CCS Technology across the Capture / Transport / Storage Chain

by

Dr Magnus Melin

The LRET Research Collegium
Southampton, 11 July – 2 September 2011

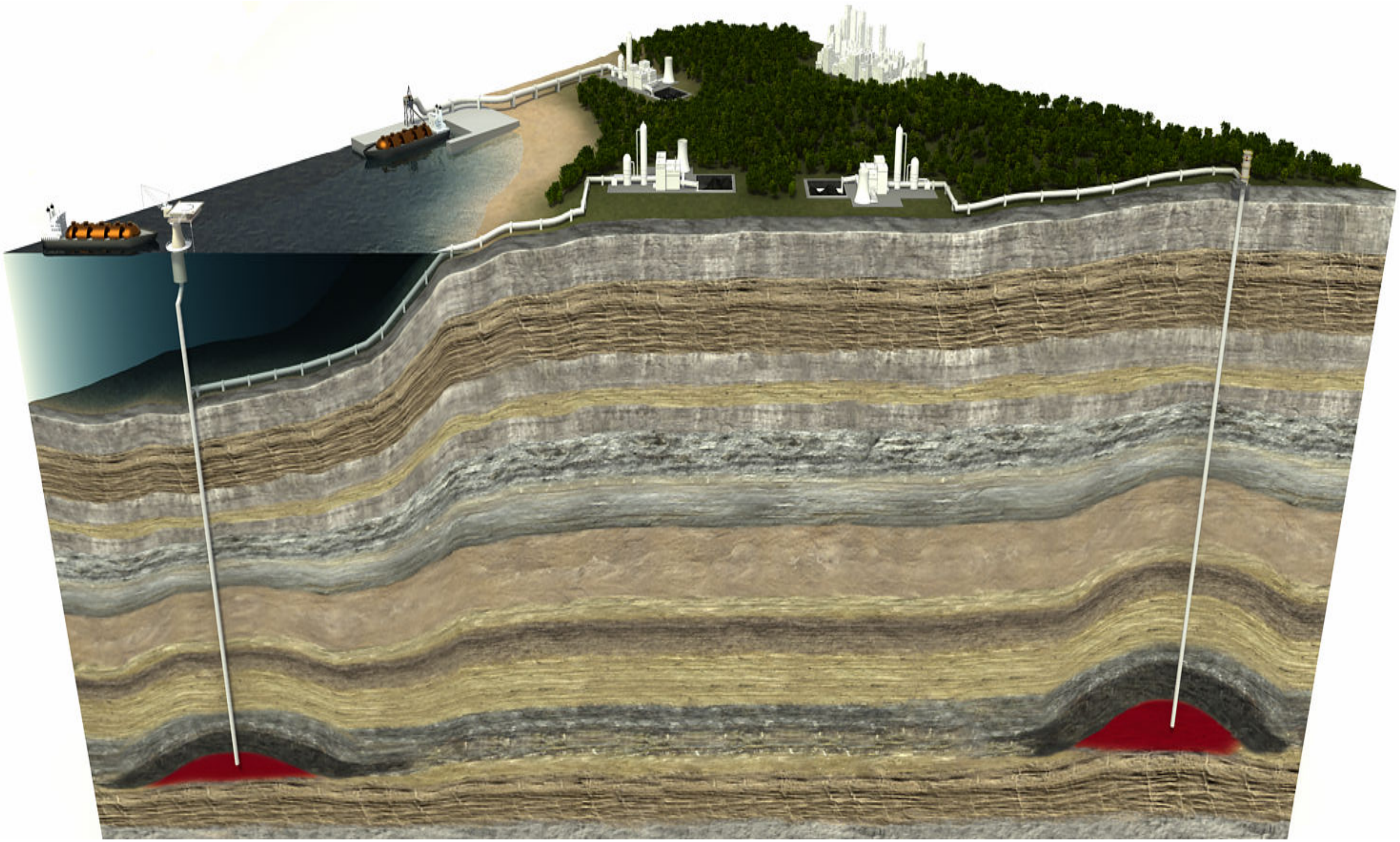
"CCS Technology across Capture / Transport / Storage chain"

Magnus Melin
Lloyd's Register

July 12, 2011

LR ET Collegium presentation: “CCS technology across Capture / Transport / Storage chain”

Carbon Capture and Storage (CCS)



Illustrations: The Bellona Foundation and IEA

Lloyd's Register

LIFE MATTERS

CAPTURE

LIFE MATTERS

Sources of CO_2

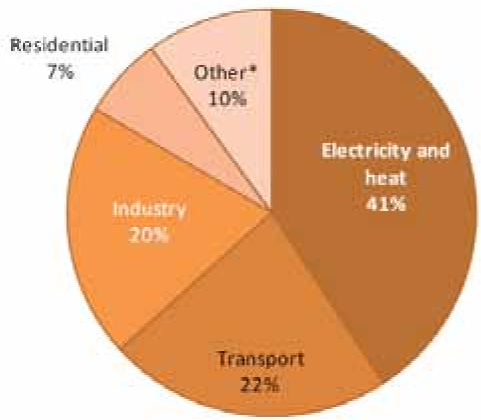
- The heaviest CO_2 emitters are mainly fossil-fuel fired power plants.
- Other large emitters include steel, cement and refineries.
- CCS is generally considered feasible for large point sources that emit more than 100,000 tonnes CO_2/year
- Globally, there are around 8,000 plants emitting above this level and in total these sources emit approximately 50% of the global man-made CO_2 emissions
- A ”typical” coal plant of 800 MWe emits in the order of 3-4 million tonnes CO_2 per year

Lloyd's Register
LIFE MATTERS

Sources of CO_2 – some food for thought

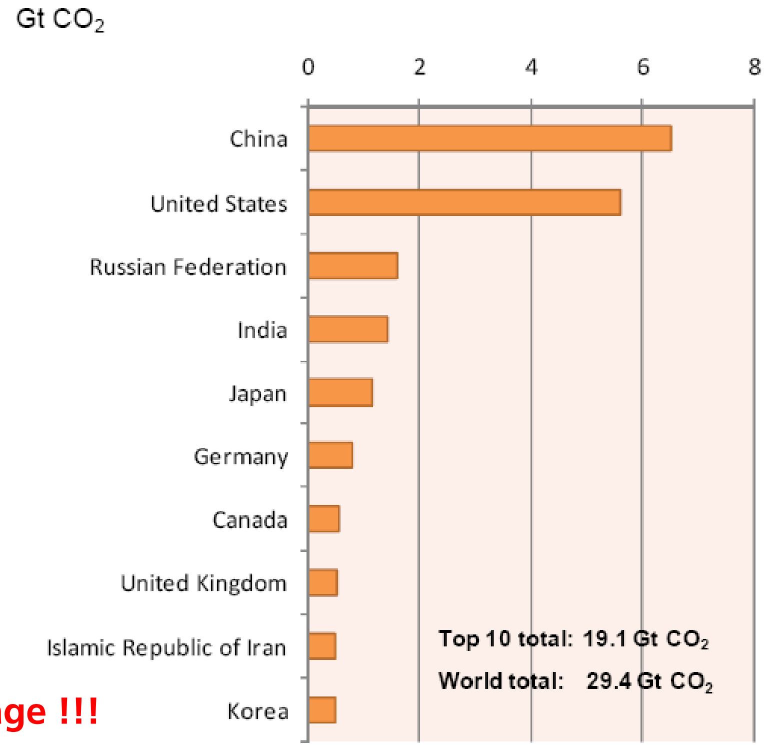
IEA "CO_2 emissions from fuel combustion – highlights". 2008.

Figure 5. World CO_2 emissions by sector in 2008



* Other includes commercial/public services, agriculture/forestry, fishing, energy industries other than electricity and heat generation, and other emissions not specified elsewhere.

Figure 4. Top 10 emitting countries in 2008



Note: different definitions provide different message !!!

"See the world as it is – not as you would wish it to be"
Jack Welch – former CEO and Chairman of GE

Lloyd's Register
LIFE MATTERS

Capture technology

- Three main technologies; post-combustion, pre-combustion and oxy-fuel
- Technology is well-understood but remains to be demonstrated at full-scale. Approximately 70-80 demo projects worldwide.

Global CCS Institute

(June 2011)

Post-combustion capture method

- CO_2 is captured from flue gas using chemical cleaning utilizing an absorbent, for example amine, that attracts CO_2.

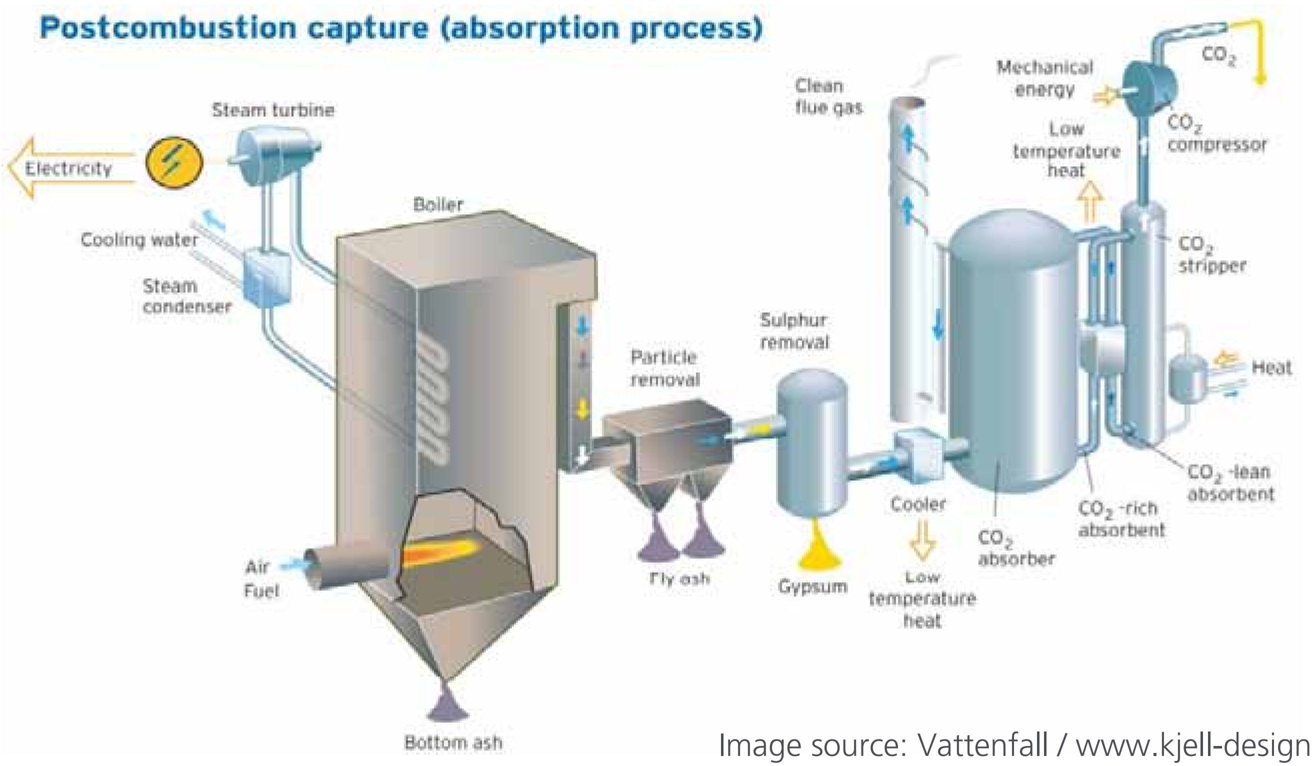


Image source: Vattenfall / www.kjell-design.com

Lloyd's Register
LIFE MATTERS

Post-combustion capture method

- Approximately 80-90% of the CO_2 can be captured

- **Pros (+)**
  - Well-proven technology
  - Can be fitted to existing power plants

- **Cons(-)**
  - High energy consumption, primarily caused by the heat required for regeneration of the absorbent

Pre-combustion capture method

- CO_2 is removed from the fuel prior to combustion using a steam reformer that converts the fuel to hydrogen (H_2) and carbon monoxide (CO). The CO-gas and steam is then converted into H_2 and CO_2. Finally, the H_2 and CO_2 gas is separated in the same way as in post combustion

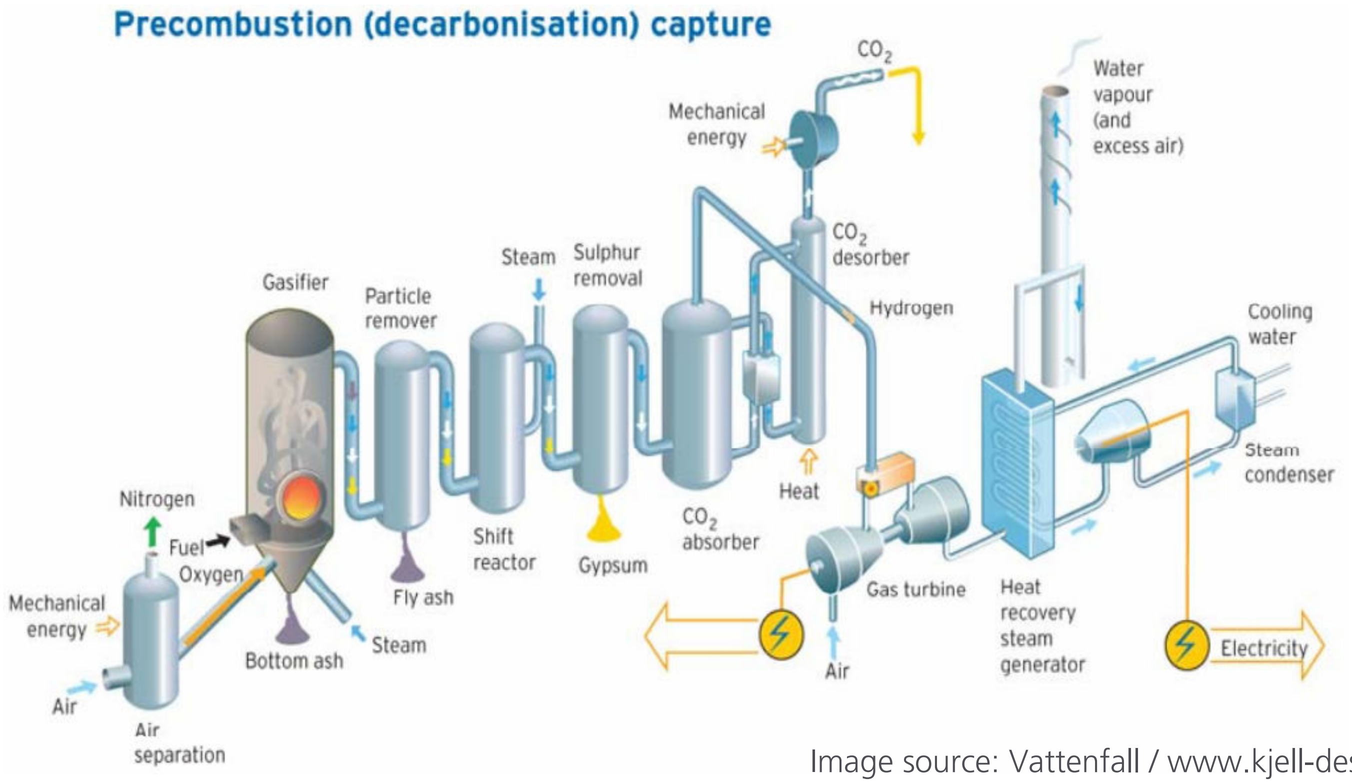


Image source: Vattenfall / www.kjell-design.com

Pre-combustion capture method

- Precombustion technology is linked to "IGCC" technology (Integrated coal Gasification Combined Cycle), where coal is converted into CO_2 and H_2 before combustion.

- **Pros (+)**
  - CO_2 captured on fuel flow (limited volume) and not on flue gas
  - Study indicates that pre-combustion applied to IGCC plant is most financially attractive solution for new power plant (with CCS)
- **Cons(-)**
  - Can only be applied to new power plants
  - High capital costs
  - Less developed and tested compared to post-combustion
  - Technical challenges with operating gas turbines on hydrogen

Oxy-fuel combustion capture method

- A traditional fossil fuel power plant is operated by combusting fuel and air. Oxy-fuel combustion uses oxygen instead of air. This is very advantageous when it comes to CO_2 capture, as the flue gas is mainly composed of steam and CO_2, which can be very easily separated.

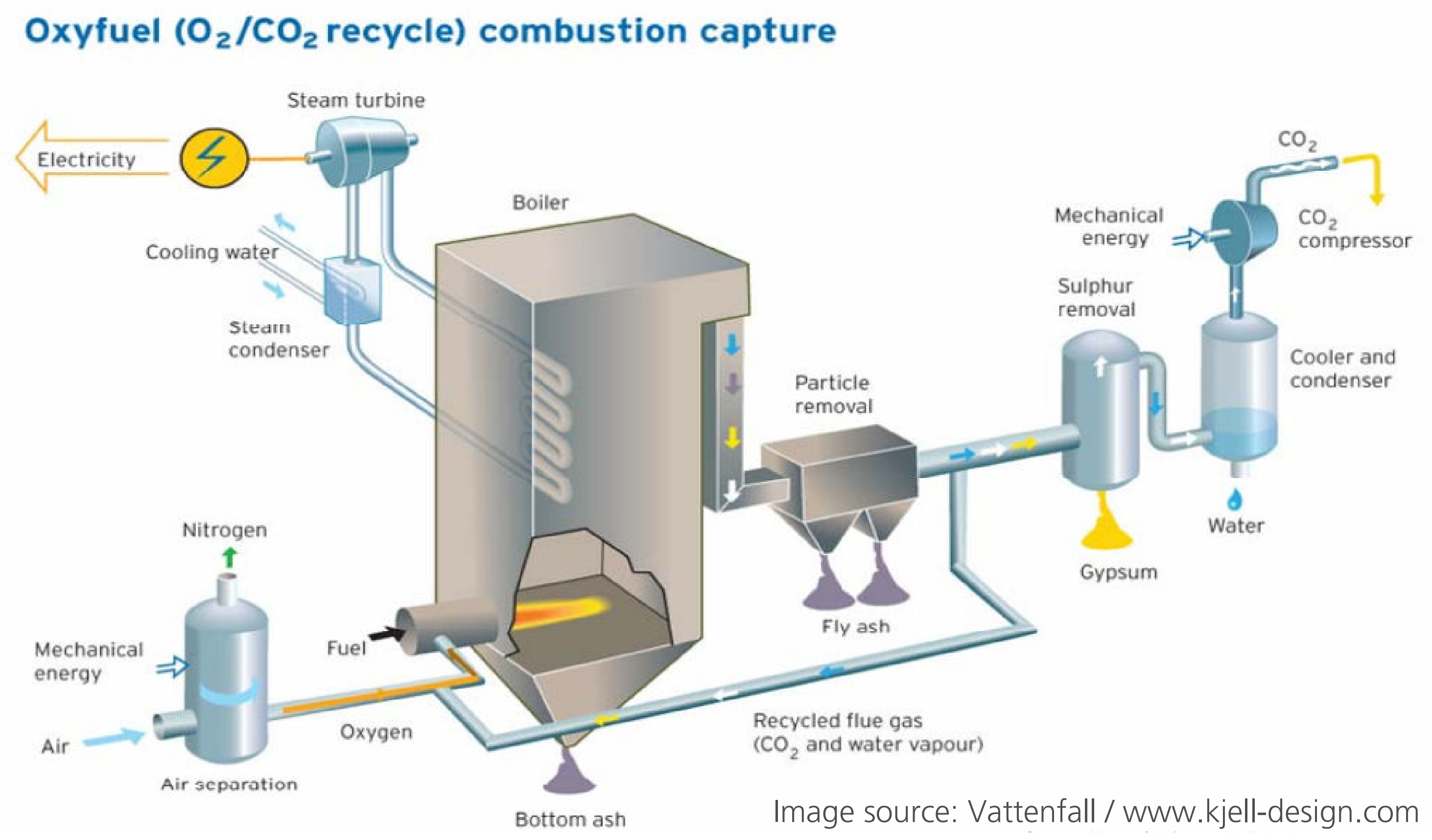


Image source: Vattenfall / www.kjell-design.com

Oxy-fuel combustion capture method

- 100% of the CO_2 can be captured

- **Pros (+)**
  - Easy to capture CO_2
  - 100% of the CO_2 can be captured

- **Cons(-)**
  - Production of pure oxygen is expensive
  - Less developed and tested compared to post-combustion

TRANSPORT

Pipeline and/or ship

- Two main alternatives: pipeline and/or ship
- > 30 years experience in North America of CO_2 pipelines (>6,000 km in U.S.)
- Pipeline option
  - \+ simple
  - \+ large capacity
  - \+ economical (especially onshore)
  - \- long lead-time, less flexibility
- Ship option
  - \+ flexibility
  - \+ economical (long distances)
  - \+ quick mobilisation
  - \- irregular supply
  - \- cost for liquefaction, loading, unloading, pressurisation

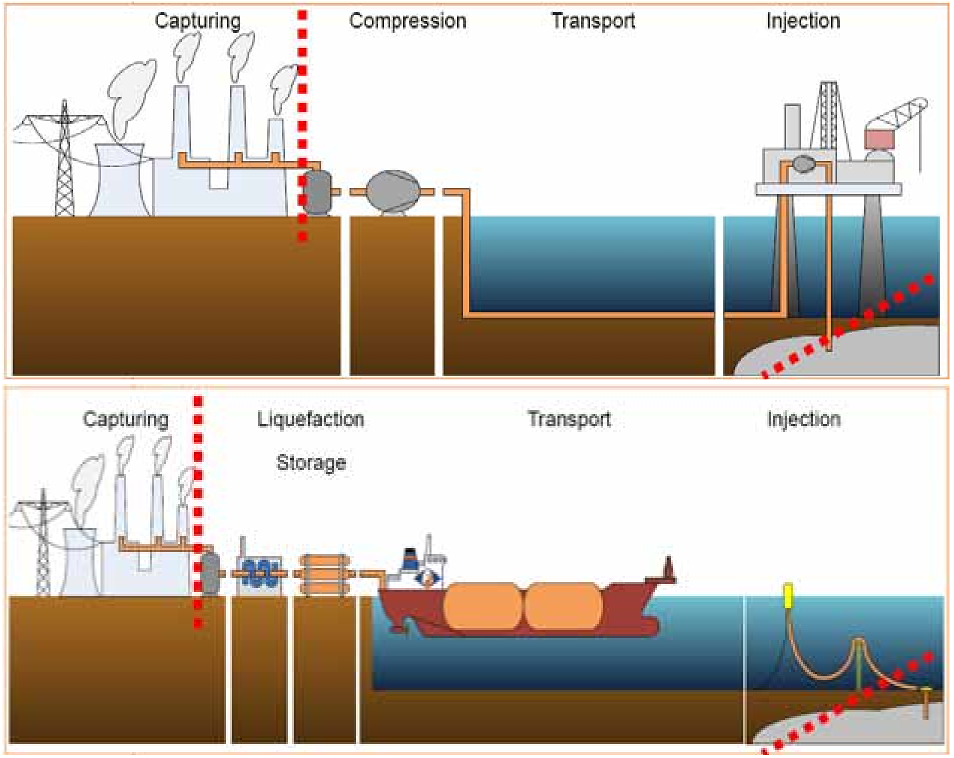
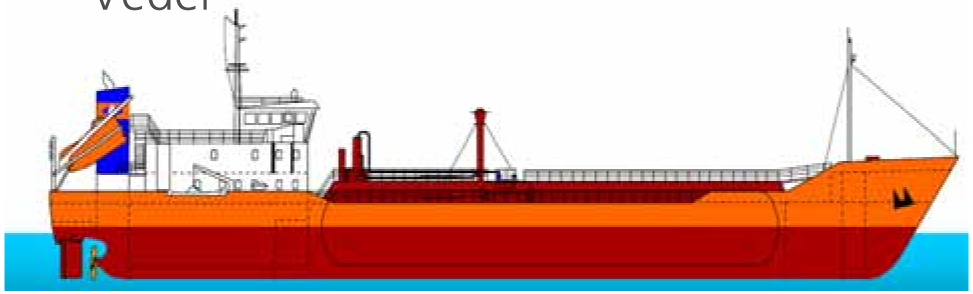


Illustration: Anthony Veder

Lloyd's Register
LIFE MATTERS

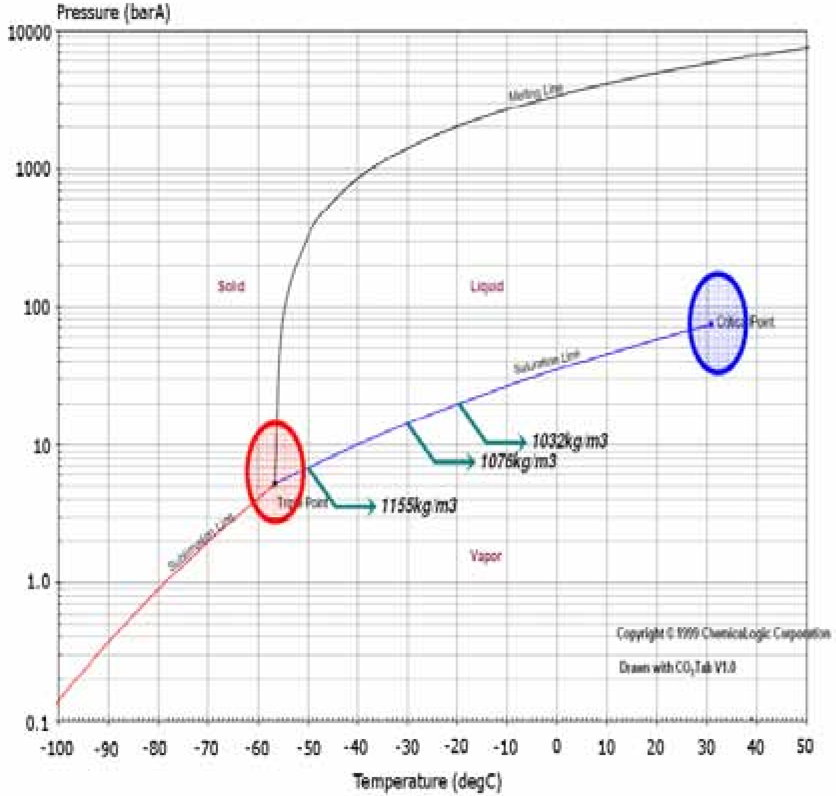
Transportation by ship

- CO_2 is transported in liquid phase close to triple point (-56.5 degC, 5.2 barA)
- Liquefaction necessary
- Similar to todays LPG carriers
- A handful of ships transport CO_2 currently, primarily small quantities for the food industry
- Example: "Coral Carbonic", Anthony Veder



LOA	Speed	Tank capacity	Tank temp.	Tank pressure
79 m	12.5 kn	1,240 m³ CO_2	-40 degC	18 barg

Phase diagram for CO_2



Conversion of existing LPG ships

- The LPG market is well developed with >1,000 LPG tankers in traffic
- Semi-refrigerated type with capacity 5,000-20,000 m^3 seems to be most feasible for conversion
- Possibility for conversion depends on many factors and it is likely that only a small portion of all existing LPG carriers are suitable
- Necessary modifications would as a minimum include modified pumps and discharge arrangements. Depending on offshore unloading scheme additional equipment might be necessary (DP, compression to injection pressure, heater etc)
- Further detailed analysis needed

LOA	115 m
Speed	16 kn
Tank capacity	6,500 m^3 CO_2
Tank temp.	minimum -104 degC
Tank pressure	max 6 barg

Lloyd's Register
LIFE MATTERS

New ships for CO_2 transport

- New design concepts published (DSME, Maersk, TGE, Anthony Veder ...)
- Many concepts similar to existing LPG carriers using cylindrical or bi-lobe type tanks.
- Dual-type LPG/CO_2 designs published by several ship builders
- Alternative concepts include DSME’s very large CO_2 carrier using 100 vertical tube-shaped tanks and TGE’s barge container concept
- Tank capacity 10,000-100,000 m^3 CO_2 (near triple point; -56.5 degC, 5.2 barA)
- Example of designs for offshore unloading and processing are ”Floating Storage and Injection Units” (FSIU) and “Floating Liquefaction Storage and Offloading” (FLSO)
- Lead time for new CO_2 carrier in the order of 2-3 years

Design concepts for CO_2 ships

TGE

DSME

Maersk Tankers / HHI

TGE

Lloyd's Register
LIFE MATTERS

Logistical challenges with CO_2 ship transport

- Ship-based solution requires detailed study to ensure proper logistics
- Distance, loading- and unloading time, weather, injection capacity, buffer capacity, compression, weather …

Scenario #1

8 hours	Loading
12 hours	Transport
12 hours	Unloading
4 hours	Waiting

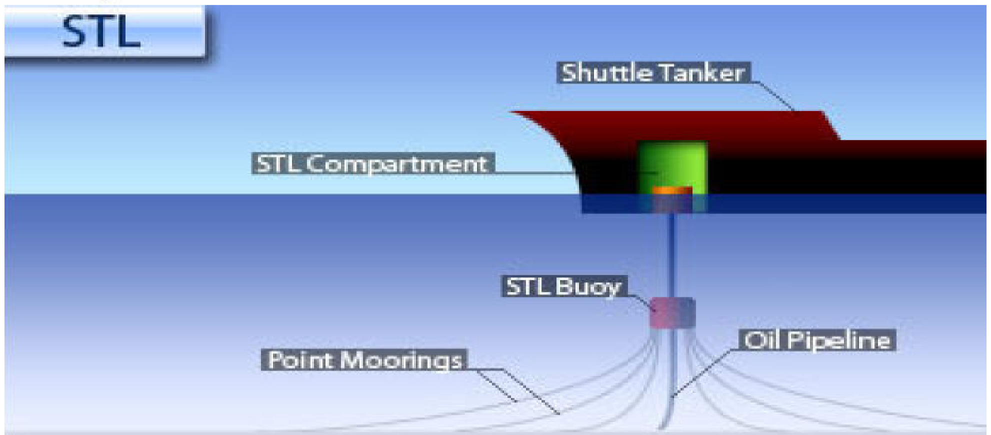
Day	Day 1						Day 2						Day 3					
Time	0	4	8	12	16	20	0	4	8	12	16	20	0	4	8	12	16	20
Ship A			W	Loading		Transport			Unloading			Transport			W	Loading		
Ship B			Unloading			Transport			W	Loading		Transport			Unloading			

CCS feasibility study by LR. Download report: http://www.lr-ods.com/News-and-Events/CCS_study.html

Lloyd's Register
LIFE MATTERS

Offloading CO_2 offshore from ship

- Unloading CO2 offshore is challenging
- Offshore
- Conditioning of CO2 (pressure/temperature/flow rate)
- Connectivity with receiving equipment / well
- Injection rate limited by well and not ship in most cases
- Overall supply / demand must match
- Various concepts have been put forward



LIFE MATTERS

CO_2 transport using pipeline

> 30 years experience in North America of onshore CO_2 pipelines

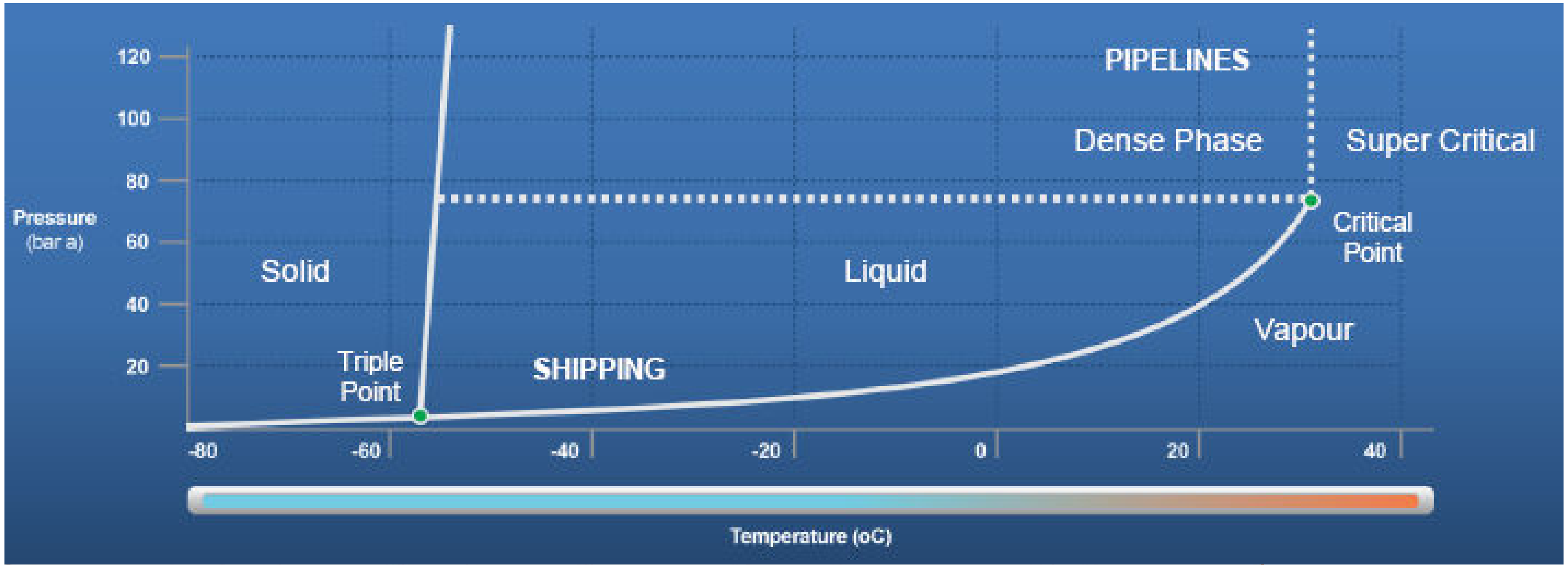
>6,000 km in U.S.

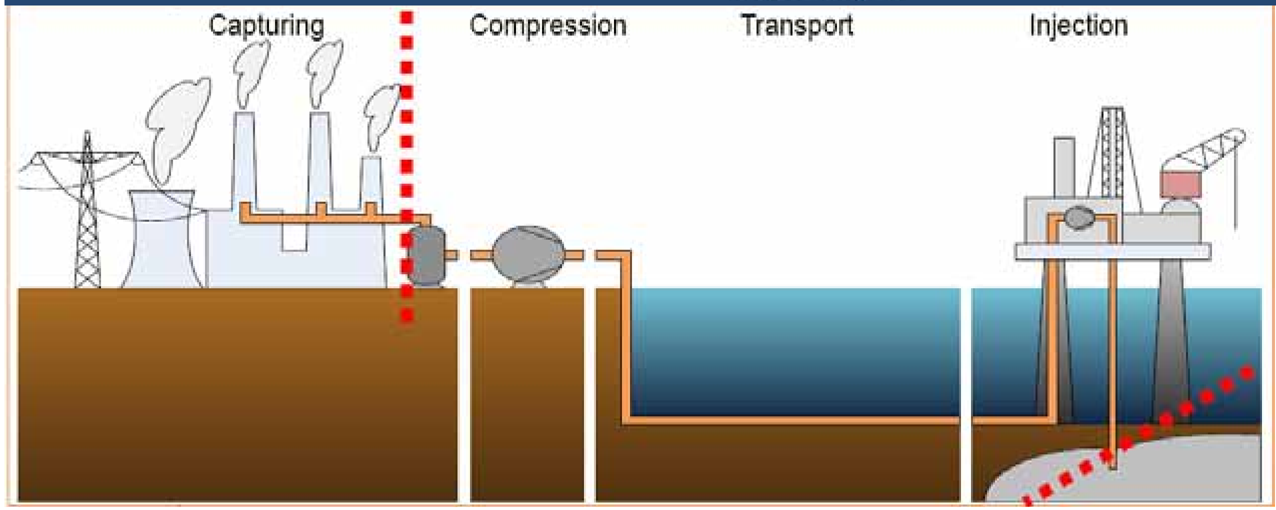
Figure 4.1 CO_2 pipelines in North America. (Courtesy of Oil and Gas Journal).

Lloyd's Register
LIFE MATTERS

CO_2 transport using pipeline

- CO_2 is transported in compressed state (dense) at ambient temperature





Design considerations for CO_2 pipeline

- CO_2 pipelines are similar to natural gas pipelines but there are important differences:

  - higher pressure, different chemical properties
- Design and operational experience cannot directly be extended to CO_2 pipelines
- Water content and other impurities have large effect on CO_2 behaviour
- Corrosion
- Hydrate formation
- Rupture of pipe - dispersion of CO_2

Example of CO_2 incidents

Industry

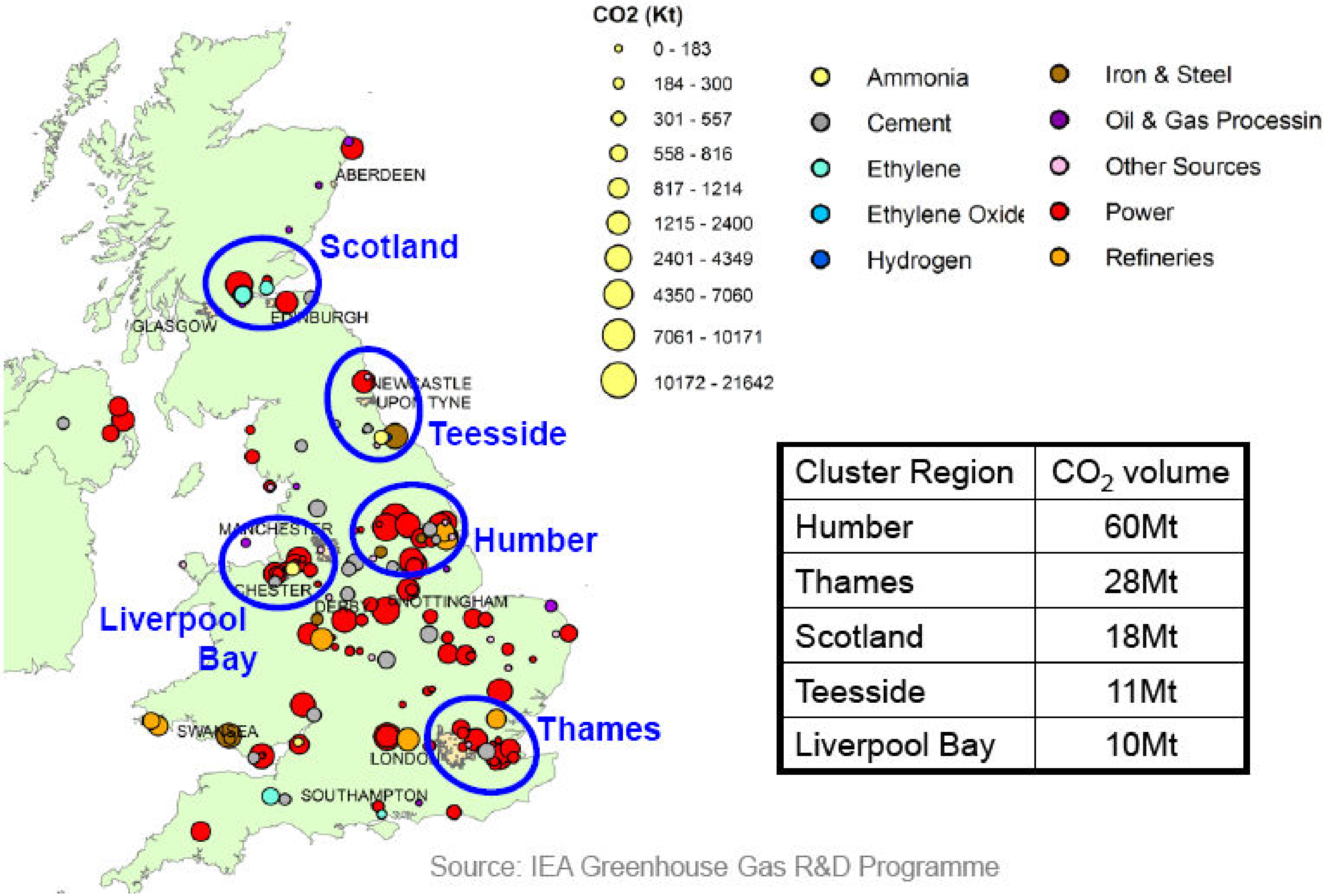
- Leak from fire suppressant system: 107 intoxicated, 19 hospitalised, no fatalities – Monchengladbach, Germany 2008
- CO_2 tank (30 Tonnes) BLEVE: 3 fatalities, 8 further injuries – Worms, Germany 1988
- Oil well release of 81% CO_2 (with H_2S): 2,500 people evacuated - Nagylengyel, Hungary 1998

Geological

- Lake Nyos, Cameroon, 1986 – 1,700 fatalities, 1,600 kT release
- Dieng volcano, Indonesia – 1979, 142 killed, 200 kT release

Lloyd's Register LIFE MATTERS

Clusters of CO_2 sources

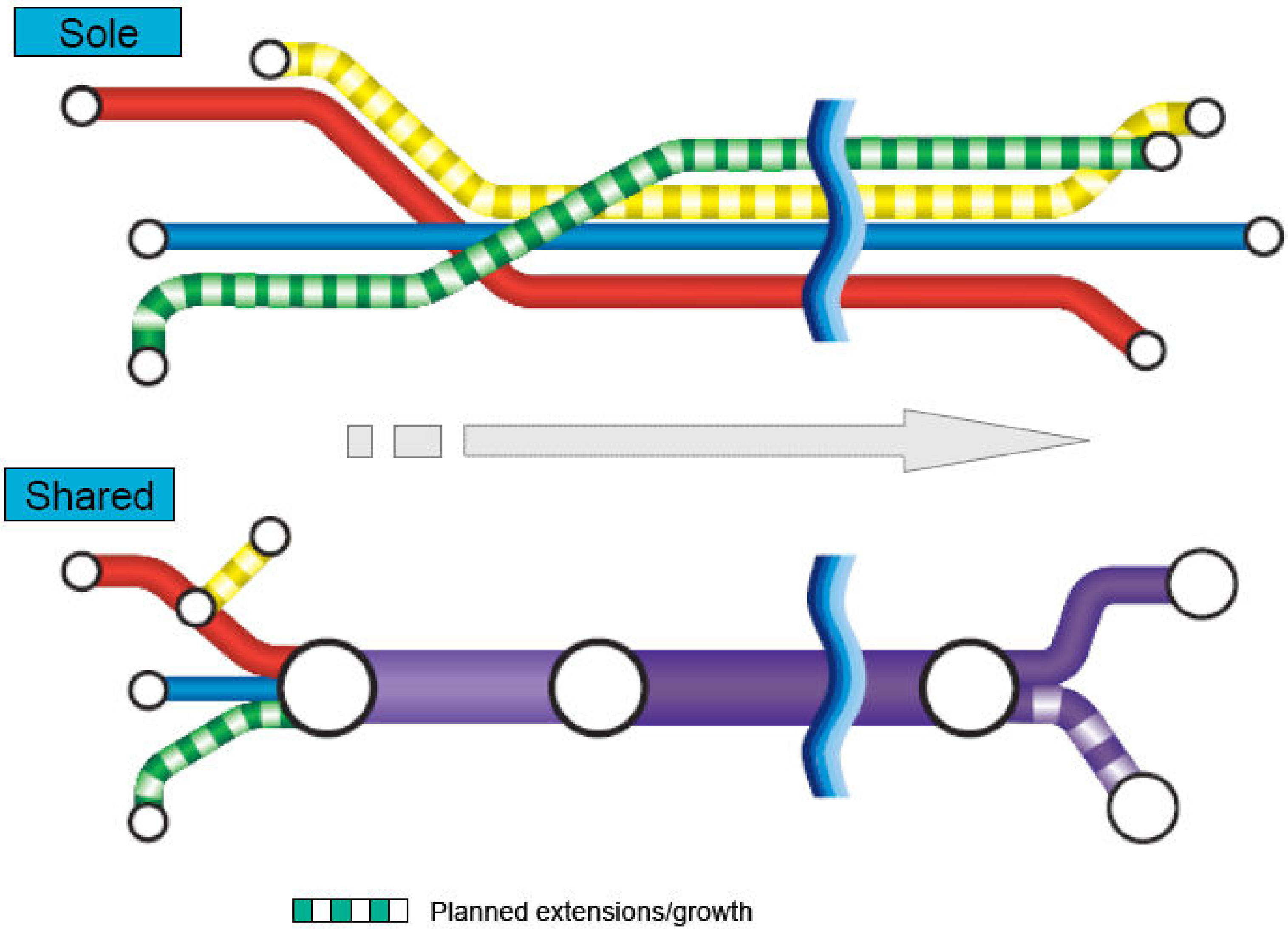


Cluster Region	CO_2 volume
Humber	60Mt
Thames	28Mt
Scotland	18Mt
Teesside	11Mt
Liverpool Bay	10Mt

Source: IEA Greenhouse Gas R&D Programme

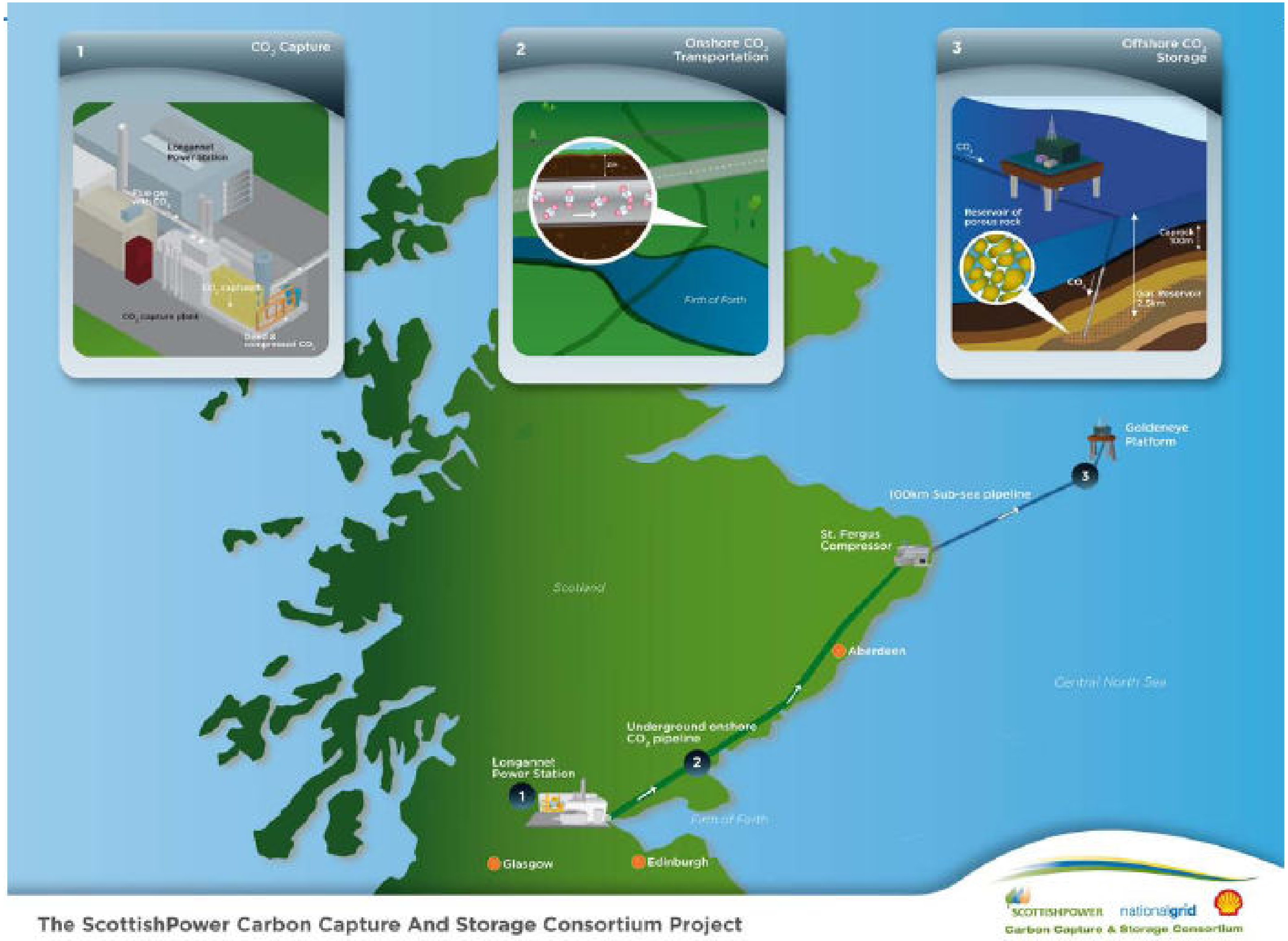
Lloyd's Register
LIFE MATTERS

Pipeline cluster options



LIFE MATTERS

CO_2 transport by pipeline in Longannet project

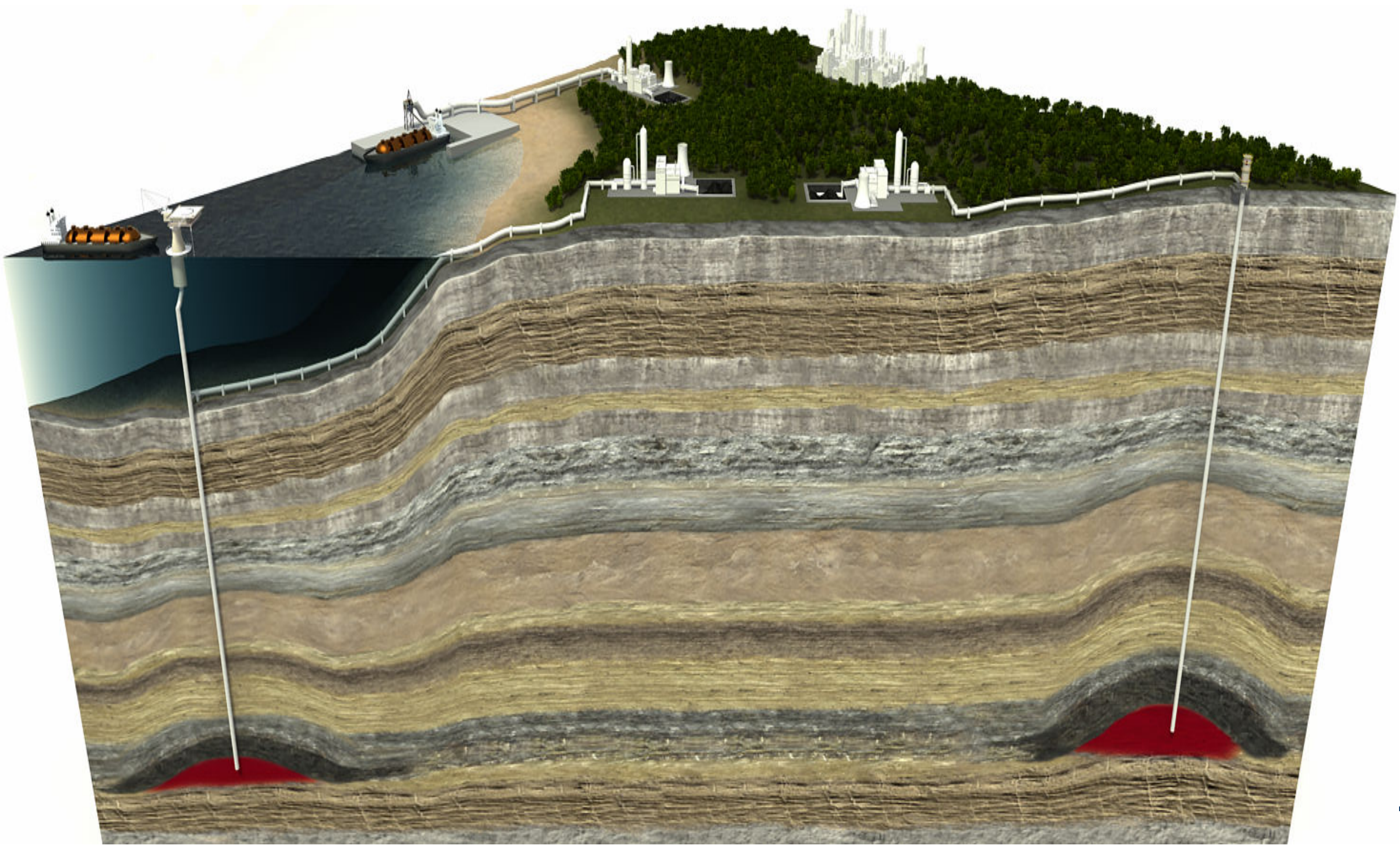


Challenges with CO_2 transport using pipeline

Examples:

- Public perception (safety)
- Complex properties of CO_2 and effect of impurities/water
- Large scale integration of pipeline network (cross-national)
- Financials
- Regulations including financial liability

STORAGE

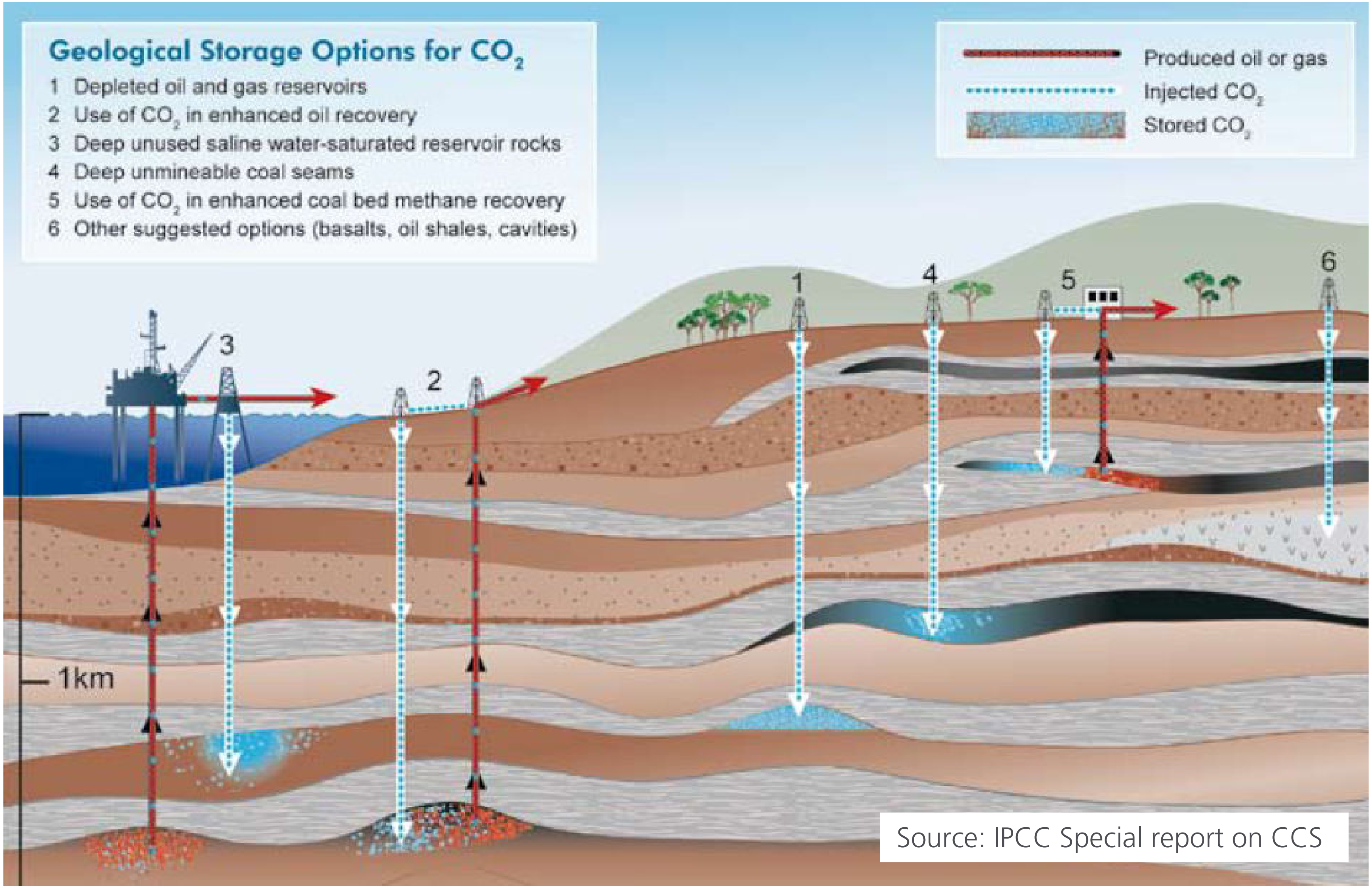


Requirements on CO_2 storage sites

- Accomodate large volumes of CO_2
- Safe for very long time scales
- Financially feasible
- Allow required monitoring (of potential CO_2 leakage) and hand-over from operator to ”competent authority” (member state in EU)

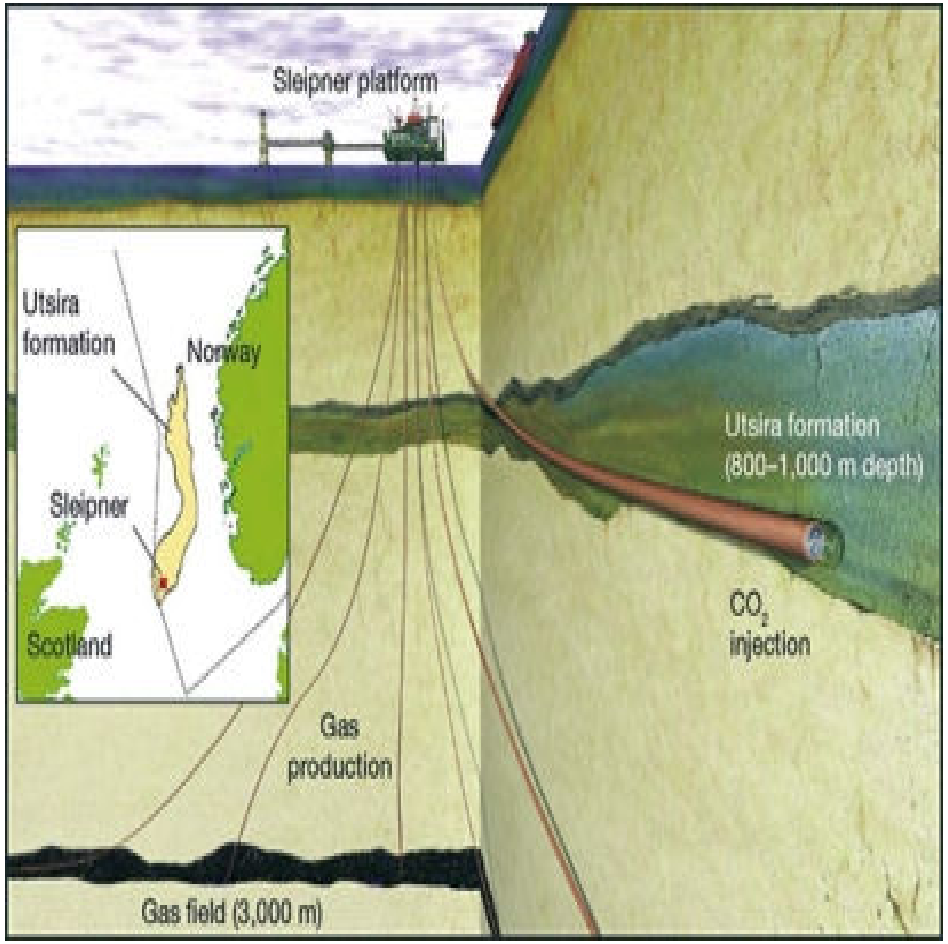
LIFE MATTERS

Storage options



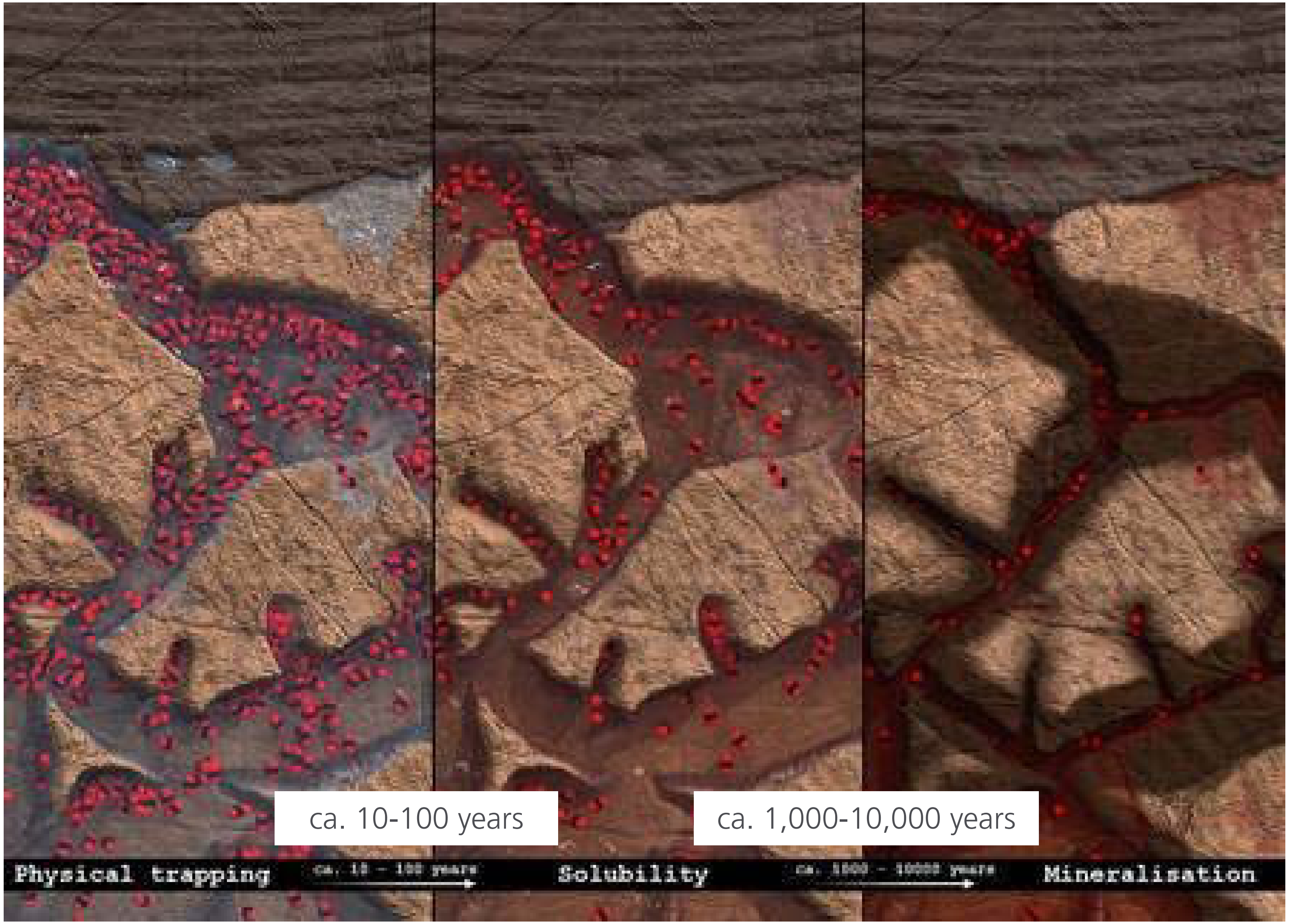
Project example – offshore storage

- Example on active projects include Utsira (illustrated) and Snøhvidt. Both capture CO_2 from natural gas
- Utsira storage in saline formation at approximately 1 km depth
- About 1 million tonnes of CO_2 has been stored in the Utsira formation annually since 1996 without any indication of leakage.



LIFE MATTERS

Trapping mechanisms



Is it safe?

People in favour of CO_2 storage say **YES** because:

- Current storage sites do not leak
- The likelyhood of leakage is very low
- We can simulate and monitor how the CO_2 will behave underground
- Even if it leaks, say 1% in 500 years, this should be compared to current situation (100% ”leakage” immediately at 100% probability)
- There will be rigorous regulation of the storage sites

People sceptical about CO_2 storage say **NO** because:

- Our knowledge and tools are not developed enough
- The time scales are very long
- Things always go wrong sooner or later

Lloyd's Register
LIFE MATTERS

Enhanced Oil Recovery (EOR) using CO_2

- Large scale injection of CO_2 for Enhanced Oil Recovery (EOR) has been done for more than 30 years in North America
- Lot of experience onshore but not yet proven commercially feasible offshore

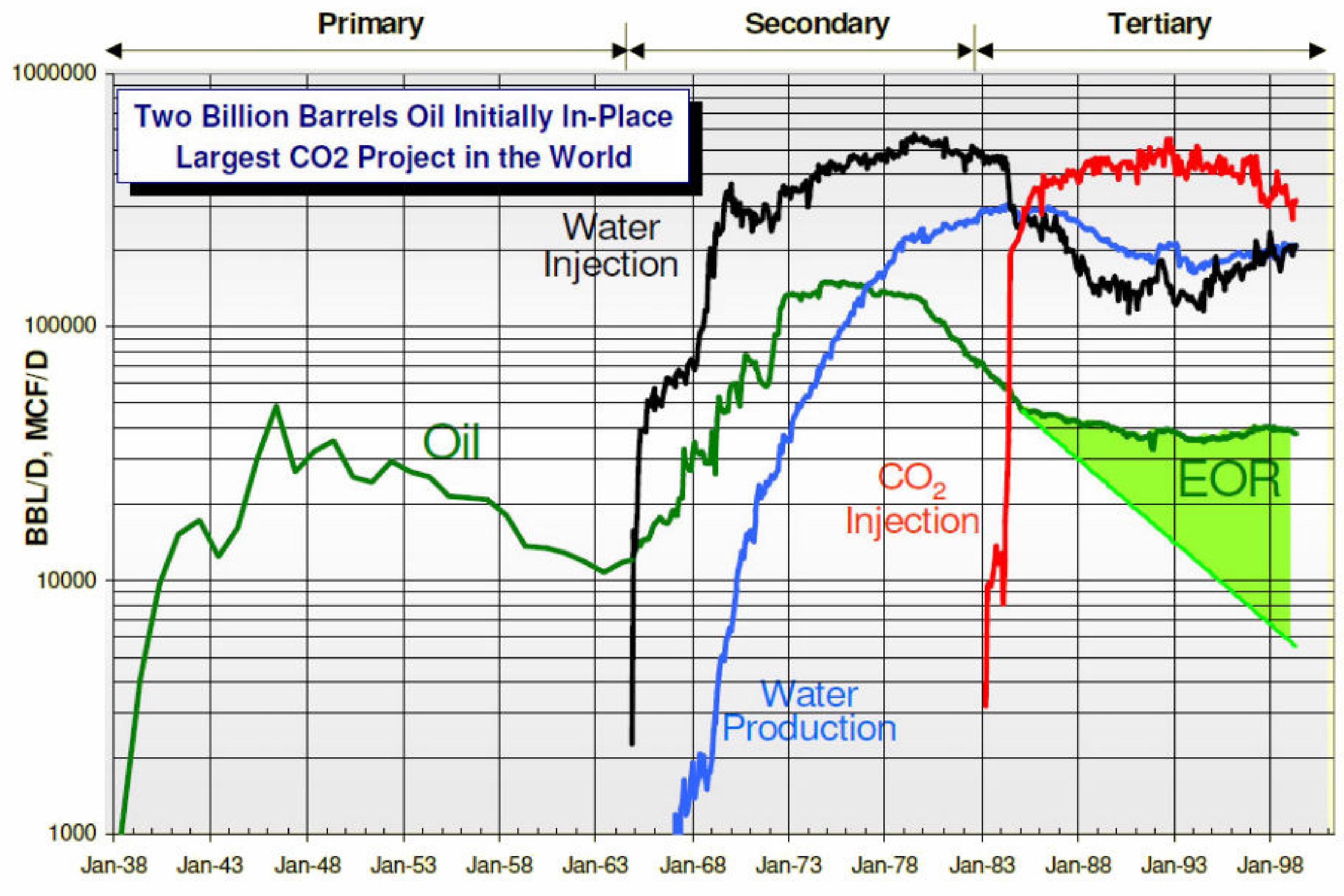
How does it work?

Let’s have a look…

LIFE MATTERS

Enhanced Oil Recovery (EOR) using CO_2

Example from Denver onshore field in Texas:



EOR using CO_2 : relevance to CCS

CO_2 for EOR is increasingly seen as a potentially favourable option to help growing the CCS industry. Some of the reasons for this are:

1. Injection of CO_2 in oil reservoirs mobilizes additional oil, thereby **offsetting some of the costs** with demonstrating CCS.

2. Several oil fields in the North Sea are near end of commercial field life. CO_2 EOR would in most cases unlock additional reserves to potentially delay abandonment. **This would in turn enhance the security of supply** which is valuable for many reasons.

3. An EOR project is regarded **as a CO_2 storage site and receives ETS credits for the stored CO_2**.

CONCLUDING REMARKS

Concluding remarks CCS

- All aspects of CCS have been proven to work technically but further work remains to demonstrate feasibility at commercial scale
- Work is being done to progress with the ambition to have large demo projects go live by 2015 and start of commercial scale projects by 2020
- Billion € funding available from governments and EU
- Challenges to overcome for large-scale deployment:

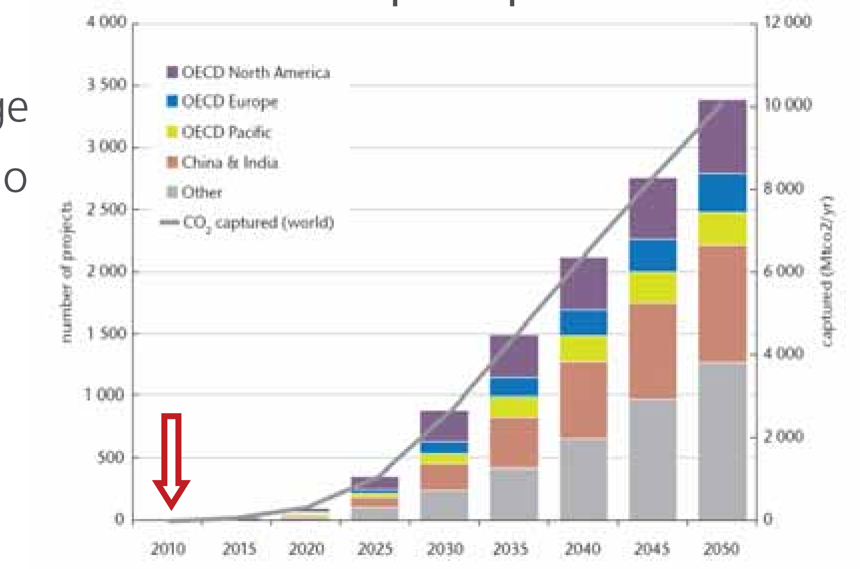
  - Regulatory uncertainty

  - Cost, cost, cost

  - Significant financial risk from large investments and long return perio

  - Public perception (safety)

IEA roadmap for expansion of CCS



For more information, please contact:

Magnus Melin

Global Thermal Power Leader

Lloyd’s Register Energy

T +46 8 55 60 99 62

E magnus.melin@lr.org

W www.lr.org