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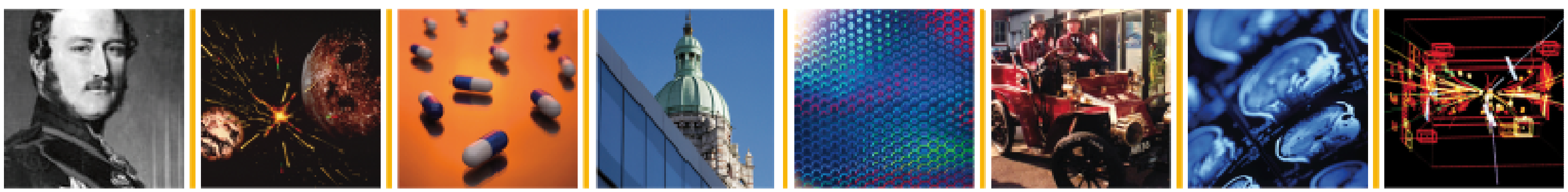
Design of carbon dioxide storage



Martin J Blunt

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Inconvenient truths

Rising population – 6.7 billion now to 10 billion in 2100

Energy shortage and security: are we at peak oil? Almost certainly beyond peak oil per person.

Desire for improved, or at least maintained, standard of living

Climate change

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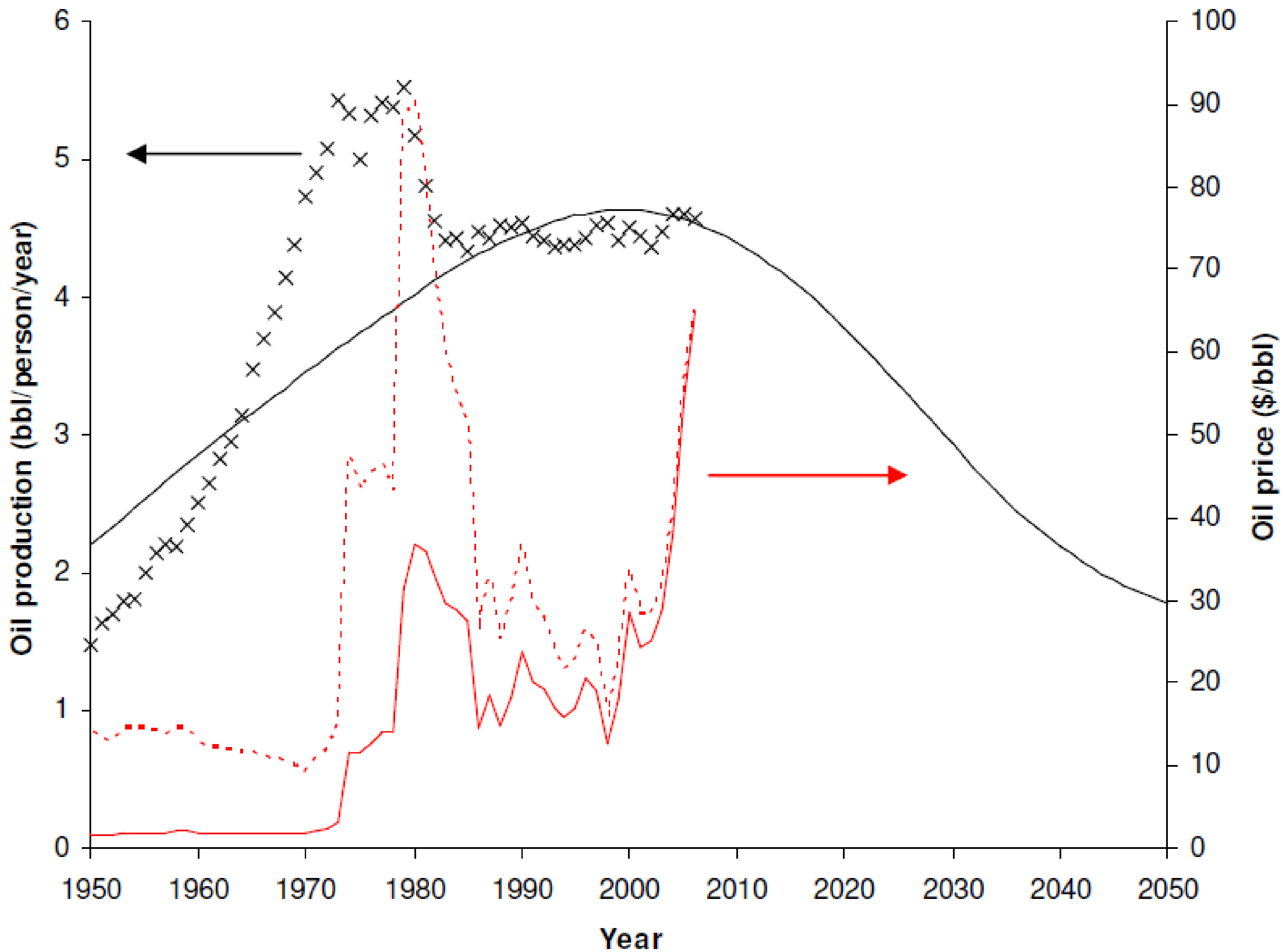
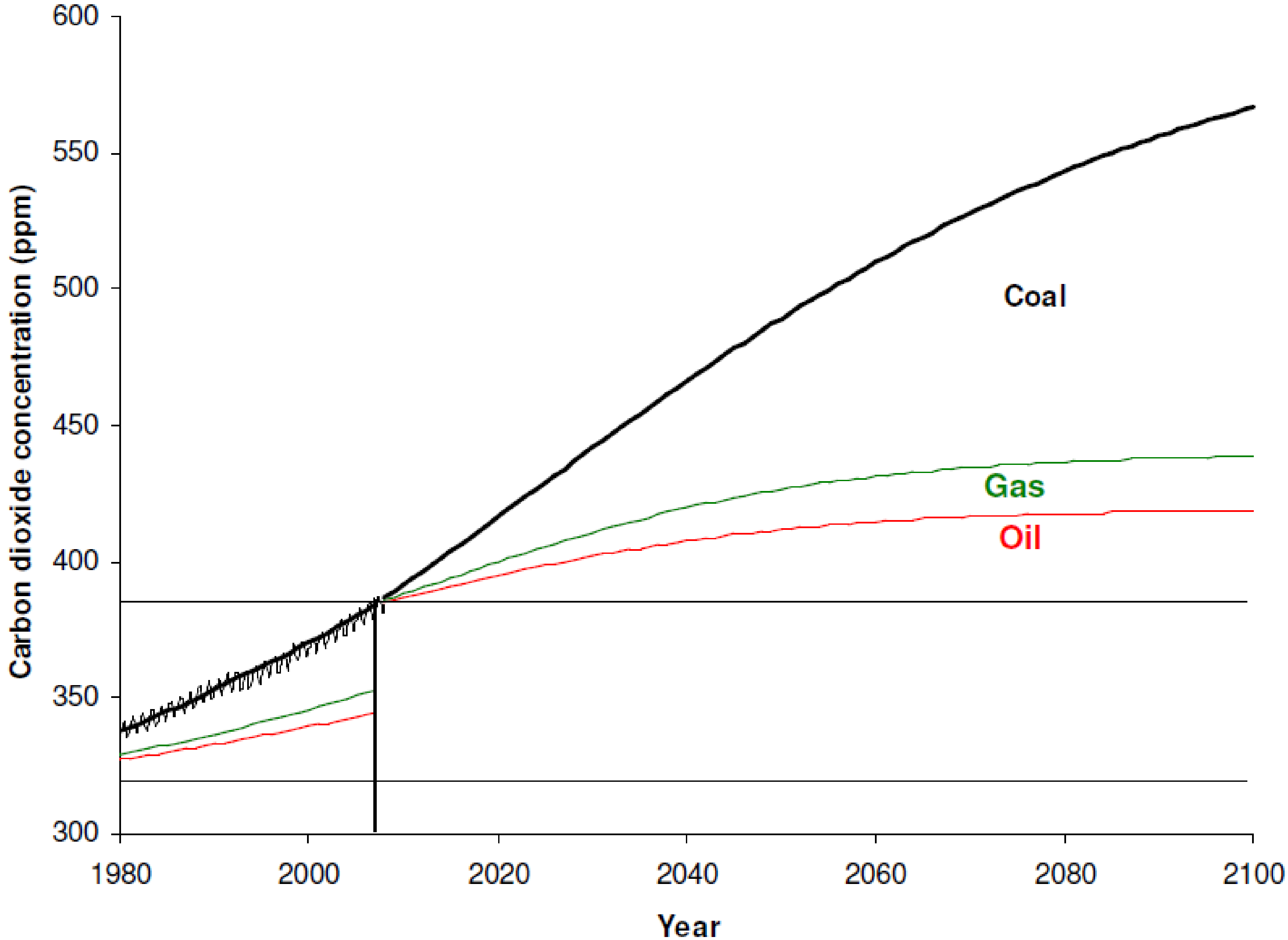
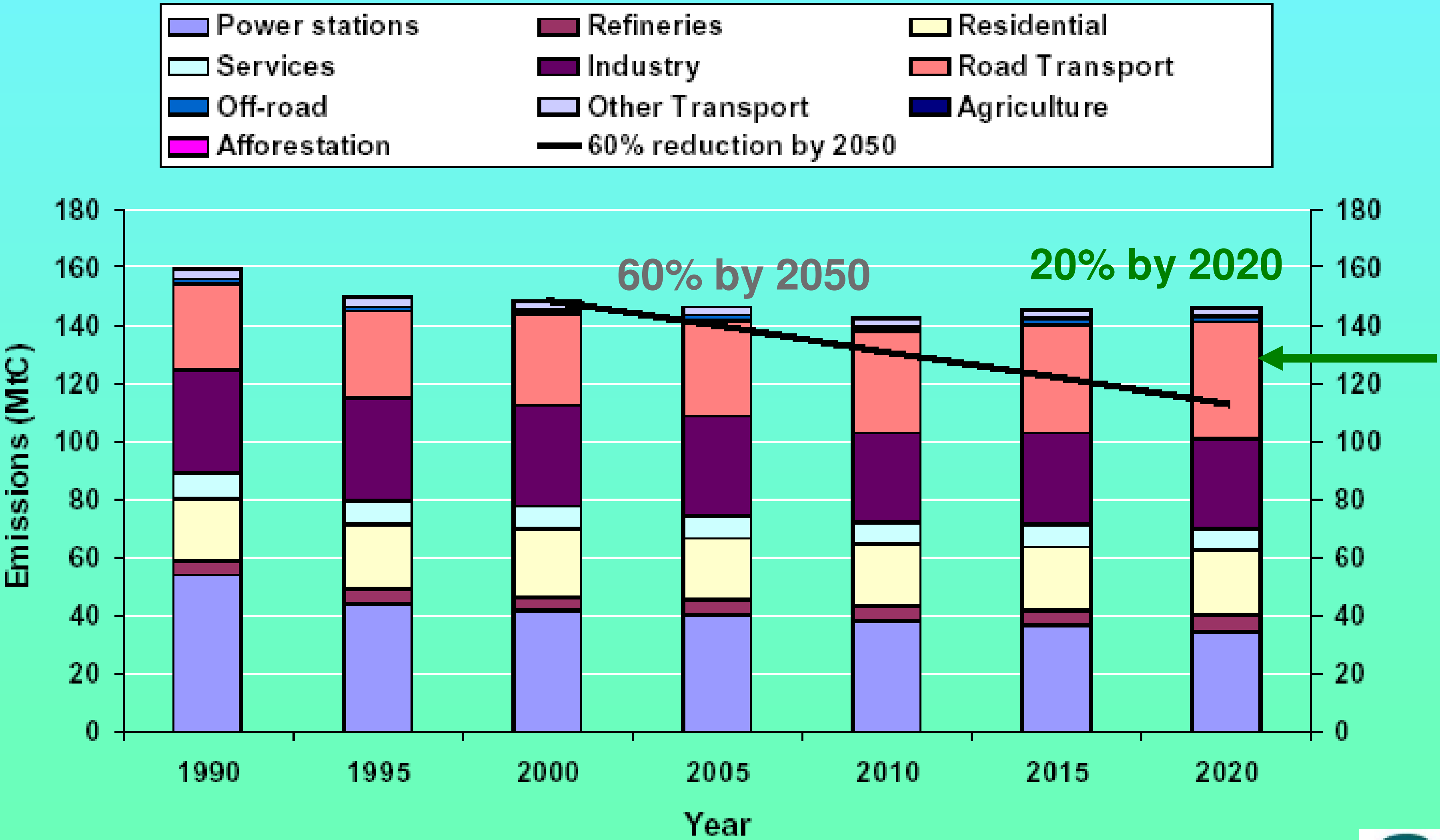
Are we running out of oil?



And what does this mean for CO_2 concentration?



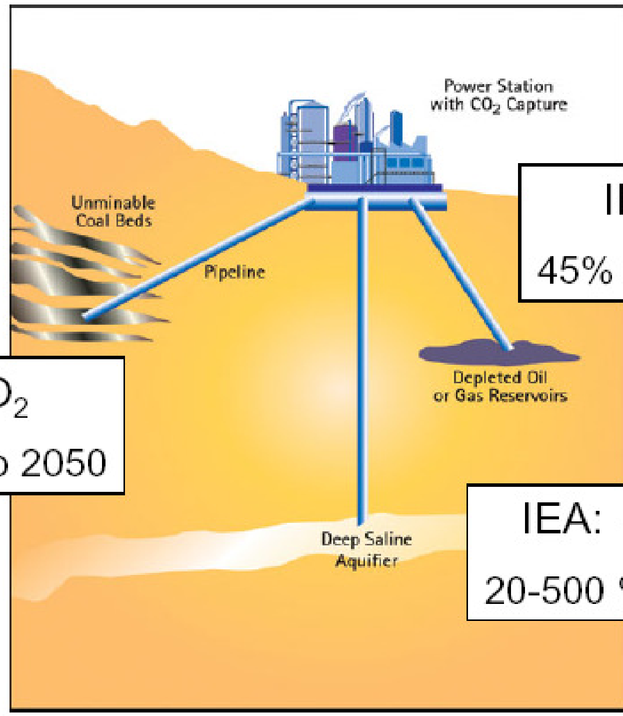
UK carbon emissions by sector



http://www.dti.gov.uk/energy/sepn/uep.pdf

Carbon capture and storage

Carbon Capture and Storage (CCS)



IEA: 920 Gt CO_2

45% of Emissions to 2050

Parson & Keith: 740-1850 Gt CO_2

IEA: 40 Gt CO_2

<2% of Emissions to 2050

Parson & Keith: 370-1100 Gt CO_2

IEA: 400-10 000 Gt CO_2

20-500 % of Emissions to 2050

Parson & Keith: 370-3700 Gt CO_2

Source: Freund, IEA - Comparative potentials at storage costs of up to \$20/t CO_2

Source: Parson & Keith, Science 282, 1053-1054, 1998

736 Gt in North Sea alone (DTI) ≈
CO_2 produced by all UK population for 100 years!!!

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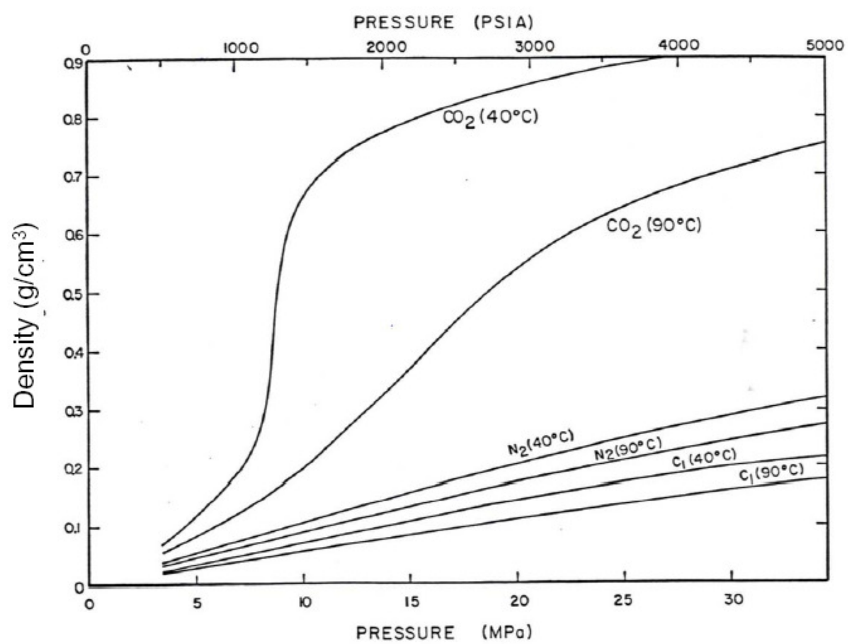
Carbon dioxide properties

Critical point of CO_2 is 31°C and 72 atm (7.2 MPa).

CO_2 will be injected deep underground at supercritical conditions (depths greater than around 800 m).

CO_2 is relatively compressible and its density, although always less than water, is similar to oil.

Low viscosity – typically around10% that of water.



Some numbers

Current emissions are around 25 Gt CO_2 per year (6 Gt carbon).

Say inject at 10 MPa and 40^{o}C – density is 700 kgm^{-3}.

This is around 10^8 m^3/day or around 650 million barrels per day. Current oil production is around 80 million barrels per day.

Huge volumes – so not likely to be the whole story, but could contribute 1-2 Gt carbon per year….

Costs: 1-2p/KWh for electricity for capture and storage; £25-60 per tonne CO_2 removed – Shackley and Gough, 2006.

Could fill the UK emissions gap in 2020.

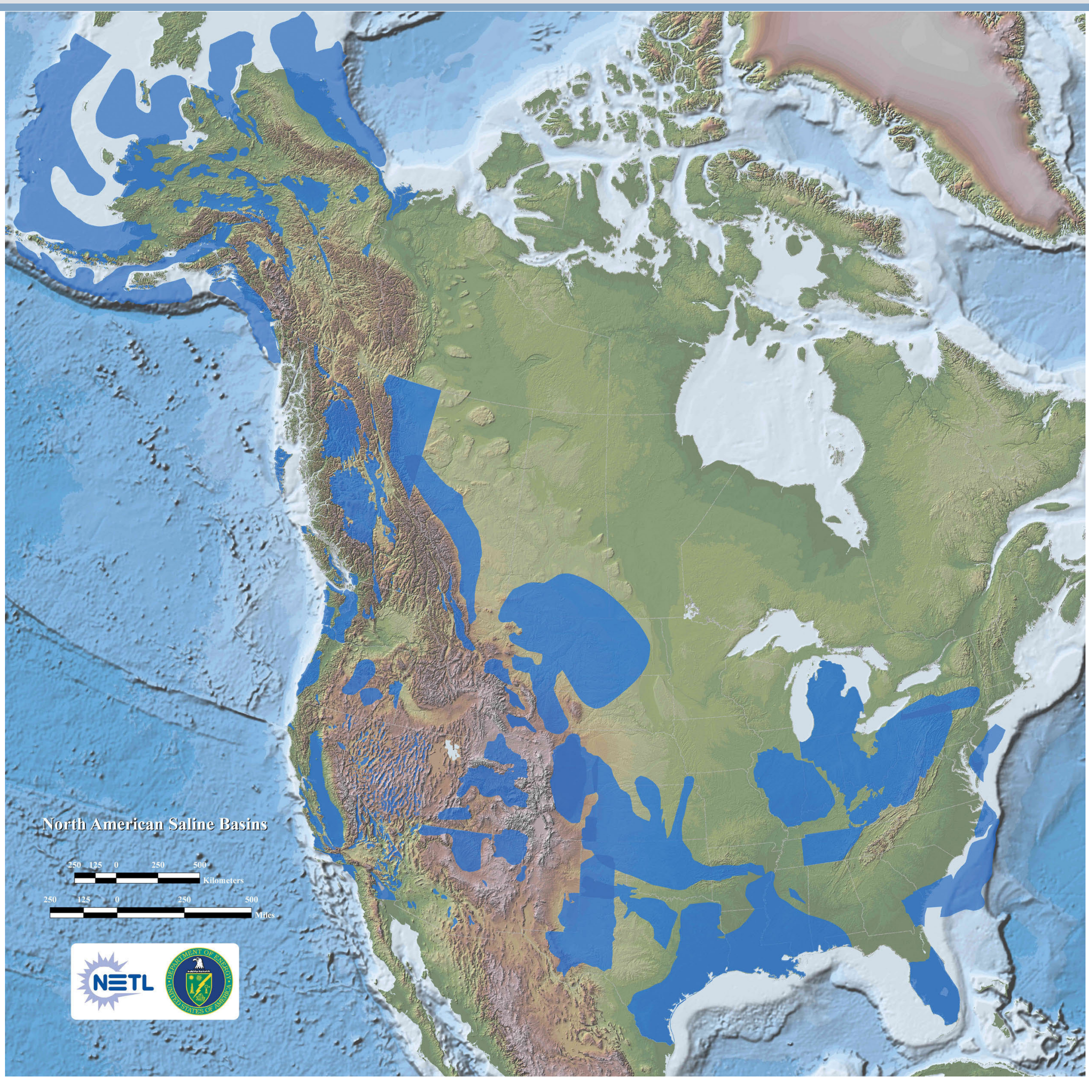
Problems with CCS

'Untried' Each component is known, but not yet demonstrated for a full-scale power-station, smoke stack to storage. Not an excuse for doing nothing – else we would still be in the Stone Age!

Hundreds of sites where CO_2 is injected: how can we ensure that it stays underground?

Decades (Imperial pilot plant in 1972) of experience with capture, but current technology is inefficient. How can we separate CO_2 effectively and cheaply at large scales?

Aquifer storage



http://www.netl.doe.gov/technologies/carbon_seq/refshelf/atlas/index.html

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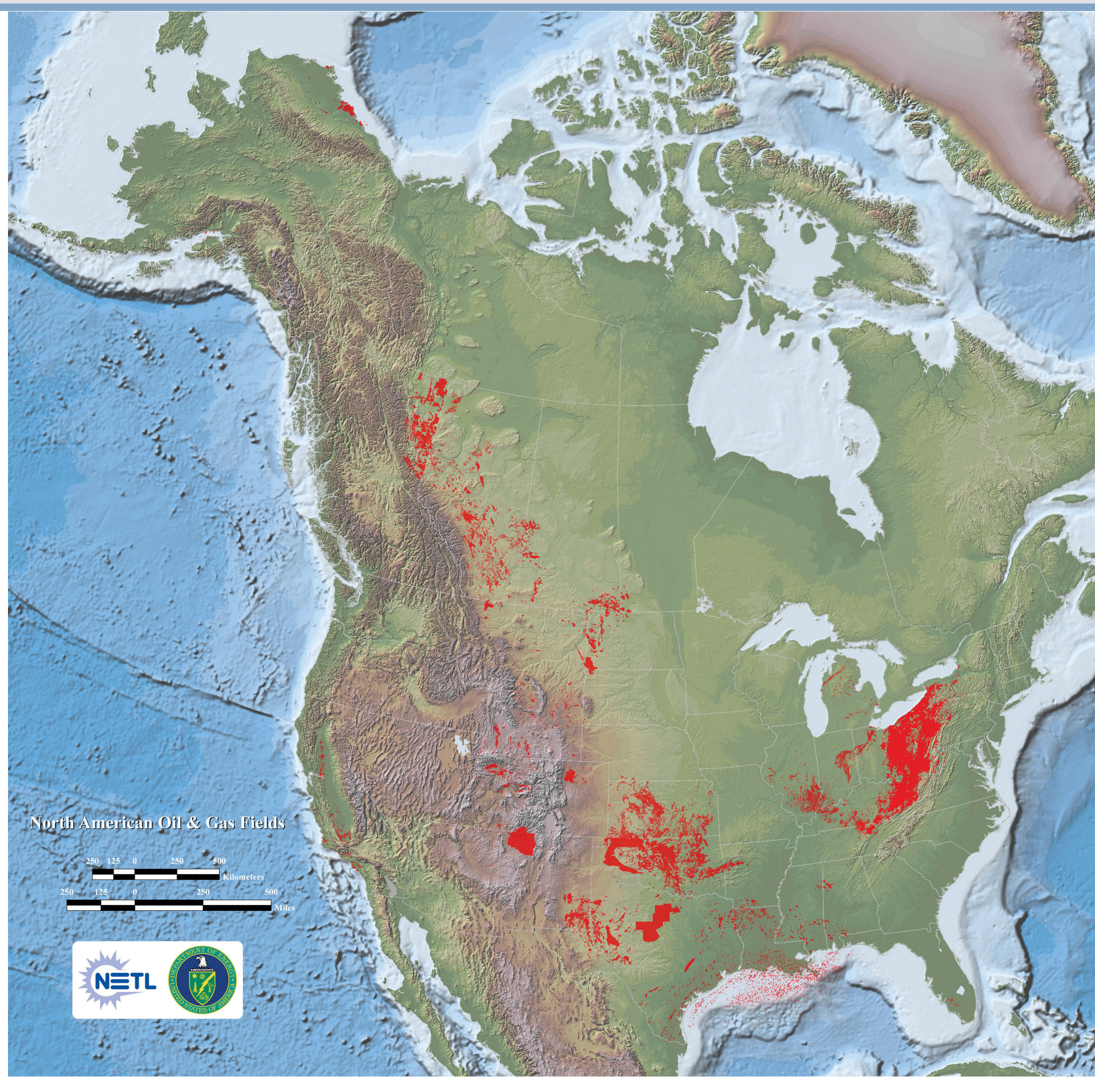
Storage in oil and gas reservoirs



http://www.netl.doe.gov/technologies/carbon_seq/refshelf/atlas/index.html

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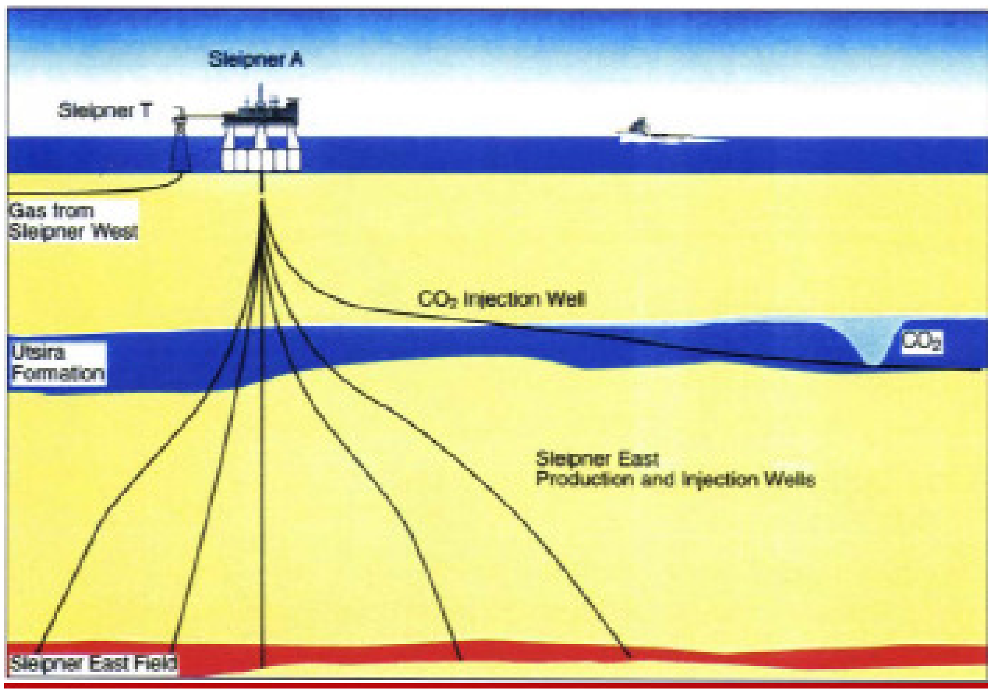
Current projects – planned or underway

Source: Peter Cook. CO2CRC

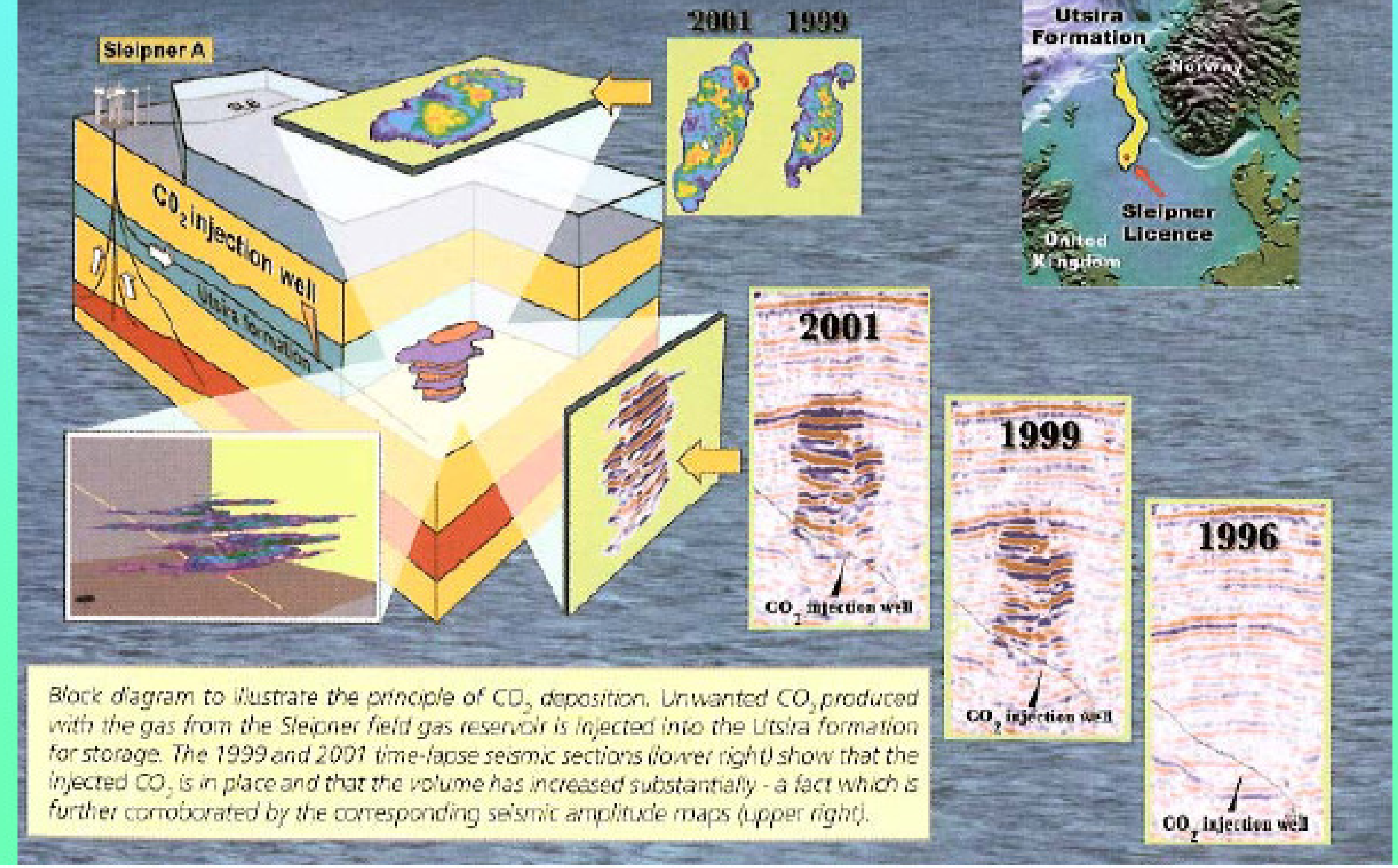
Sleipner Project

- 1 million tonnes CO_2 injected per year
- CO_2 separated from produced gas
- Avoids Norwegian CO_2 tax
- Gravity segregation and flow under shale layers controls CO_2 movement



www.statoil.com, 2002

Time lapse (4D) seismic tracking of injected CO_2



Block diagram to illustrate the principle of CO_2 deposition. Unwanted CO_2 produced with the gas from the Sleipner field gas reservoir is injected into the Utsira formation for storage. The 1999 and 2001 time-lapse seismic sections (lower right) show that the injected CO_2 is in place and that the volume has increased substantially - a fact which is further corroborated by the corresponding seismic amplitude maps (upper right).

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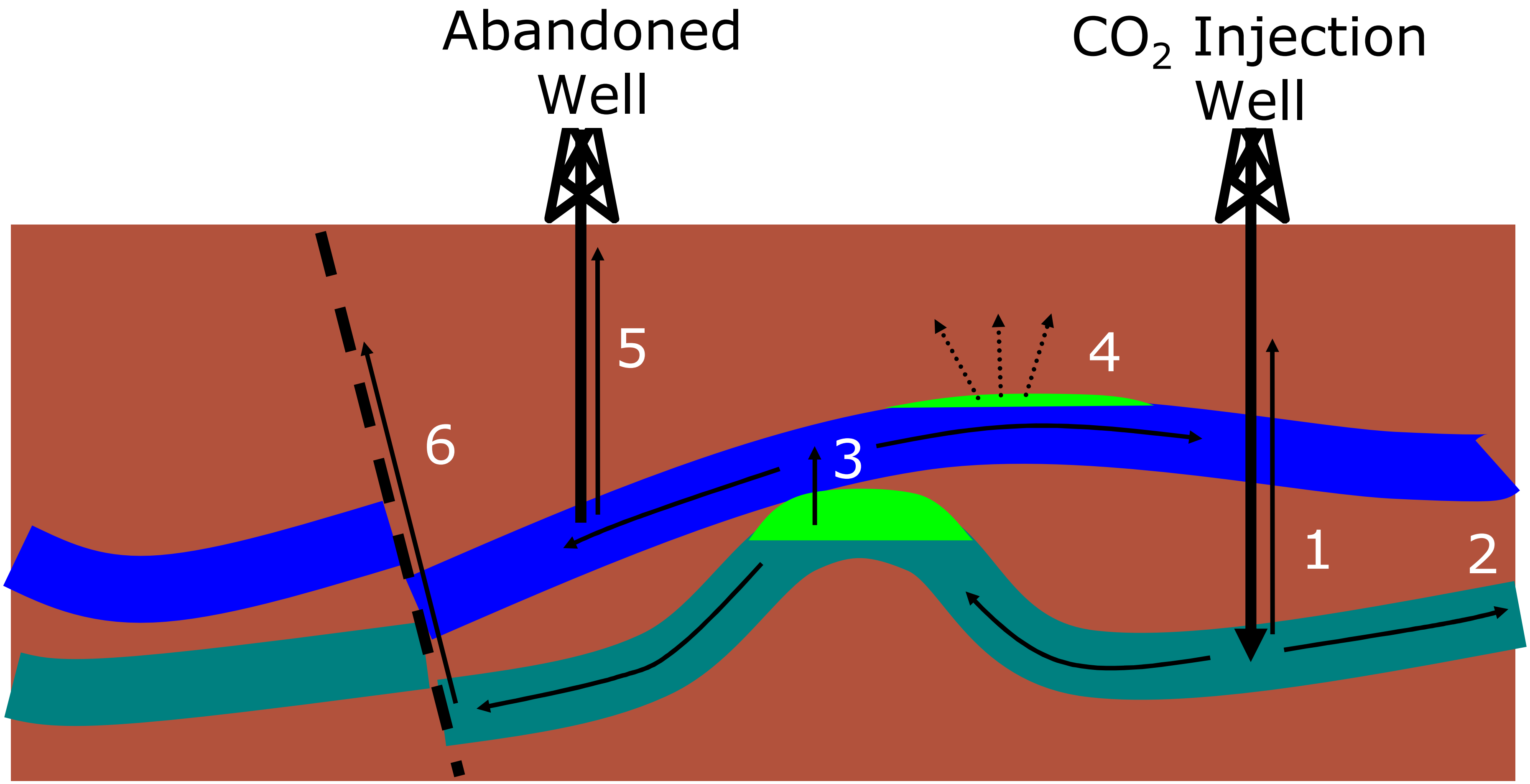
How could CO_2 escape?



Trapping background

How can you be sure that the CO_2 stays underground?

- **Dissolution**

  CO_2 dissolves in water – 1,000-year timescales

  Denser CO_2-rich brine sinks

- **Chemical reaction**

  acid formed —host rock→ carbonate precipitation – 10^3 – 10^9 years

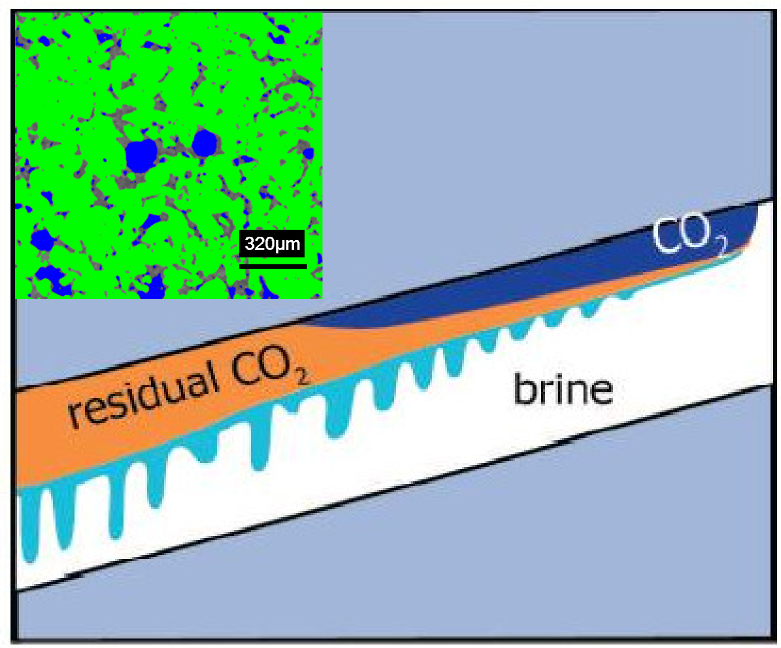
- **Hydrodynamic Trapping**

  Trapping by impermeable cap rocks

- **Capillary Trapping**

  rapid (decades): CO_2 as pore-scale bubbles surrounded by water.

  Process can be designed: SPE 115663 Qi *et al.*



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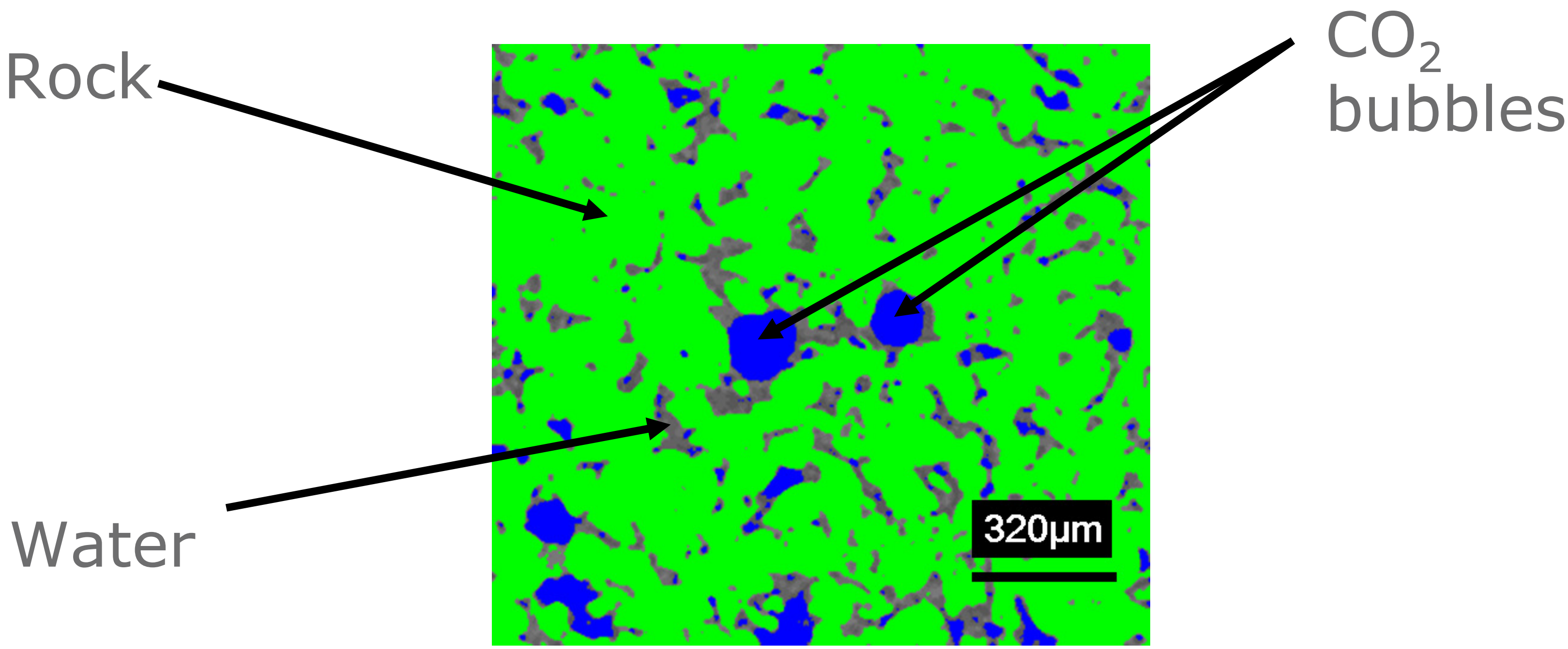
CO_2 trapping

As CO_2 migrates through the rock, it can be displaced by water, trapped in pore-scale bubbles and cannot move further



Dong, 2007

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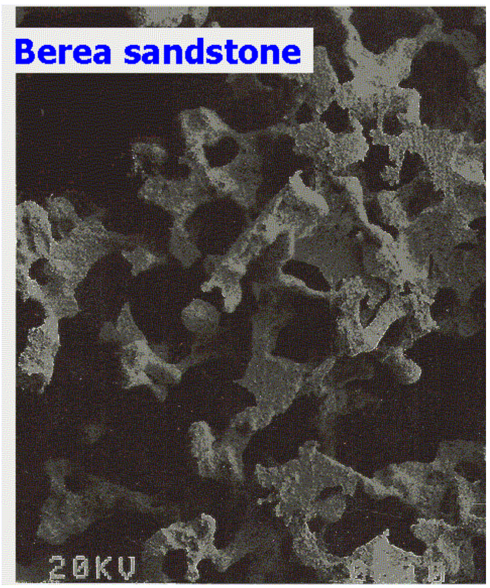
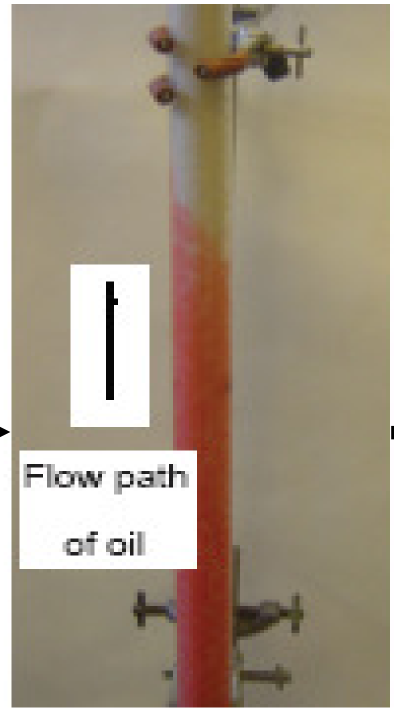
Spread of CO_2 is an inherently multi-scale process



Pore scale:

Model flow through pores directly

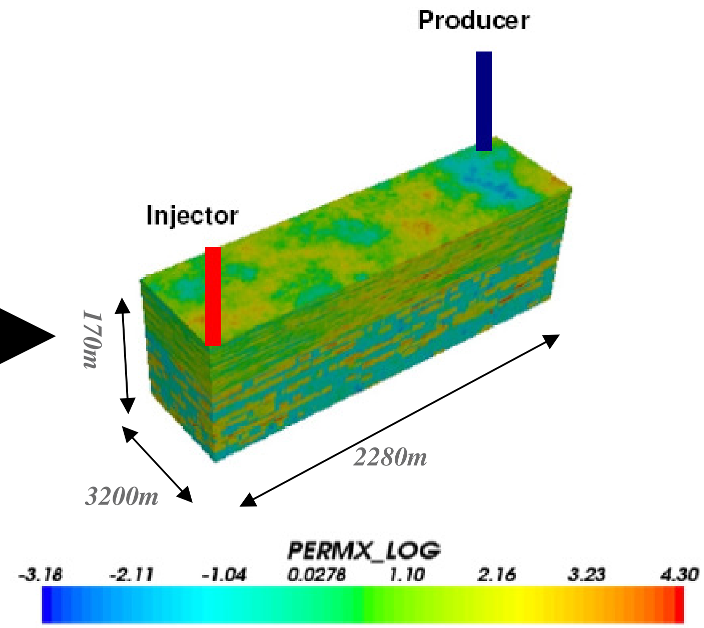
µm-mm



Laboratory scale:

Model flow using continuum approximation

cm-m



Field scale:

Model flow using continuum approximation

m-km

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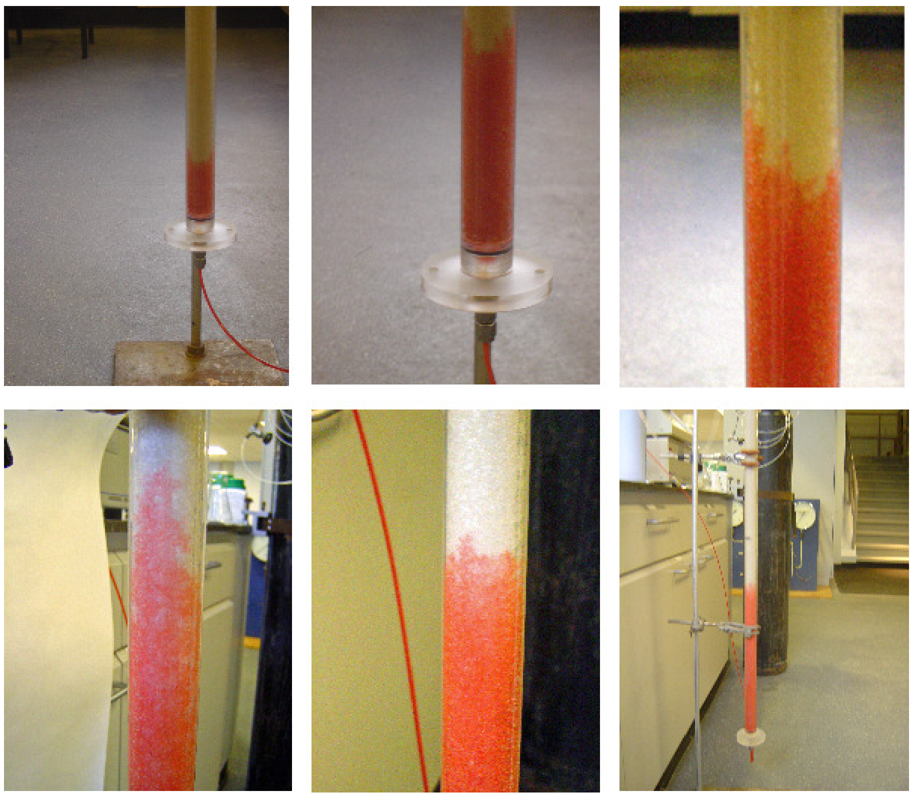
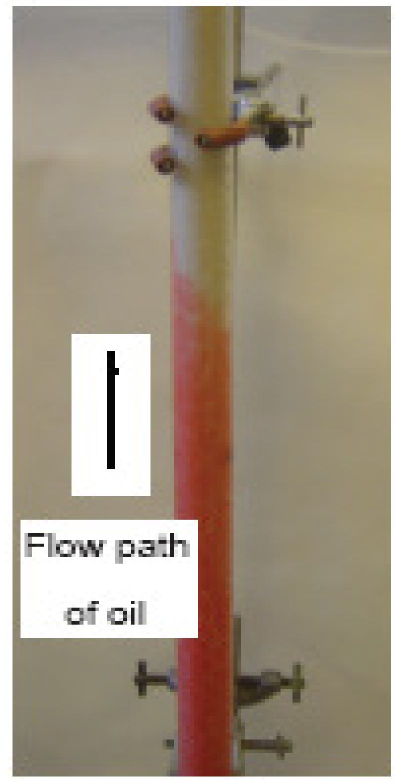
CO_2 trapping experiments



Sand-packed column injected with non-wetting fluid (oil dyed red).



Flow path of oil

Pentland et al., SPE 115697

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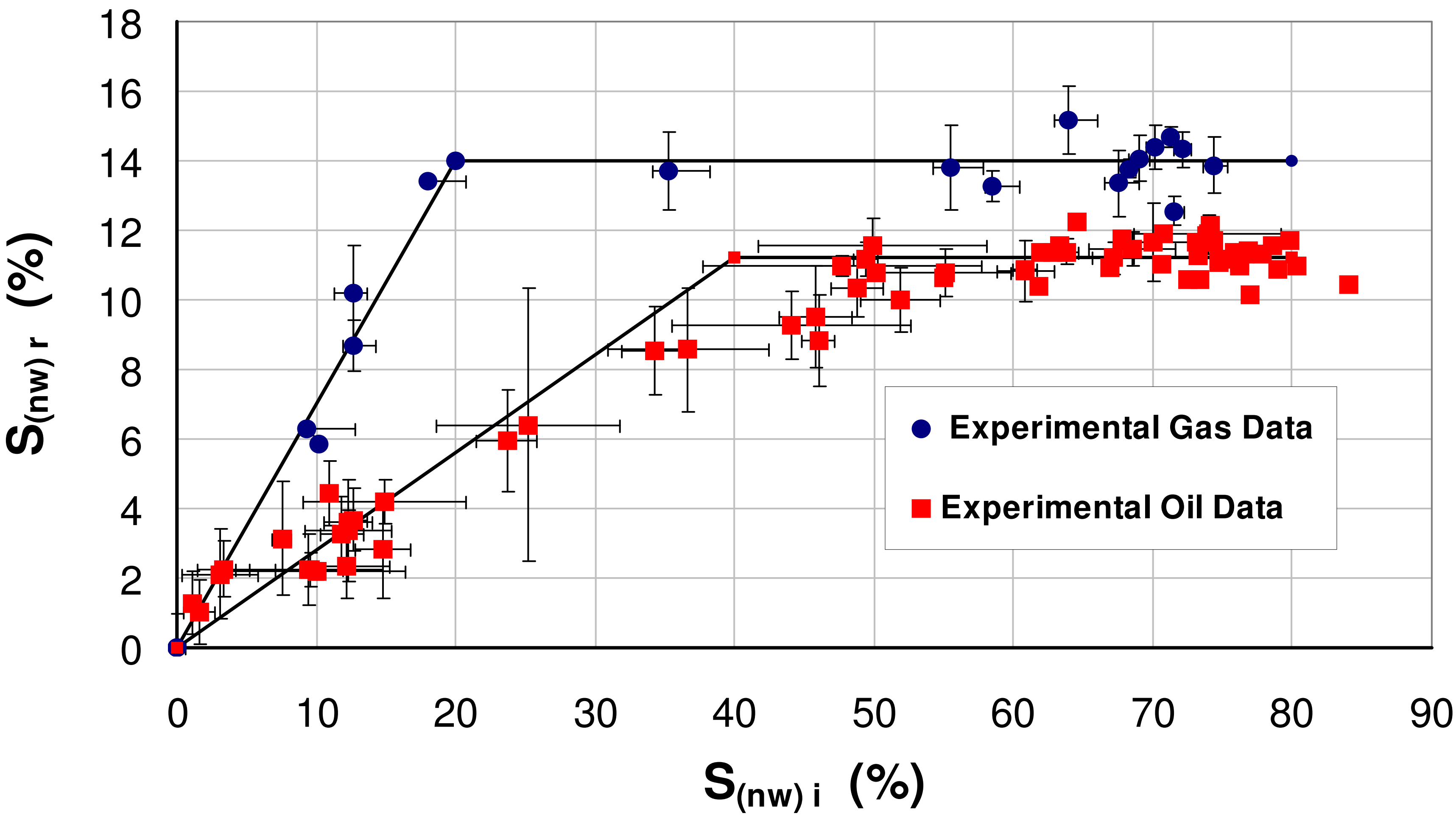
Experimental results – trapping curves



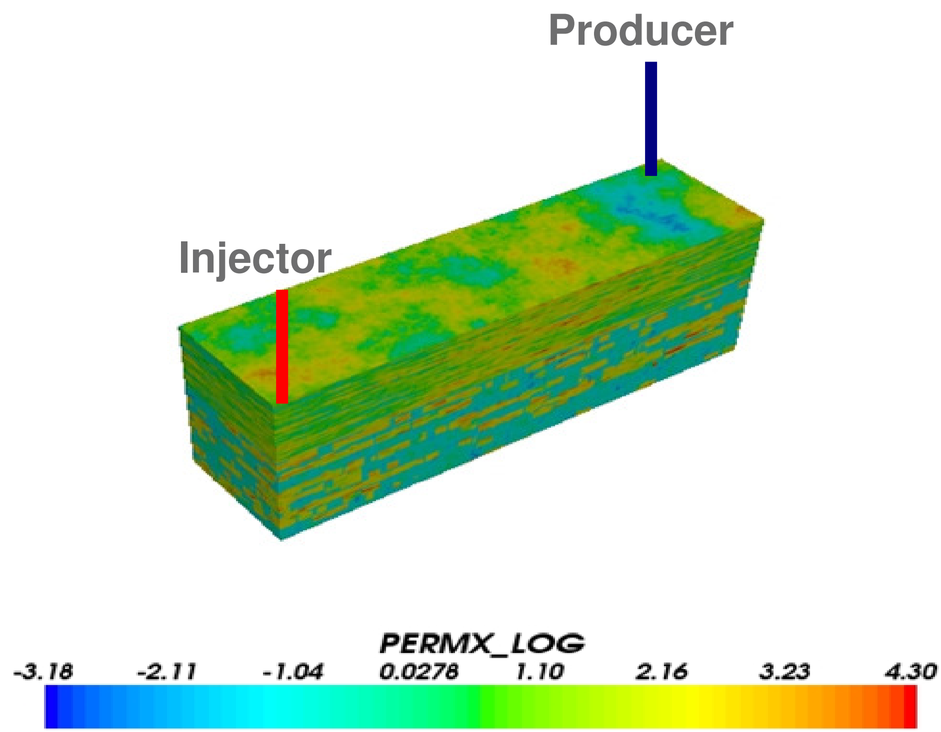
Design of CO_2 storage

A case study on a highly heterogeneous field representative of an aquifer below the North Sea:

❖ Use chase water to trap CO_2 during injection

❖ 1D results are used to design a stable displacement

❖ Simulations are used to optimize trapping



SPE 10 reservoir model, 1,200,000 grid cells (60X220X85), 7.8 Mt CO_2 injected.

Qi et al., SPE 109905

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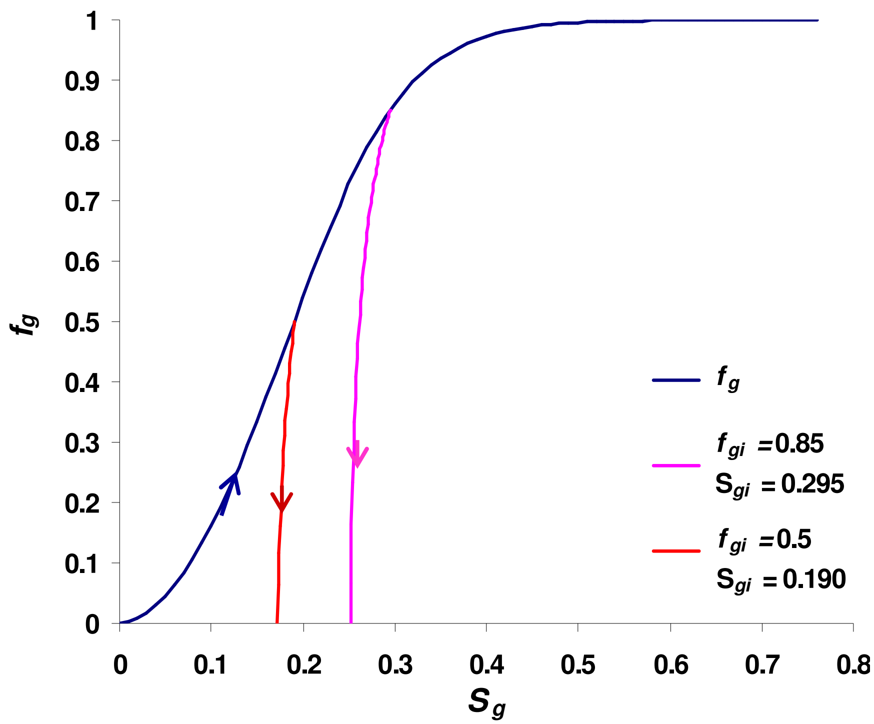
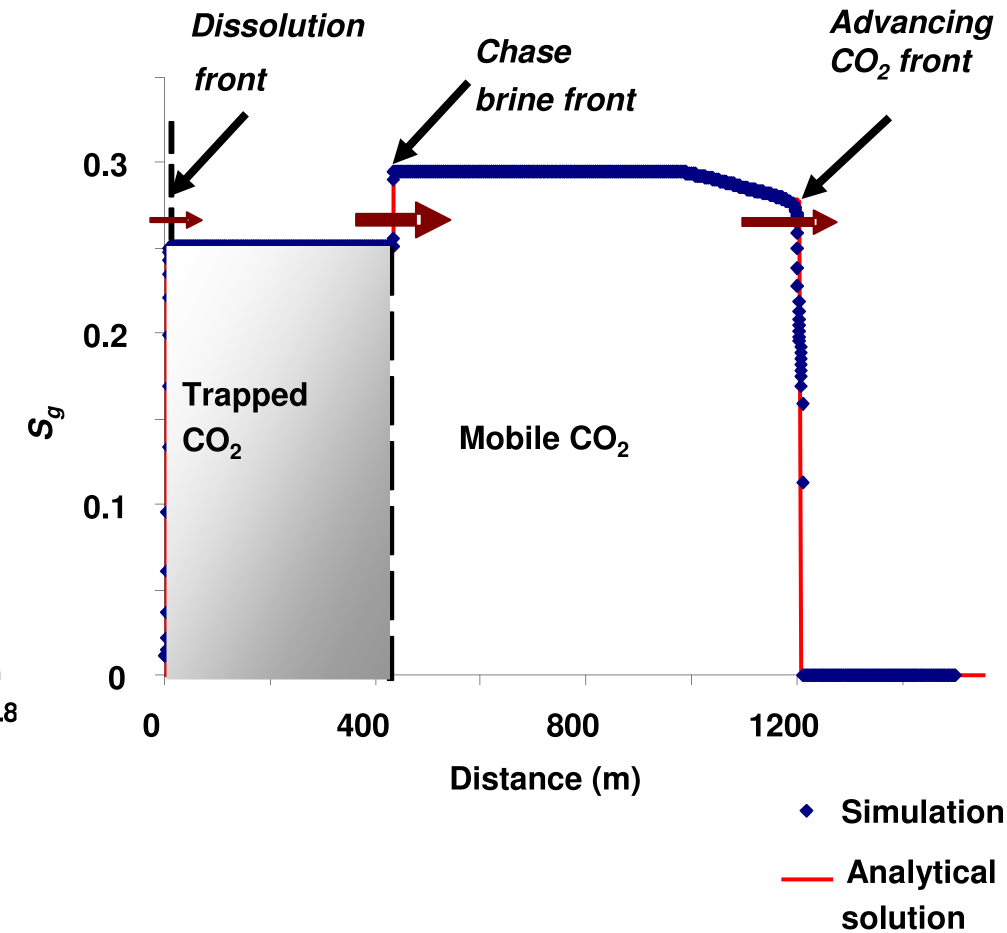
1D results for aquifer storage



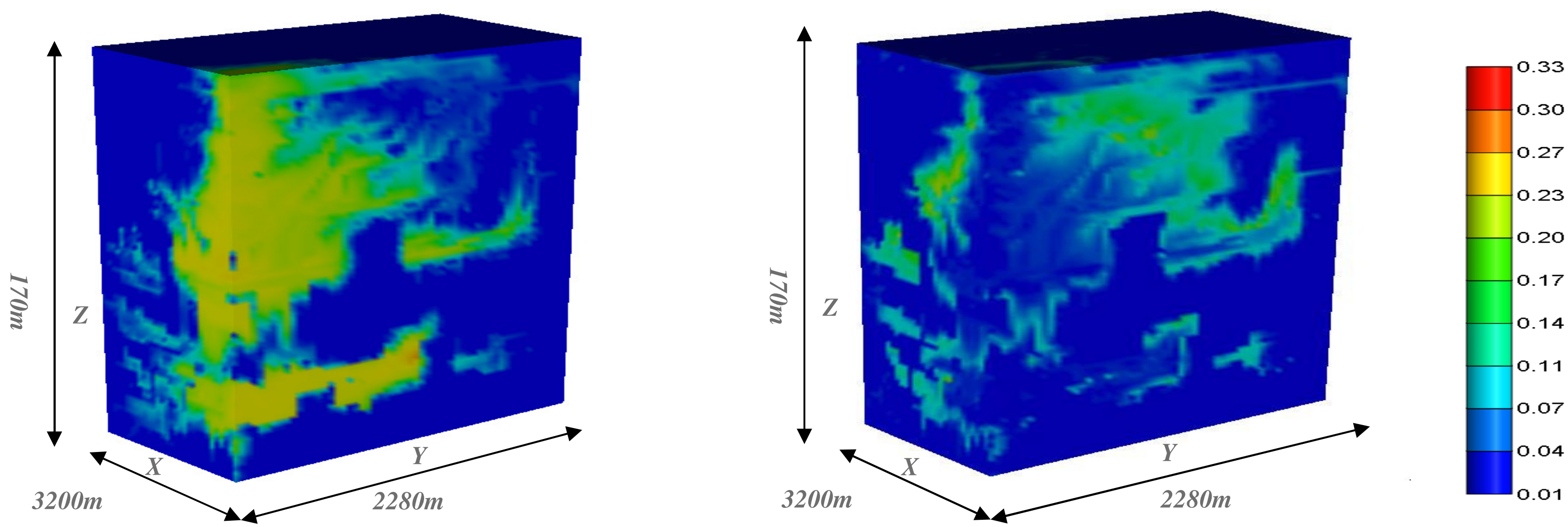
The CO_2-phase fractional flow f_g as a function of CO_2 (gas) saturation, S_g.



Qi et al., SPE 109905

3D results for aquifer storage

20 years of water and CO_2 injection followed by 2 years of water injection in realistic geology



Trapped CO_2 saturation   Mobile CO_2 saturation

95% of CO_2 trapped after 4 years of water injection

Qi et al., SPE 109905

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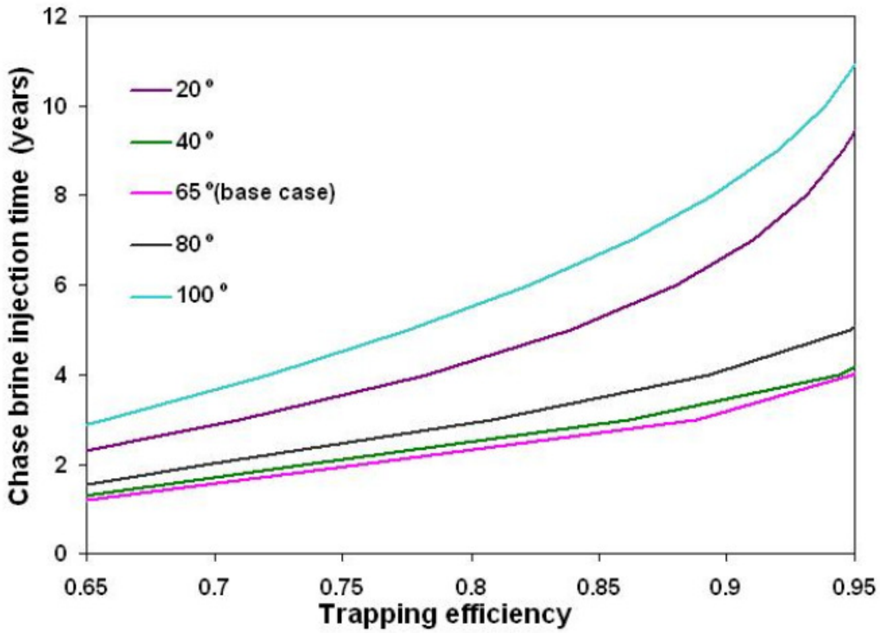
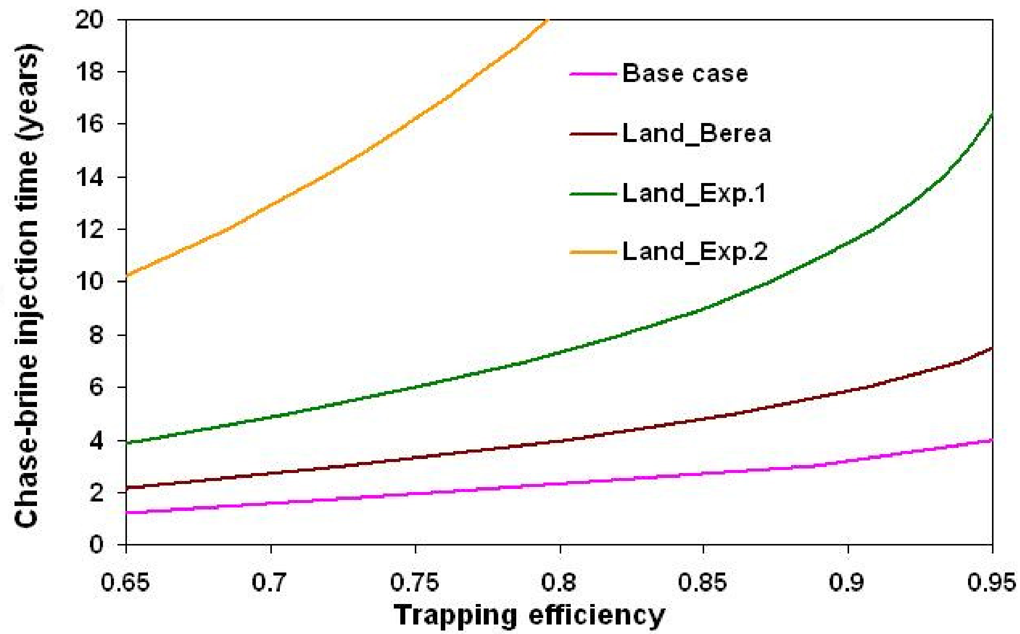
How long until the CO_2 is immobilized?

- ❖ Depends on wettability of rock and trapping model





❖But can measure this directly!

Qi et al., to appear JGGC

General injection strategy

To maximize CO_2 storage in an aquifer:

- ❖ Inject CO_2+brine where mobility ratio = 1.0 for a stable displacement
- ❖ Inject chase brine that is 25% of the CO_2 mass
  - ❖90-95% of the CO_2 is trapped for most realistic case
  - ❖ As little as 65% may be trapped for worst case
  - ❖It all rests on how much is trapped as a function of initial saturation…

Qi et al., to appear JGGC

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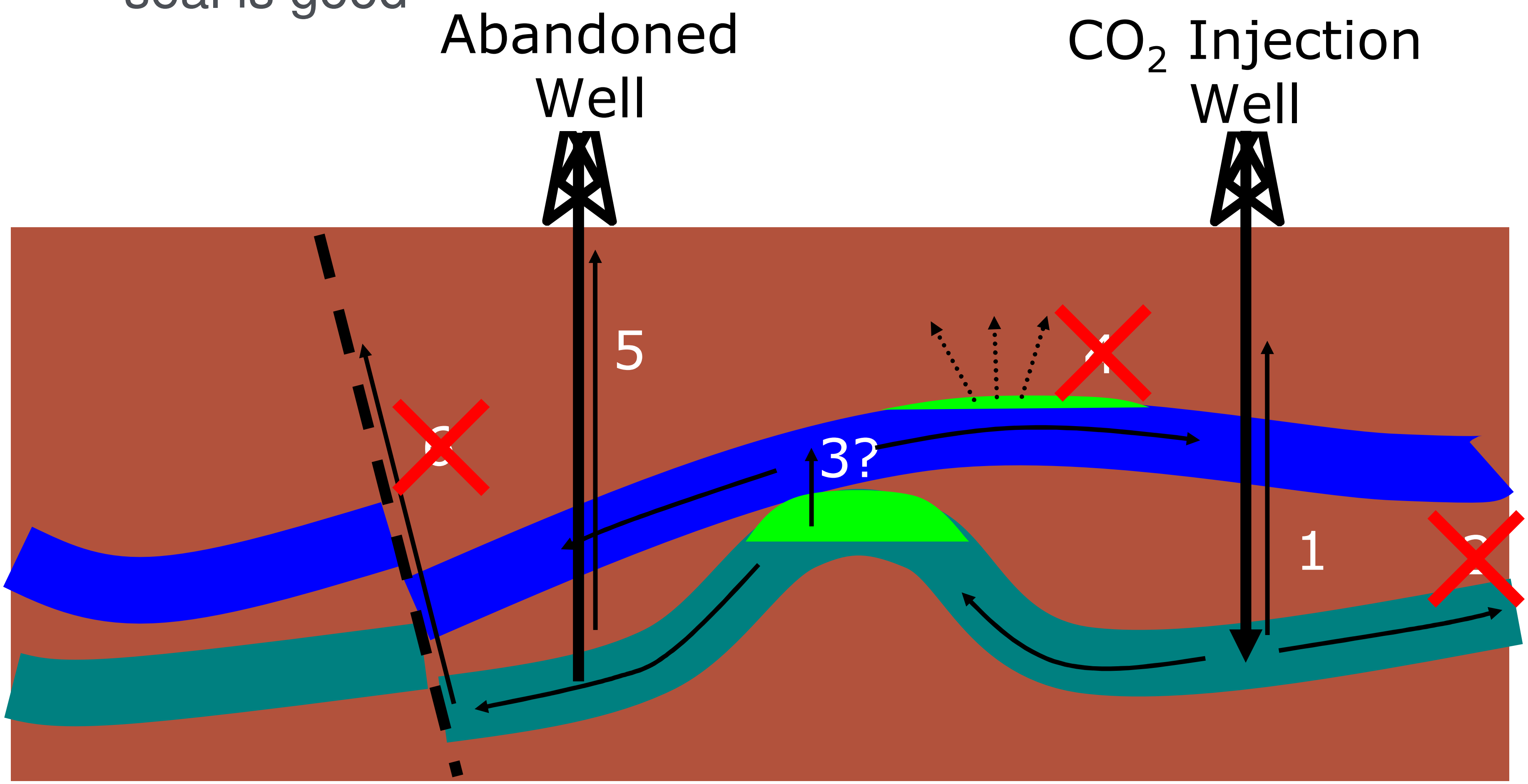
How could the CO_2 escape?

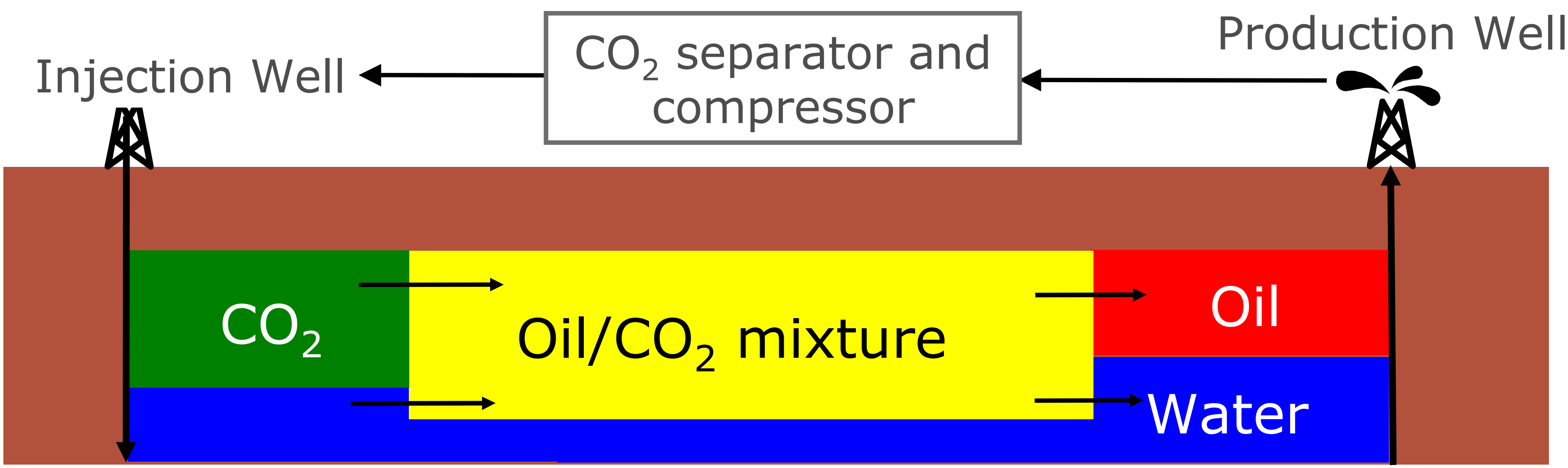
Presence of hydrocarbons indicate that the geologic seal is good



Storage in oil and gas reservoirs

- Practical experience injecting CO_2 into oil reservoirs
- Knowledge of geology so less chance of CO_2 escaping
- Far from emission sources

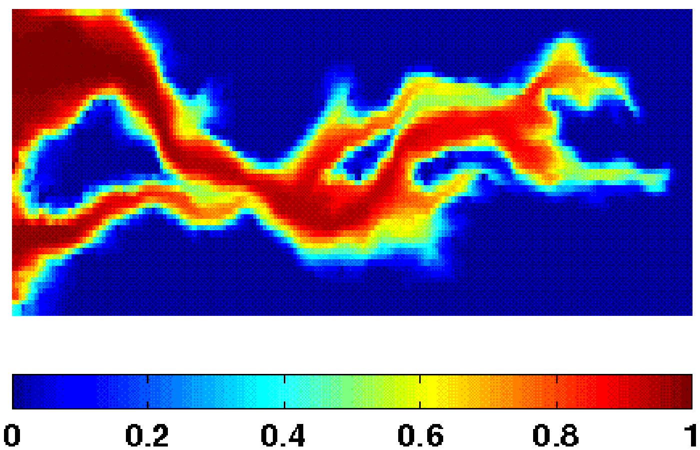
- As CO_2 migrates it is trapped at the pore scale
- CO_2 will mix with oil and improve oil recovery



CO_2 storage and enhanced oil recovery (EOR)

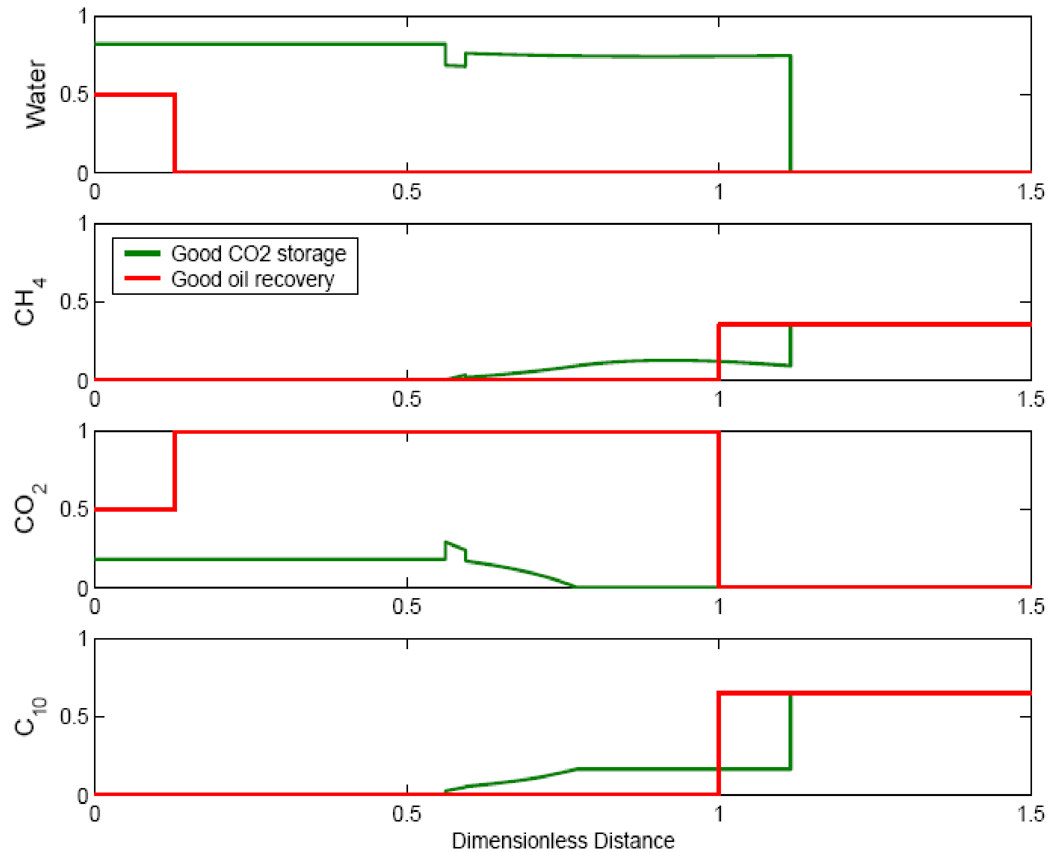
❖ CO_2 injection displaces oil very efficiency

…but has poor sweep

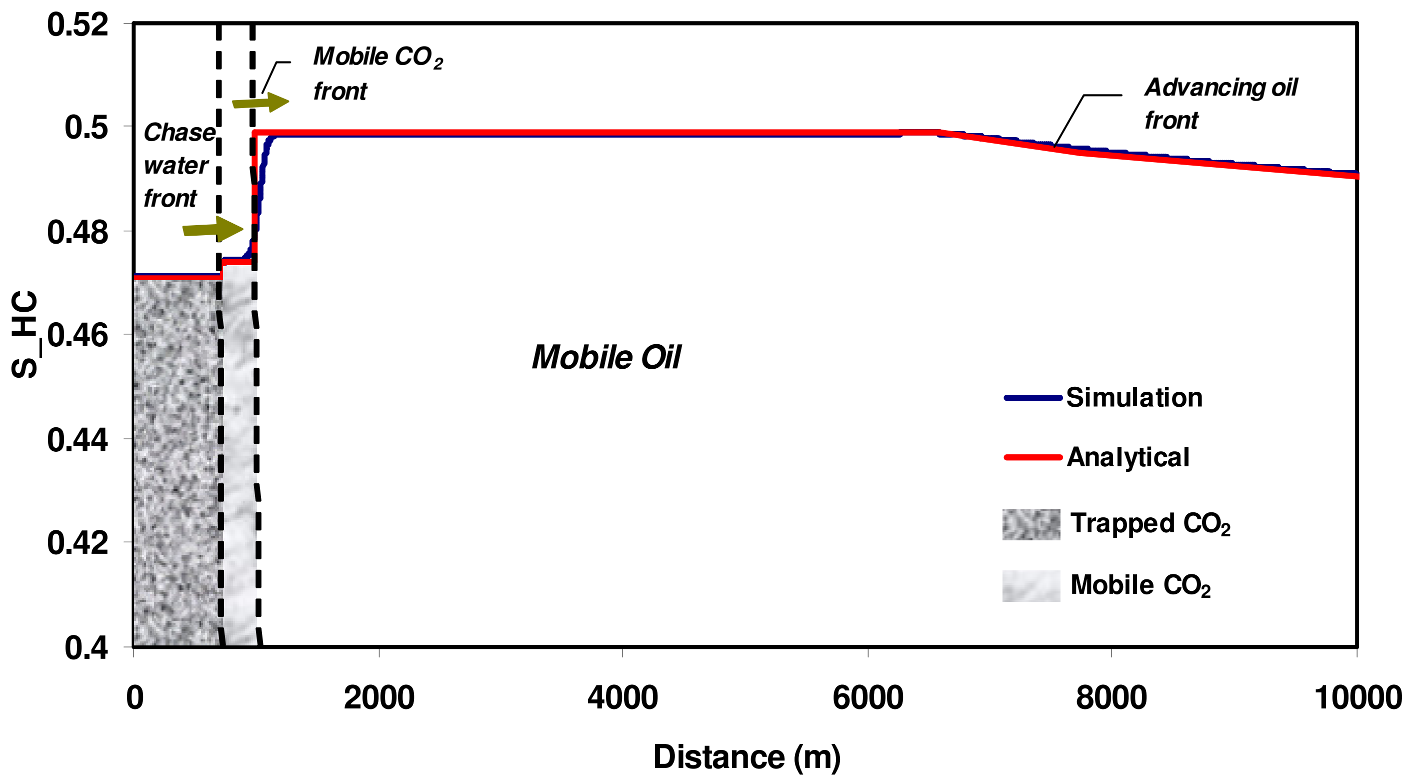


❖Water alternating with gas (WAG) injection improves sweep

❖Competing goals: CO_2 storage vs. EOR in WAG injection



1D results for reservoir storage

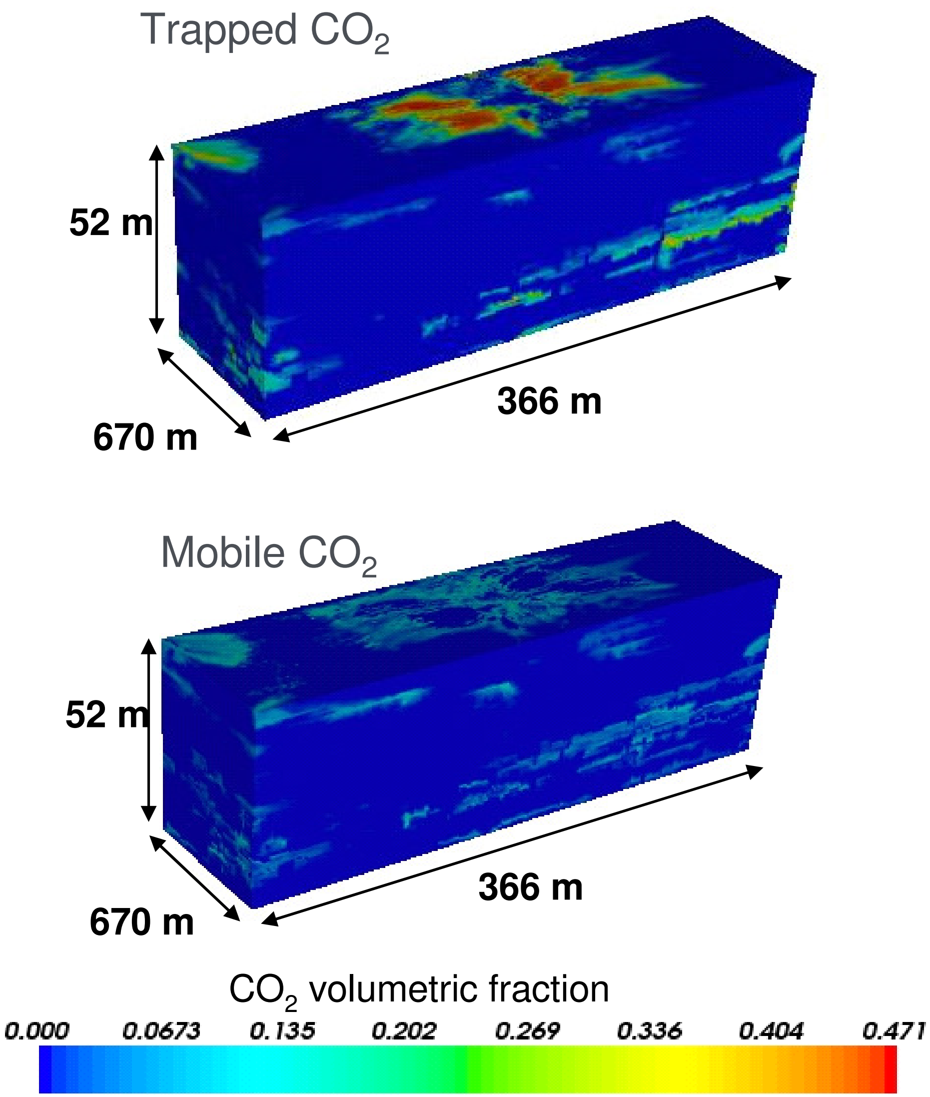


❖First-contact miscible CO_2 injection

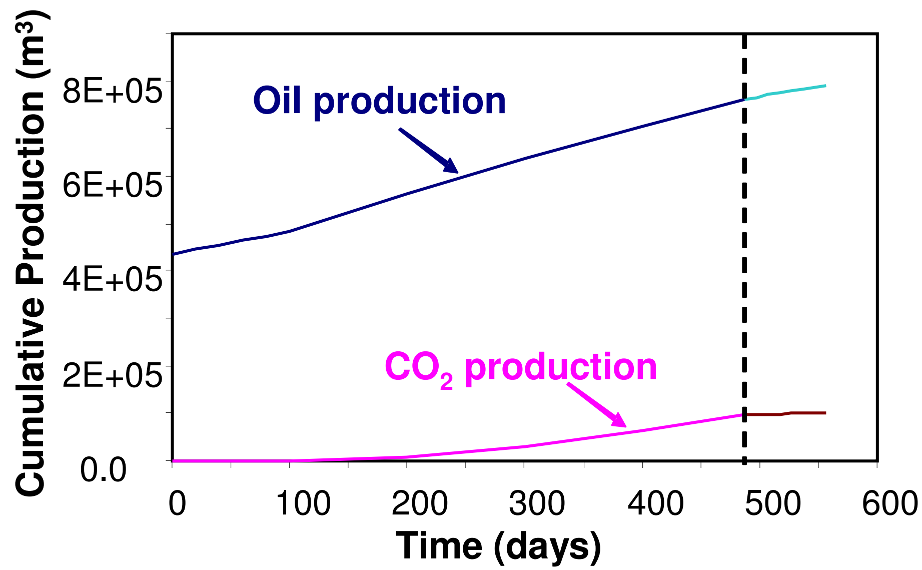
❖CO_2 injection at f_{CO2}=0.7 followed by chase water injection

Qi et al., SPE 115663

Storing CO_2 in the oil field



- ❖Increased oil recovery offsets cost of capture, making CO_2 storage more economic
- ❖Currently there are 66 CO_2 injection projects worldwide



Qi et al., SPE 115663

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Conclusions

❖ Carbon capture and storage is a key technology in our efforts to avoid dangerous climate change.

❖ If it is to make a difference, carbon capture and storage will deal with volumes of fluid similar to those currently handled by the oil industry.

❖ We have addressed a major public concern: how to ensure that the injected CO_2 stays underground.

❖ Capillary rapping is an important mechanism to store CO_2 as an immobile phase. Our study showed that brine + CO_2 injection can trap more than 90% of the CO_2 injected

Current and future work

Making the process work

- ❖ Collaborate with colleagues on novel capture technology and systems design – consider the whole process from plant to storage.
- ❖ Continue gathering **experimental data** at typical storage conditions.
- ❖ Understand behaviour in field-scale injection projects.

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Thanks To:

All of you for listening!

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Jon Gibbins – Imperial

Lynn Orr – Stanford

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Imperial