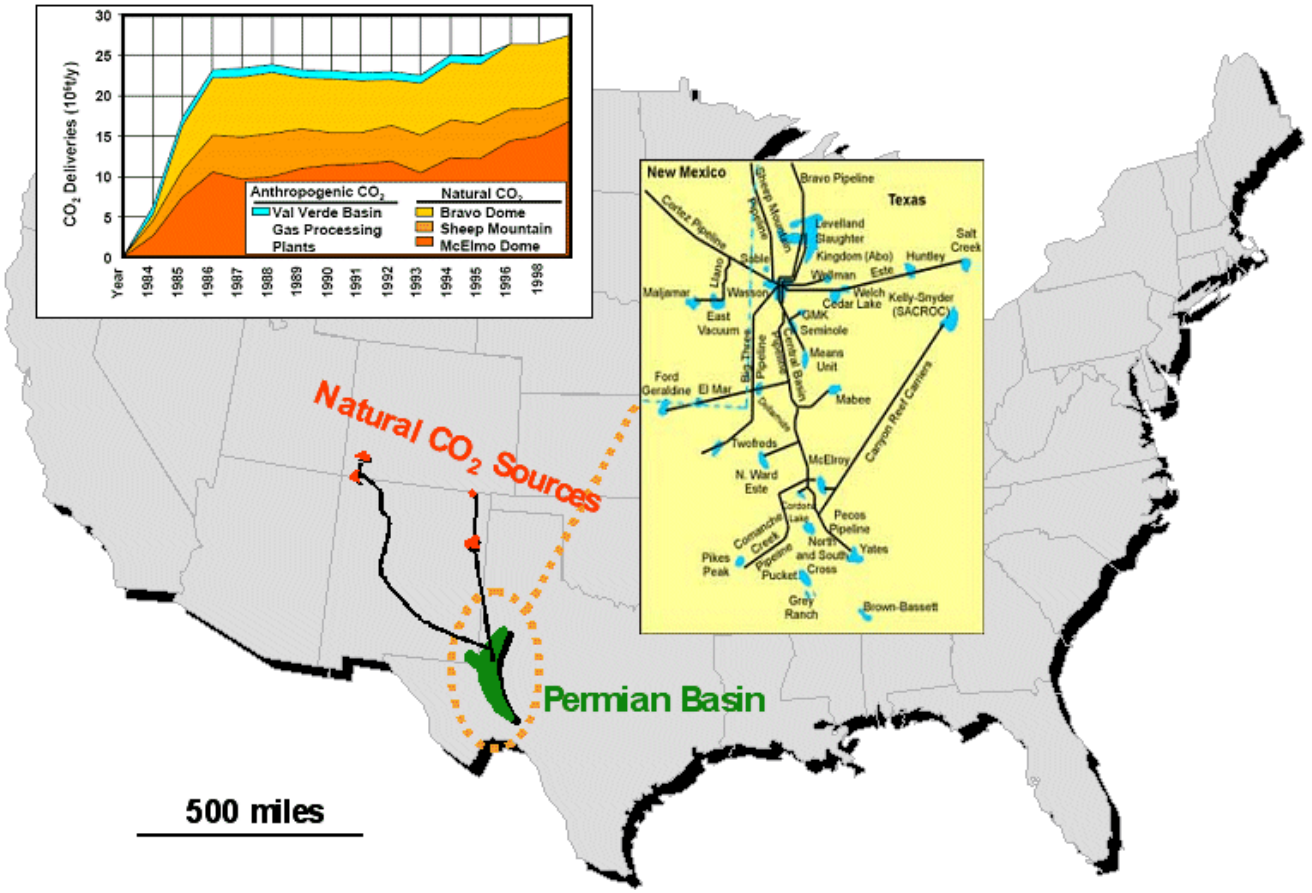
Man-made analogues for underground storage of CO_2 (1); - experience from 632 natural gas storage in geo-formations



Source: IPCC SRCCS, 2005

Man-made analogues for underground storage of CO_2 (2); → naturally occurring CO_2 used for enhanced oil recovery in USA



Source: IPCC SRCCS, 2005

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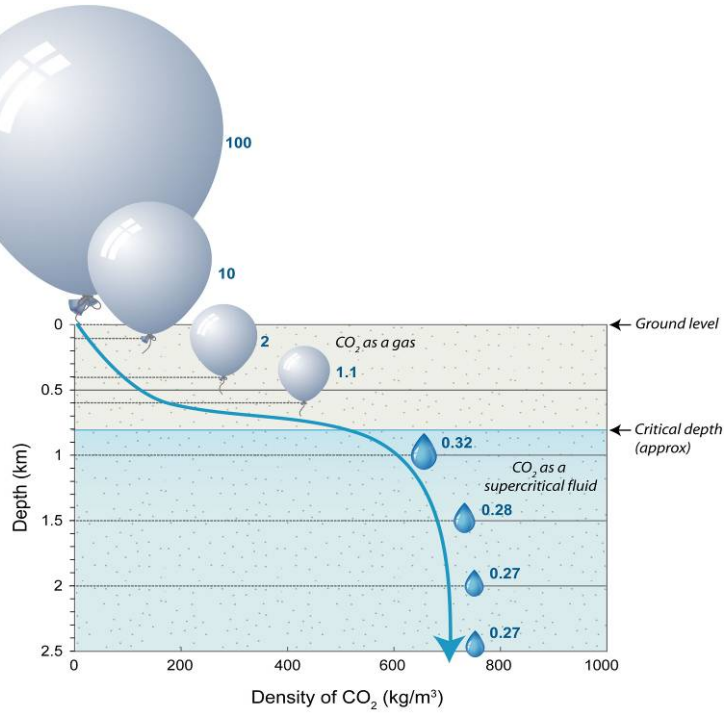
Storage safety

- **Left: The density of CO_2 increases greatly with increasing depth in the subsurface. Below around 800 meter CO_2 will normally be in the supercritical (dense) phase**
- **Right: Several trapping mechanisms works to make CO_2-storage safer over time as indicated by the dotted line**



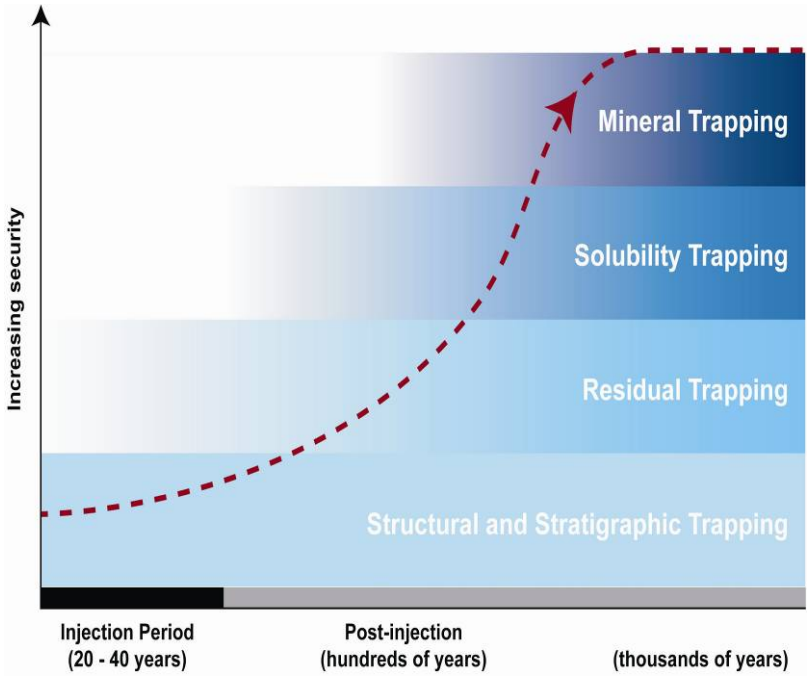


Illustration source: CO2CRC and IEA GHG

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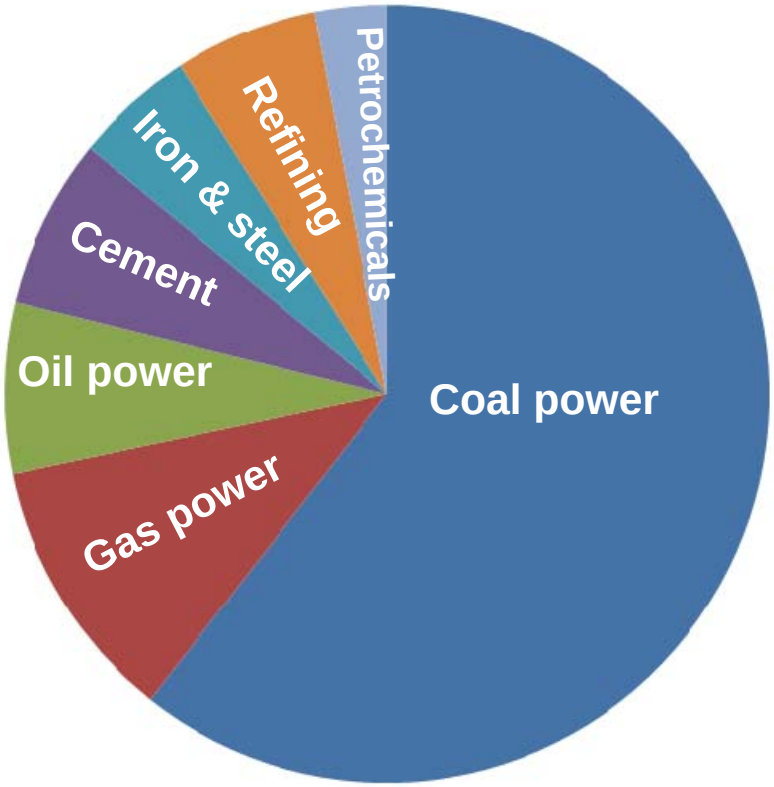
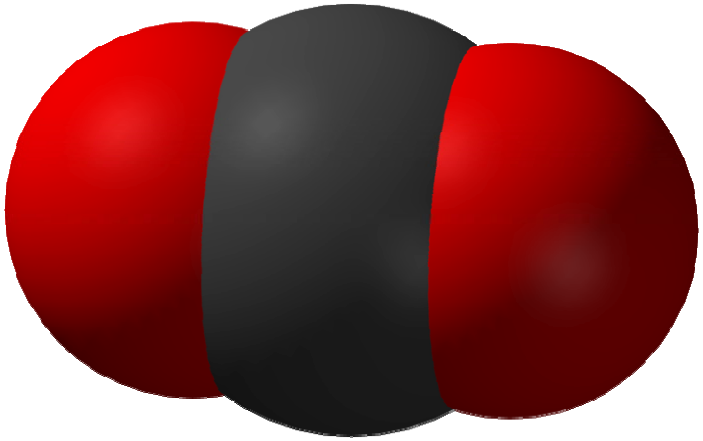
The scale of the global CCS challenge
- About 7500 large point sources in industry



- Coal power generation ~60%
- Gas power generation ~11%
- Fuel oil power generation ~7%
- Cement production ~7%
- Iron and Steel ~5%
- Oil Refineries ~6%
- Petrochemical industry ~3%

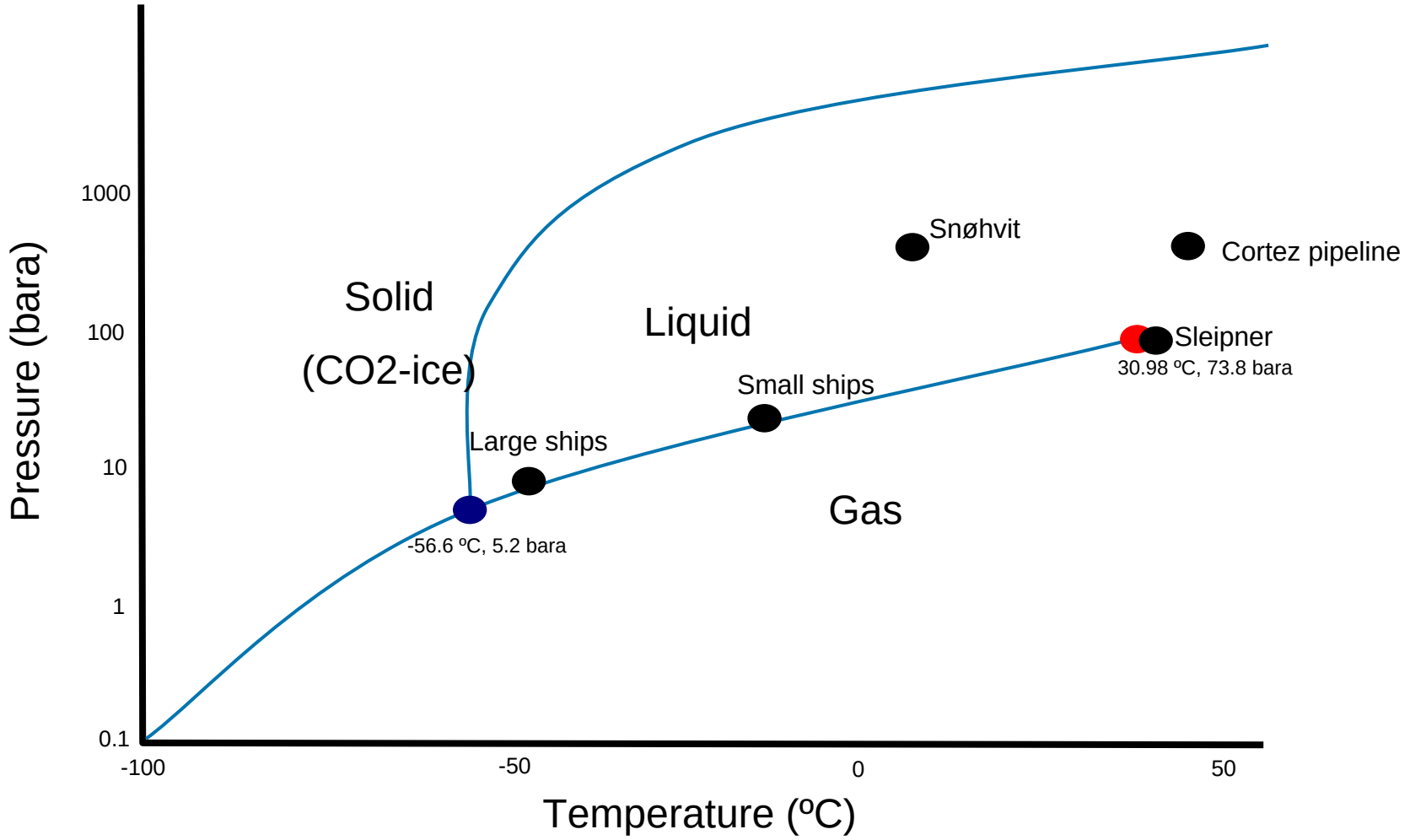
56% of all man-made CO_2-emissions

** Point sources larger than 0,1 million tons/yr CO_2*

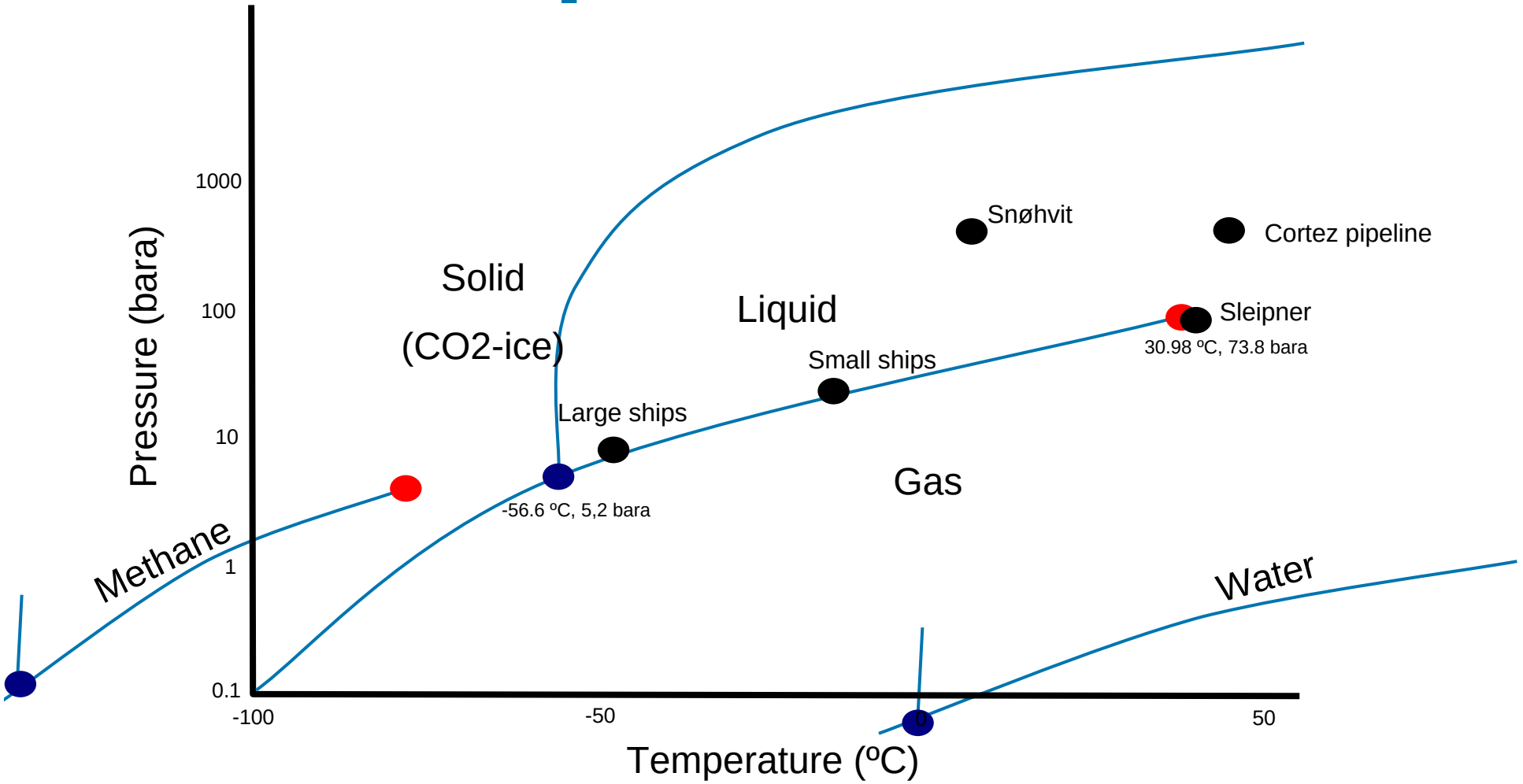


Transportation and capture of CO_2 where are we now? What is in store for the future?

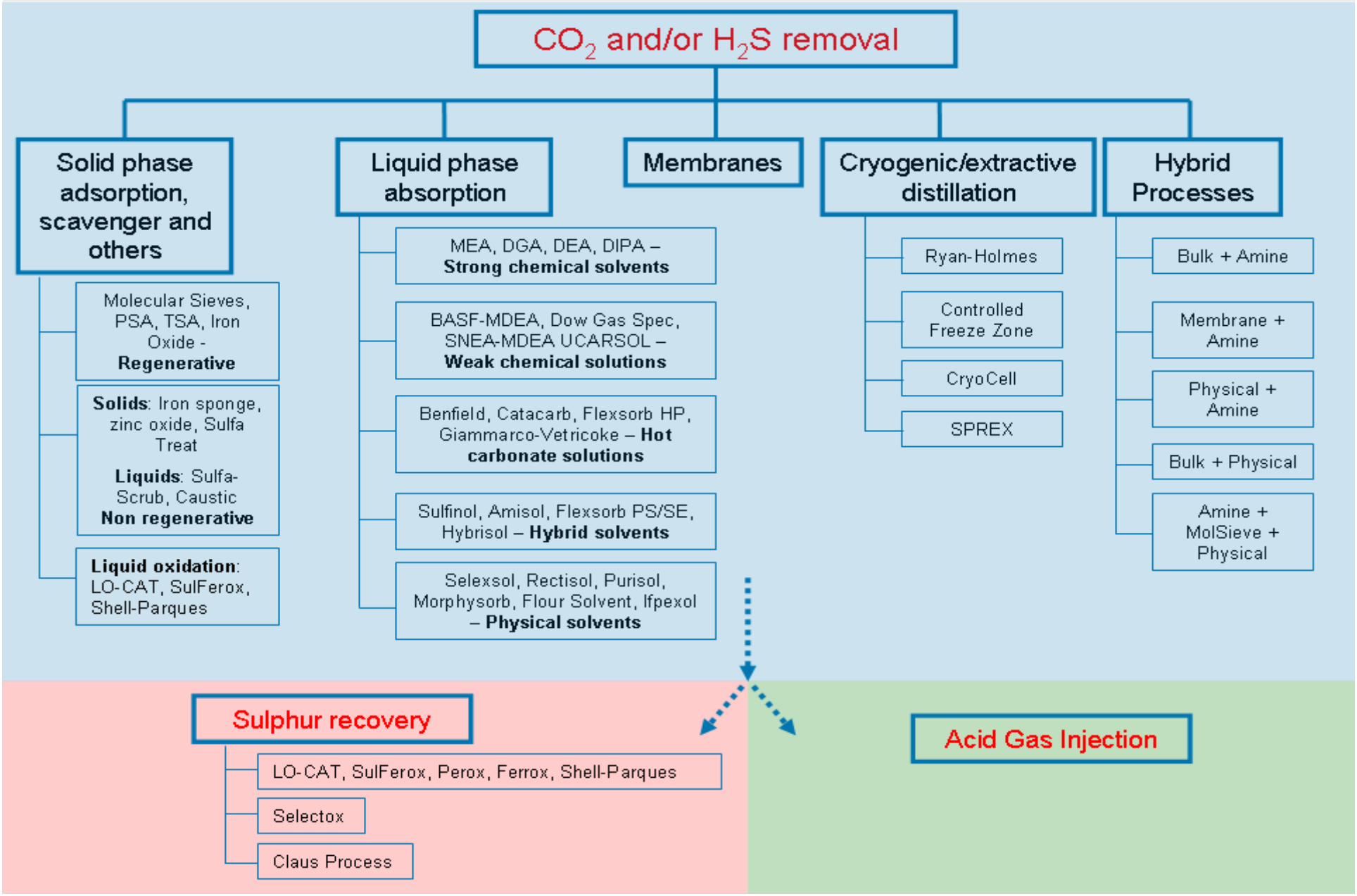
CO_2- phase diagram



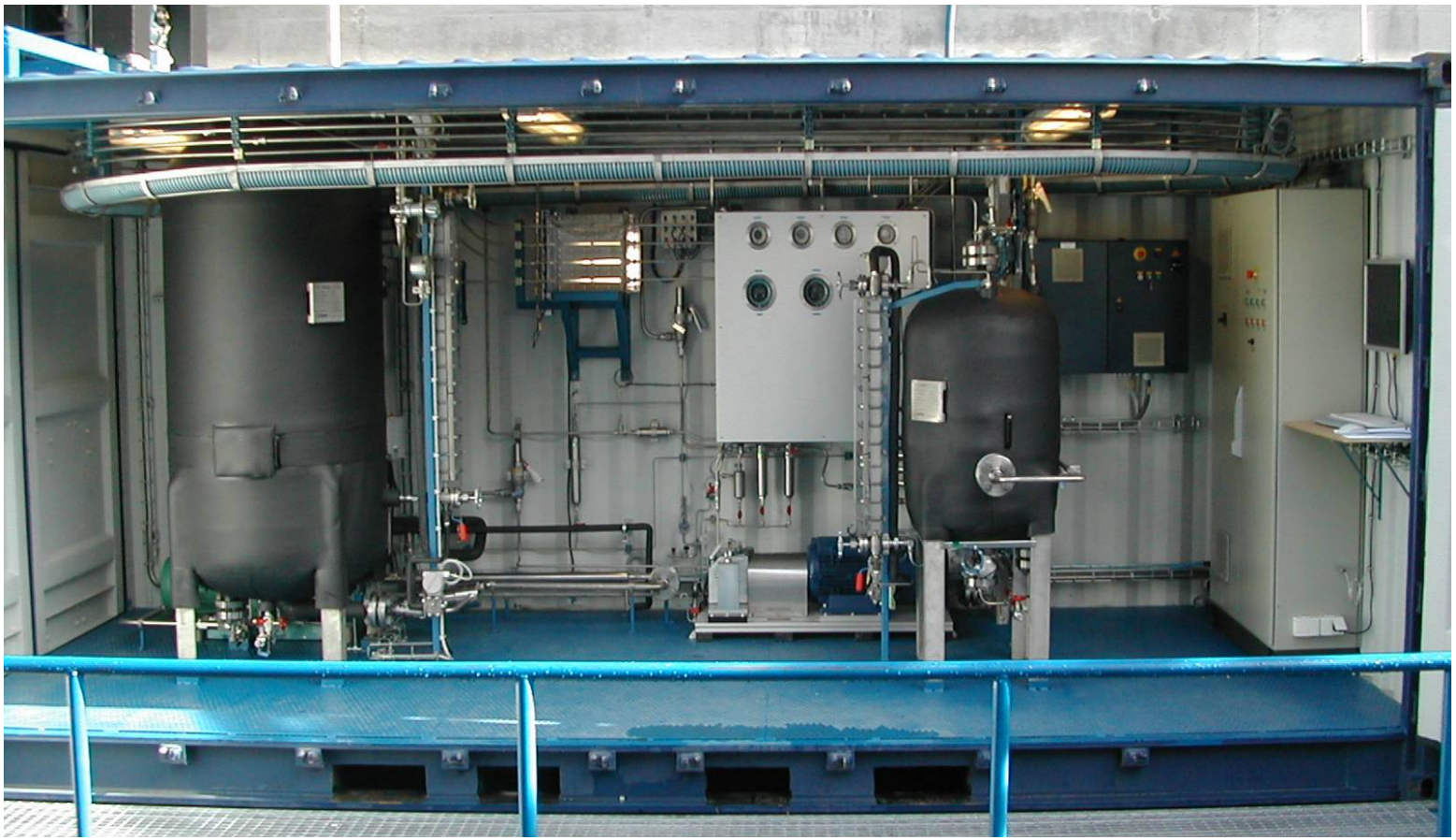
CO_2- phase diagram – while H_2O og CH_4 are mostly outside the operating envelope, CO_2 is often in the middle of it



An indicative guideline for CO_2 (and H_2S) removal from natural gas → no single solution…all cases have to be tailor made



Test rig for CO_2-transport at StatoilHydro R&D



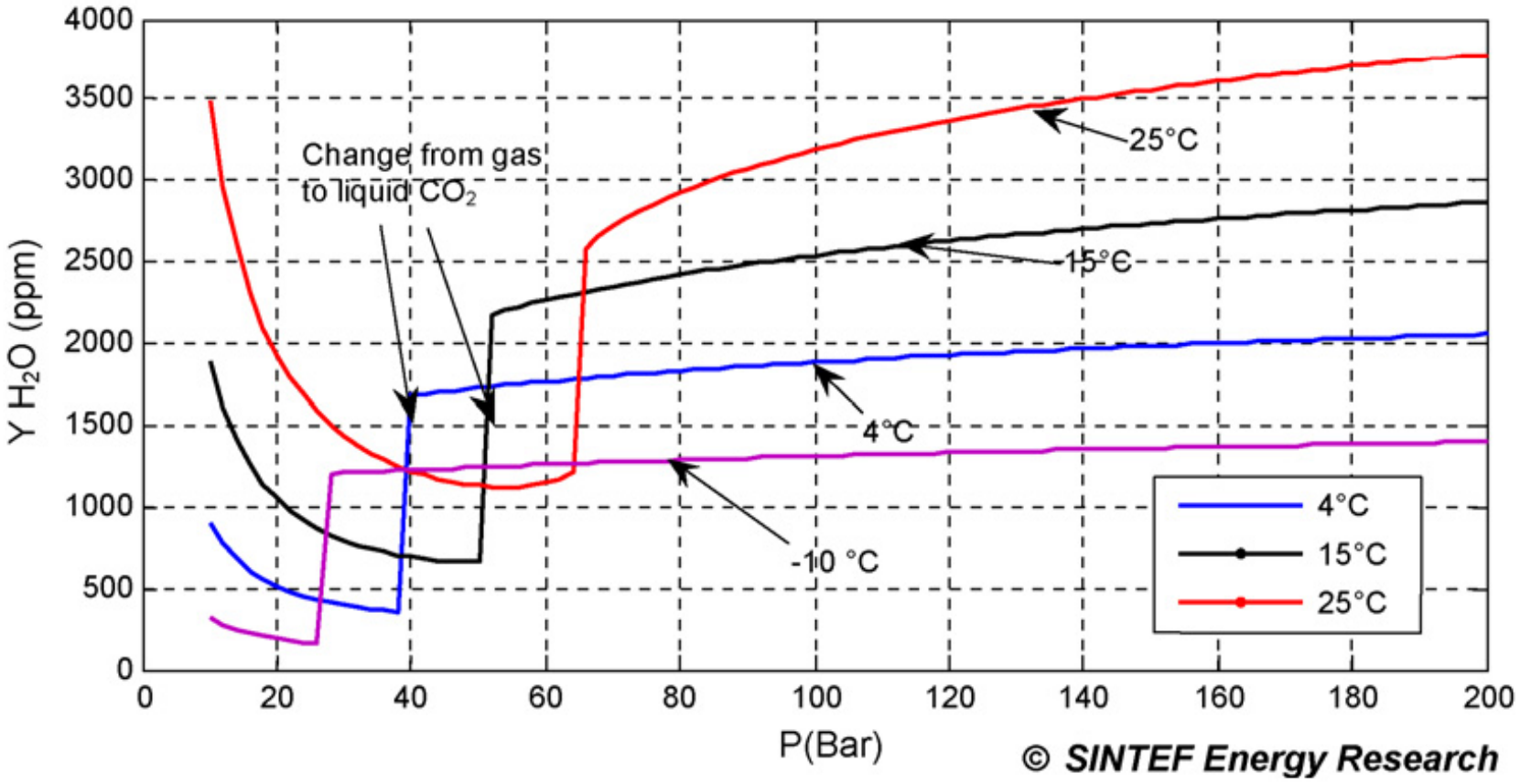
LP-tank: 1.0 m³, 100 bar

HP-tank: 0.2 m³, 160 bar

Testloop: ID=10 mm, L=139 m

Flow capacity: 10 kg/min

Solubility of water in CO_2



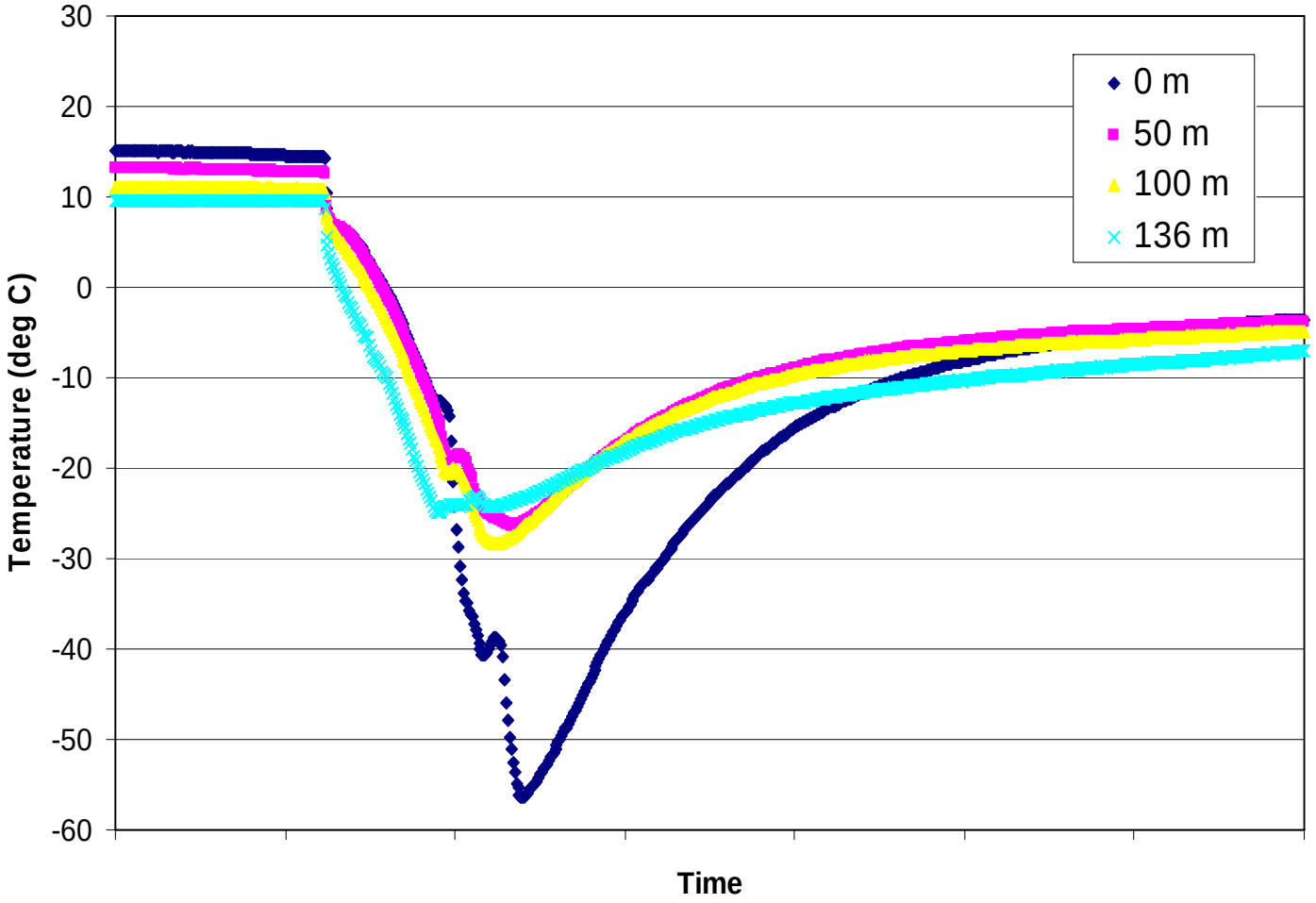
Impurities in the CO_2 to be transported and stored can cause large discussions

Table 3 – DYNAMIS CO_2 quality recommendation

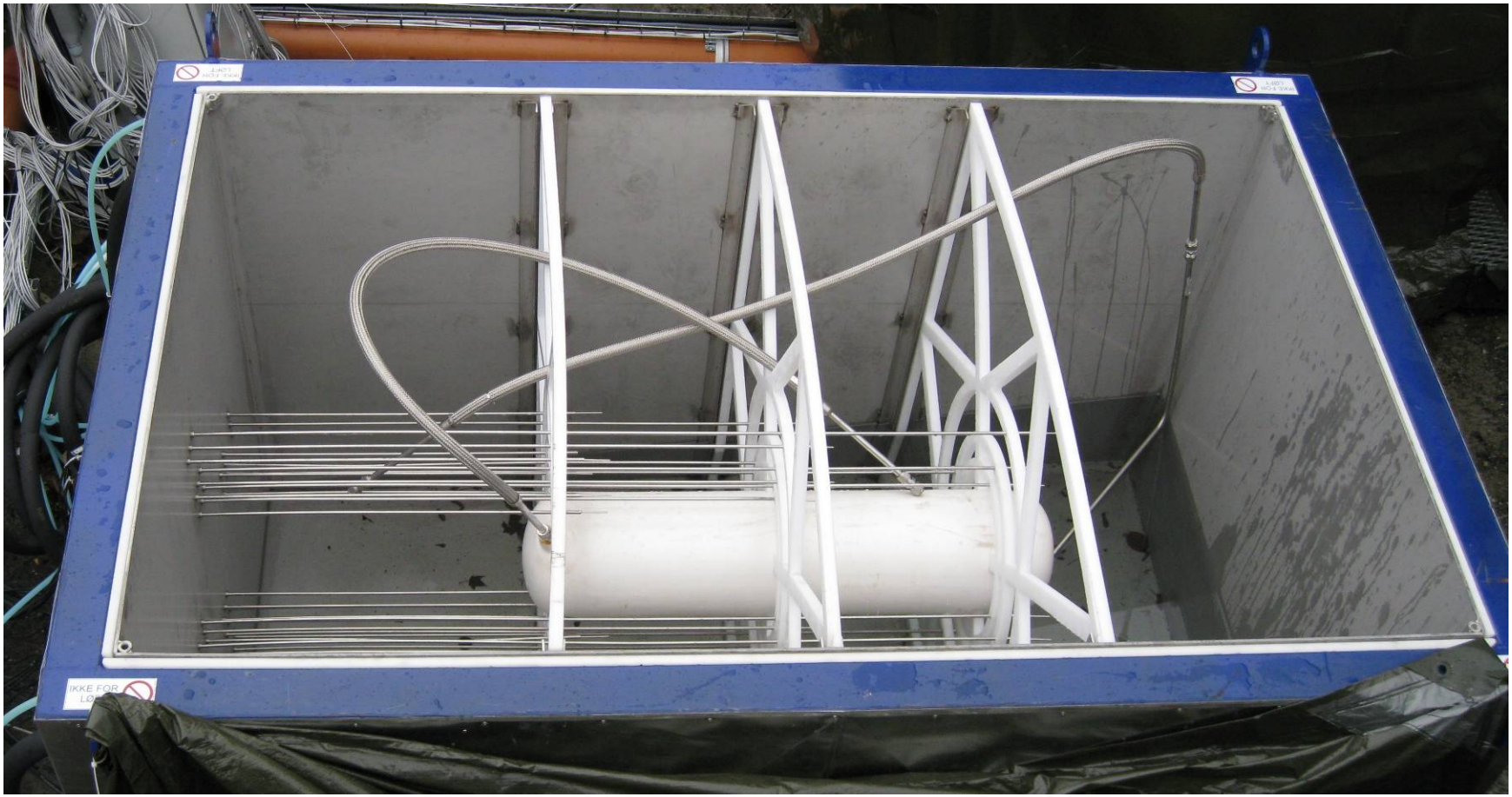
Component	Concentration	Limitation
H_2O	500 ppm	*Design and operational considerations*
H_2S	200 ppm	*Health and safety considerations*
CO	2000 ppm	*Health and safety considerations*
CH_4	Aquifer < 4 vol.%, EOR < 2 vol.%	As proposed in ENCAP project
N_2	<4 vol.% (all non-condensable gasses)	As proposed in ENCAP project
Ar	<4 vol.% (all non-condensable gasses)	As proposed in ENCAP project
H_2	<4 vol.% (all non-condensable gasses)	Further reduction of H_2 is recommended, because of its energy content
CO_2	>95.5%	Balanced with other compounds in CO_2

Recommendations ≠ Specification ≠ Regulation

Example: Pressure let down in Snøhvit sub-sea CO_2-pipeline



Test rig at StatoilHydro for heat exchange between CO_2-pipeline and sea-bed sediments

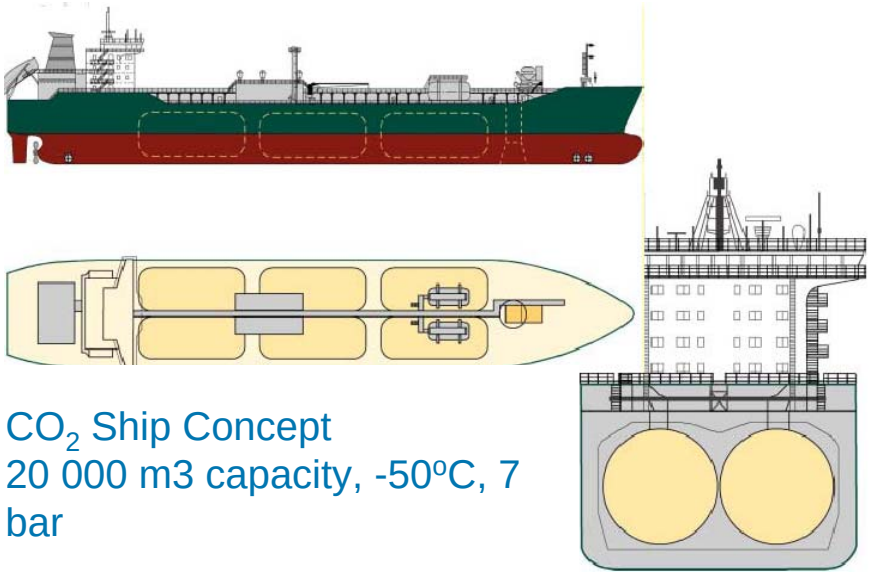


Ship vs pipeline for CO_2

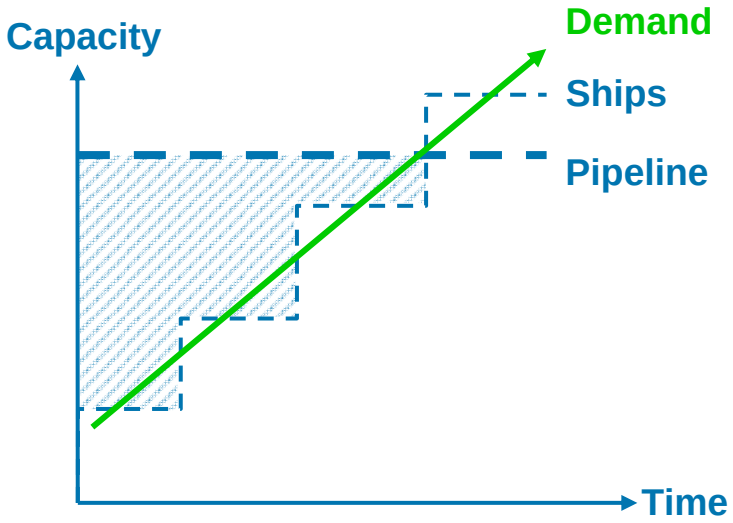
- **Large pipelines is the most economic method**

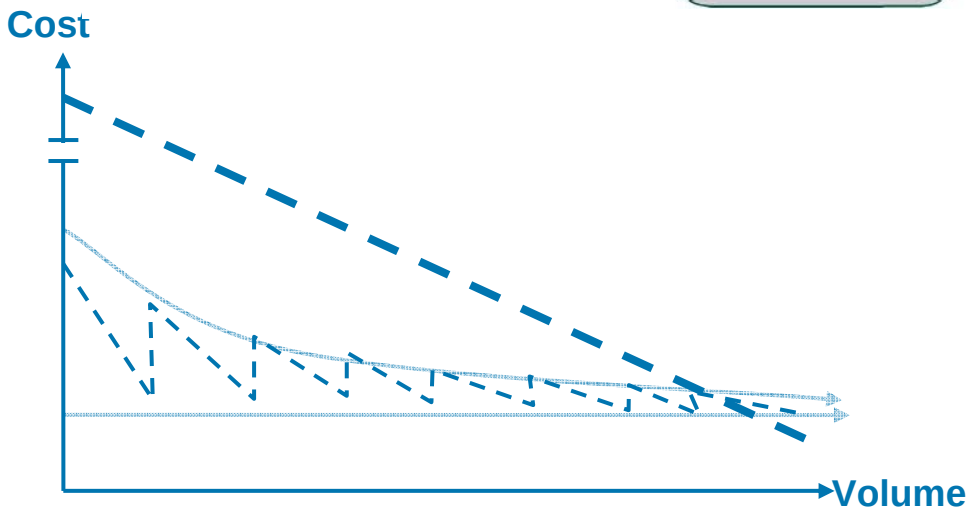
for CO2 transport

- **But ship capacity can easily be adjusted**
- **to meet capacities and destinations**



CO_2 Ship Concept
20 000 m3 capacity, -50°C, 7 bar





The most important elements in CO_2-transportation

- Transportation: Pipeline is one opportunity, ships another
- Some experience with onshore pipelines for CO2 in USA and Canada
- The StatoilHydro operated 150 km Snøhvit CO_2-pipeline is so far the only sub-sea case
- Pressure-enthalpy diagrams are useful tools for success for along the whole CO2-chain
- Heat transfer from sea/seabed sediments important aspect of depressurisation
- The issue of impurities (methane, N2, H2O etc.) in CO2 is very important along the whole chain
- Control of water in CO2 is very important

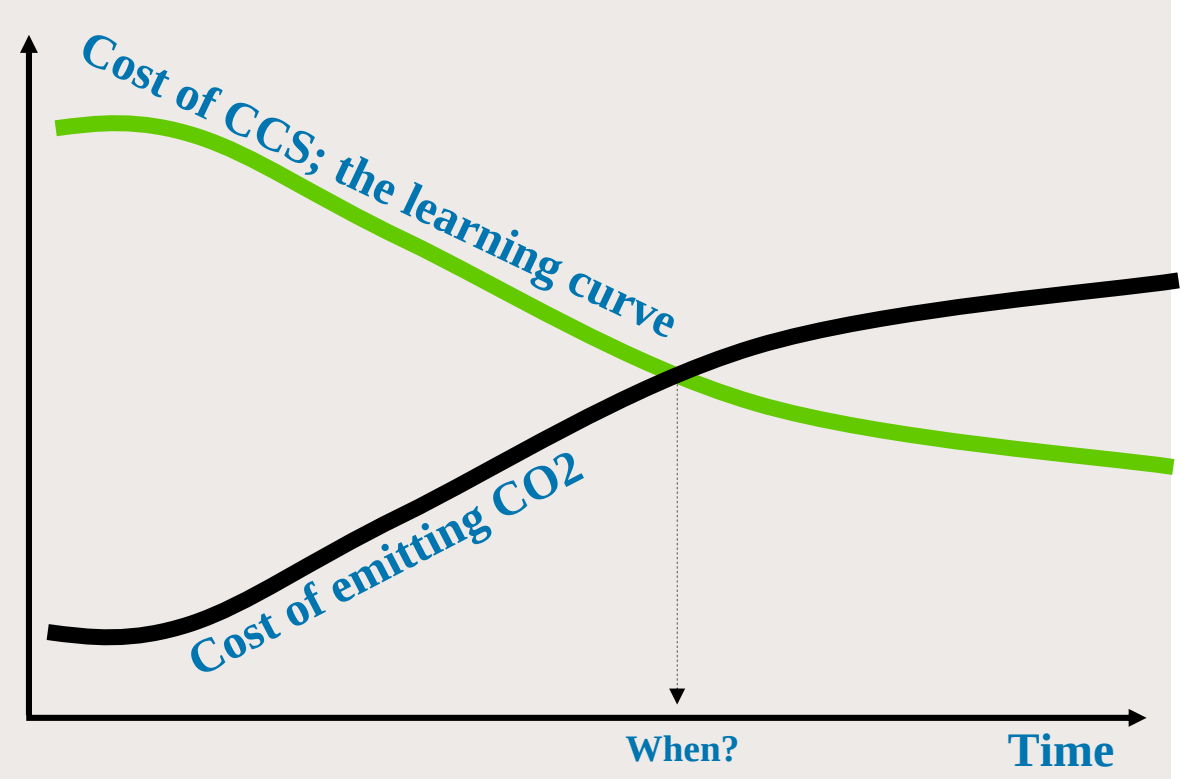
Challenges and opportunities:

What are the incentives?
…and disincentives?

Economics will decide speed and volume of CCS-deployment - but early deployment needs special mechanisms

Fill this early cost-gap through:

- -Kyoto-mechanisms, EU ETS +
- -Direct gov. subsidies
- -CO_2-EOR
- -Technology development
- -Emission limitations
- -Undersupply of credits
- -CO2-taxes



Example 1
→ EU wide financing mechanisms for CCS

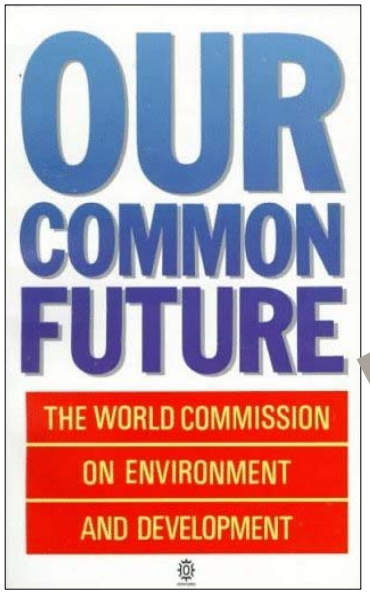
- **The EU Energy package of December 17th, 2008:**
  - **CCS to be an integral part of EU ETS**
  - **The revised EU ETS sets aside 300 million emission allowances for financing CCS demonstration projects. This may equal € 6-9 bn, depending on future allowance prices**

- **The EU economic stimulus package unveiled in January, 2009:**
  - **Carbon capture and storage emerged as one of the big winners in the package with €1,25 bn to partly fund five test projects in germany, the UK, the Netherlands, Spain and Poland**

Example 2

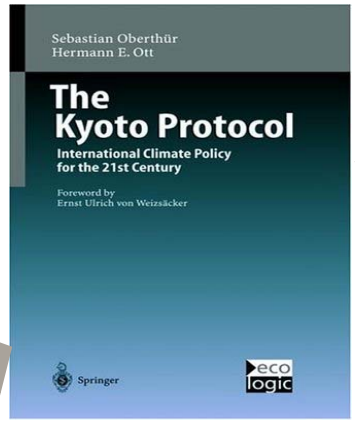
→ Last year was the 20 year Anniversary for “Our Common Future”

→ and it is 18 years since a CO2-tax was introduced in Norway



”The Brundtland Report”, 1987

Norway’s Prime Minister Gro Harlem Brundtland in Rio in 1992 (*)



The Kyoto Protocol, 1997

The Kyoto Protocol ratified, 2005

(*) The Norwegian government introduced a CO2-tax of about 45 $/ton in Norway in 1991

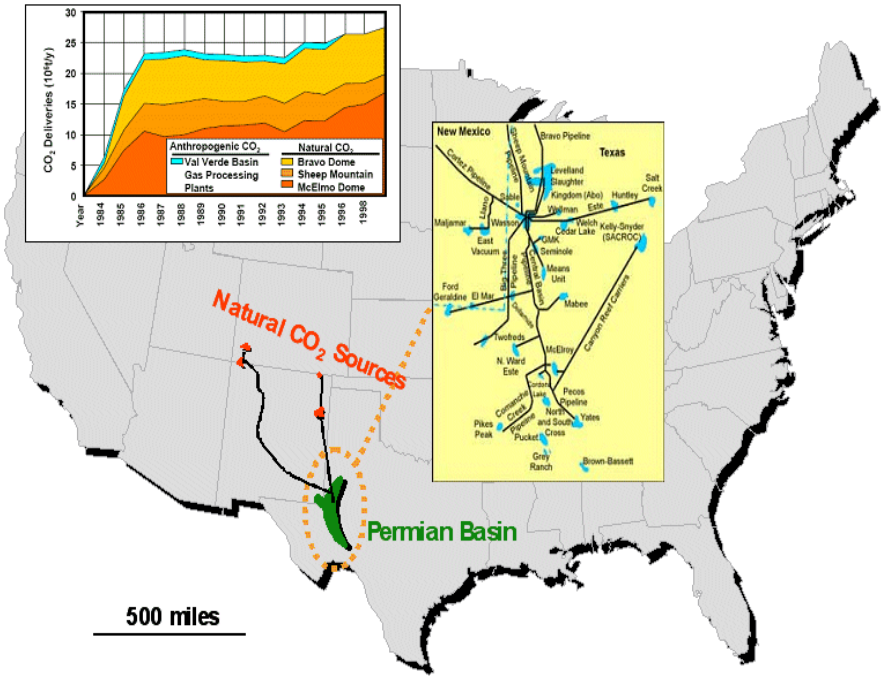
Other existing and possible incentives for CCS

- Existing incentives of several hundred mill $ magnitude in countries like USA, Canada, Australia, Japan and probably others
- The US situation – mostly on “clean coal”: The new 2009 budget bill (recently signed by President Obama) includes:
  - $404 million is included for Coal Research and Development Programs at the National Energy Technology Laboratory (NETL). This program consists of six coal R&D programs on power systems, CCS, hydrogen and clean fuels.
  - Also within the FE R&D program is $288 million for the Clean Coal Power Initiative (CCPI). This brings the total amount for this program which focuses on CCS to $1.5 billion.
- Possible incentives for the future
  - CCS has for a long time tried to be part of the Clean Development mechanism (CDM). So far unsuccessful, but new attempt in Copenhagen in December
- There are ideas for other non-CDM mechanisms in the climate change negotiations that could better suit CCS

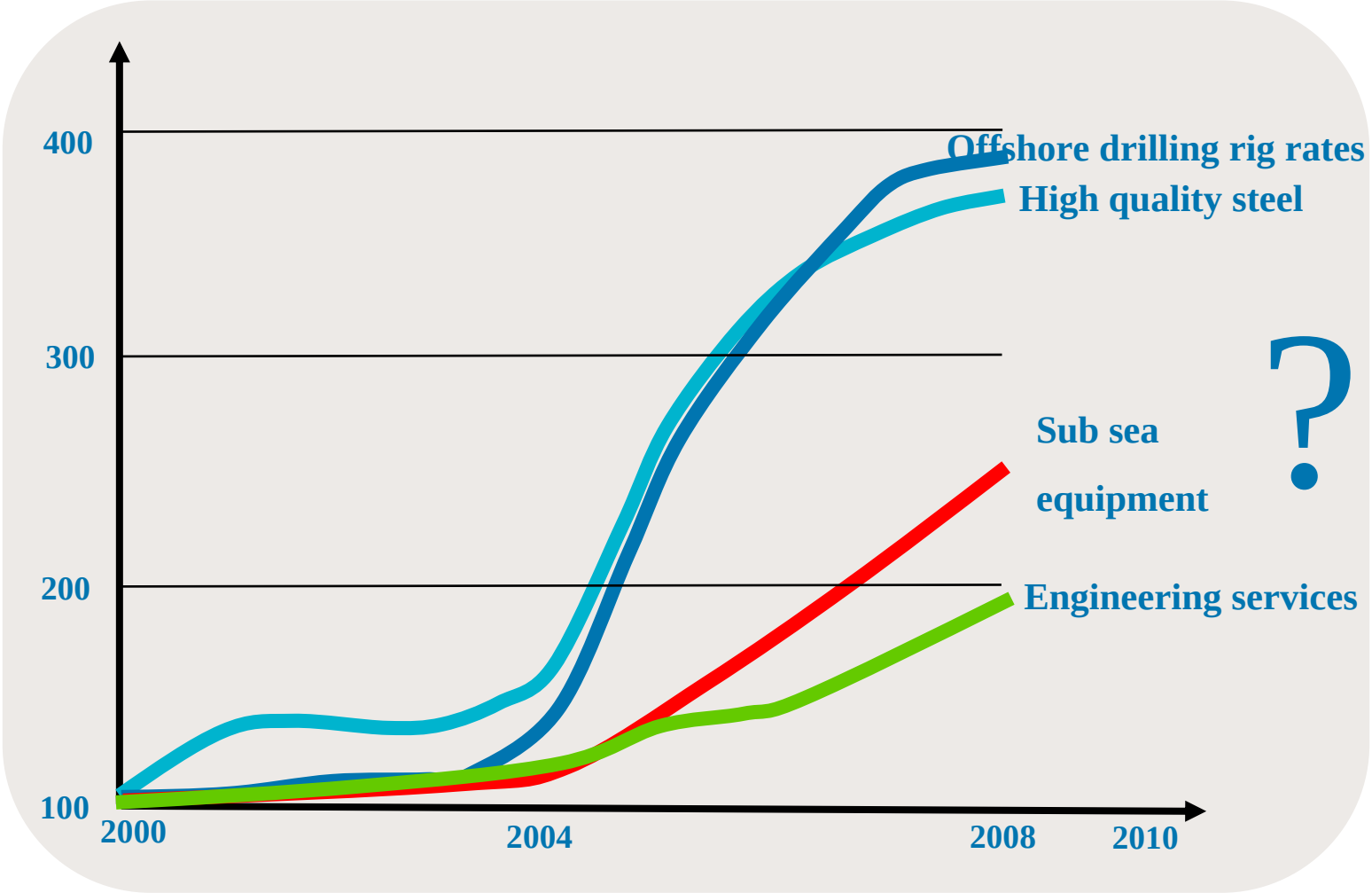
Another "incentive" or opportunity could be CO_2 for enhanced oil recovery → when we have large volumes of CO2 available, CO2-EOR are tempting

Perhaps CO2 in the future could be transported by ship to the places with older, water flooded oil reservoirs in Asia or even to the Middle East?

CO2-EOR today happens in over 80 fields in USA/Canada and also in some other countries

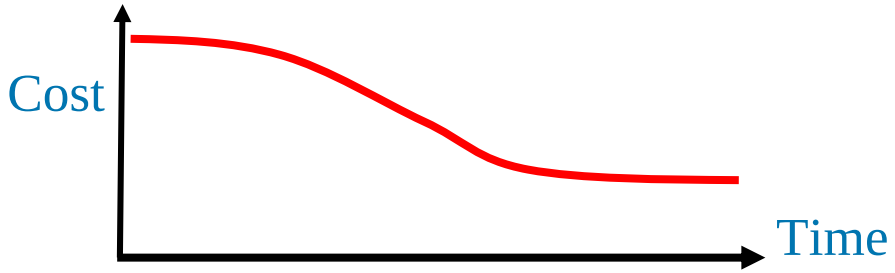


What are the disincentives?
→ CCS highly affected by todays high cost environment



Other disincentives?

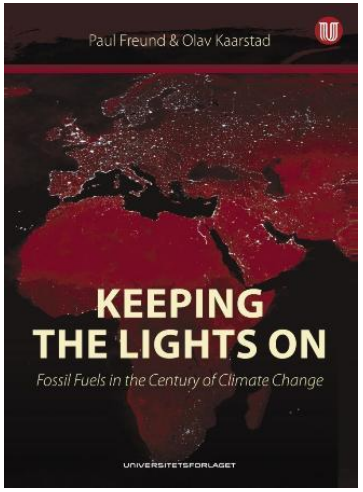
- Legal framework often lacking for such things as
  - Licensing of storage acreage
  - With whom rests the liability for storage after the injection period
  - Criteria for approving a new storage site, for monitoring and verification etc.
  - Pipelines crossing national borders on land or sub-sea
- Technology
  - For CO2-rich natural gas the removal and CO2-handling technology is there to a large extent, but we need to progress on the learning curve towards less costly processes

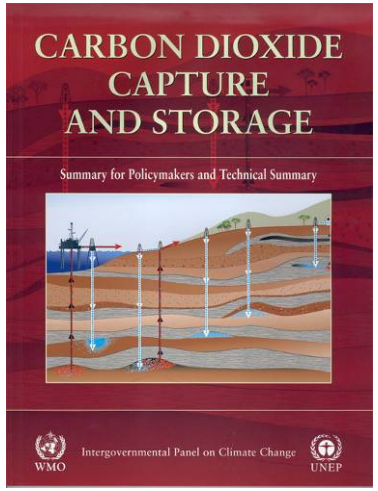


Roles for government & industry
How can they work together?

Some examples of cooperation (both carrot and stick)

- Norway
  - The CO2-tax made CCS at the Sleipner and Snøhvit fields commercially viable
  - A very high level of research and testing effort co-financed by government and industry. Education at university level part of this picture
  - Almost 100% government funding of some CCS-projects (e.g. Mongstad)
  - An open and consultative approach between parties involved in CCS
  - also voluntary agreements between government on funds to reduce SO2- and NOx-emissions
  - Environmental NGOs have played a very (positively) pushing role wrt. CCS
- European Union
  - Started out with large R&D programmes in the CCS-sector that after some time transformed into policy, legislation, finances
  - Large sums will be made available from the emission trading system for CCS-projects in the private sector
  - Enabling legislation was seen as one of the keys
  - Environmental NGOs in Europe are partly supportive to CCS, some very negative





Summary and conclusions

CO_2-capture, -transportation and –storage (CCS)

- **Likely that the natural gas and oil industry will continue pioneering CCS for years, but we need to improve our ability to tackle high-CO2 natural gas**
- **CCS one of five important climate solutions → but there are no single silver bullets in climate mitigation**
- **Making CCS happen is difficult under any circumstances (cost-boom, low CO_2-prices, regulations ++)**

- **Frameworks**
  - **Globally there is a general lack of enabling financial or legal frameworks directed towards CCS**
  - **Financial mechanisms are, however coming into place in some regions and countries**
  - **CCS is not allowed within the Clean Development Mechanism (CDM) at present**