British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

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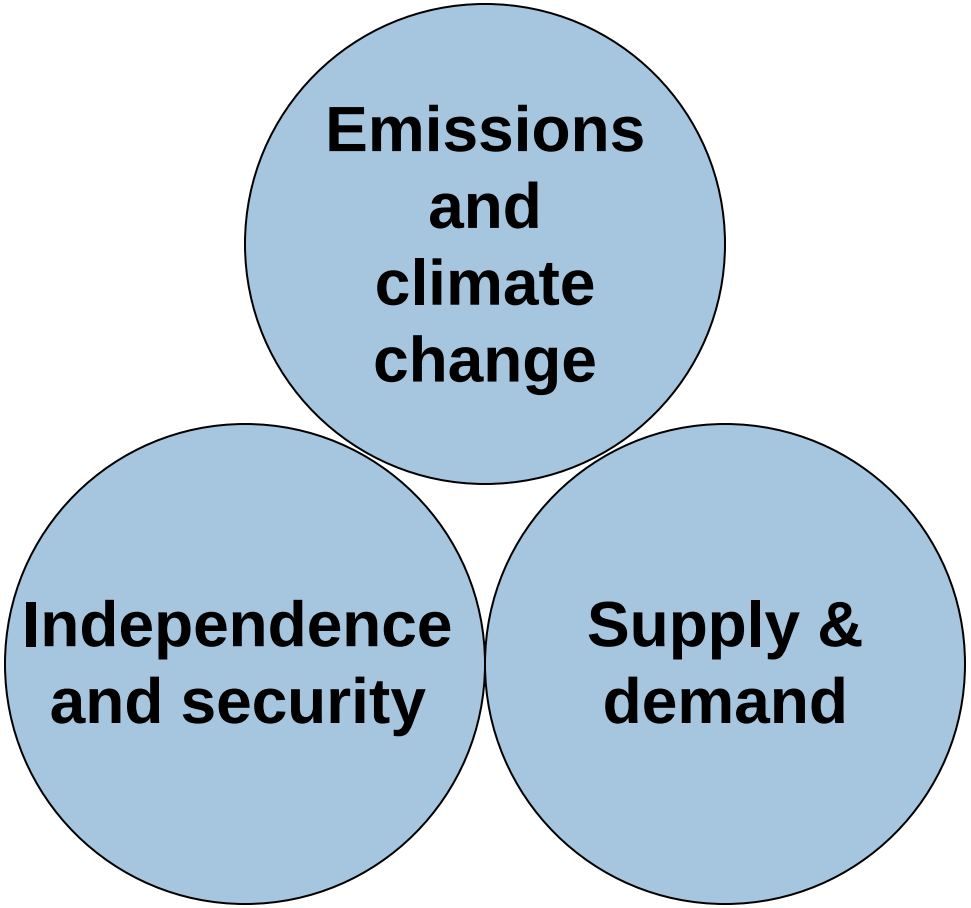
CO_2 Storage in Saline Aquifers

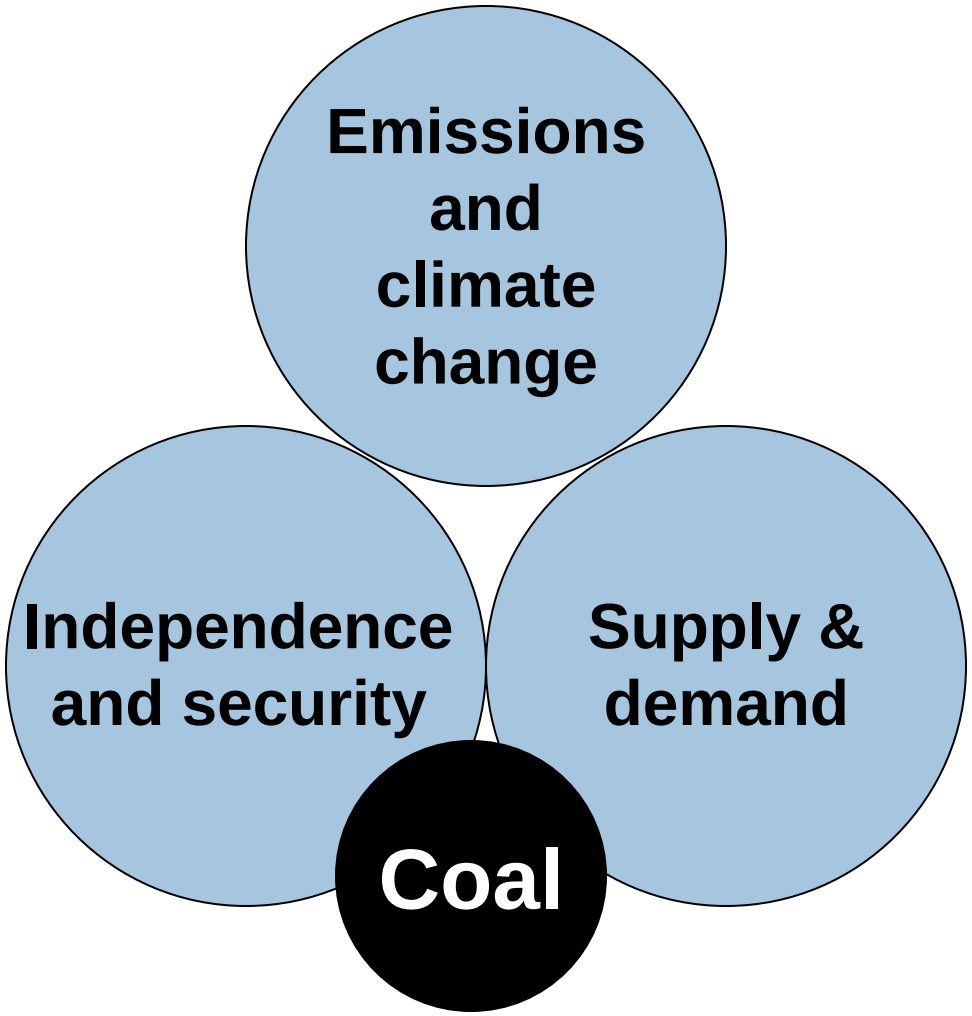
UK Groundwater Forum May 2010

Daniel Smith, British Geological Survey

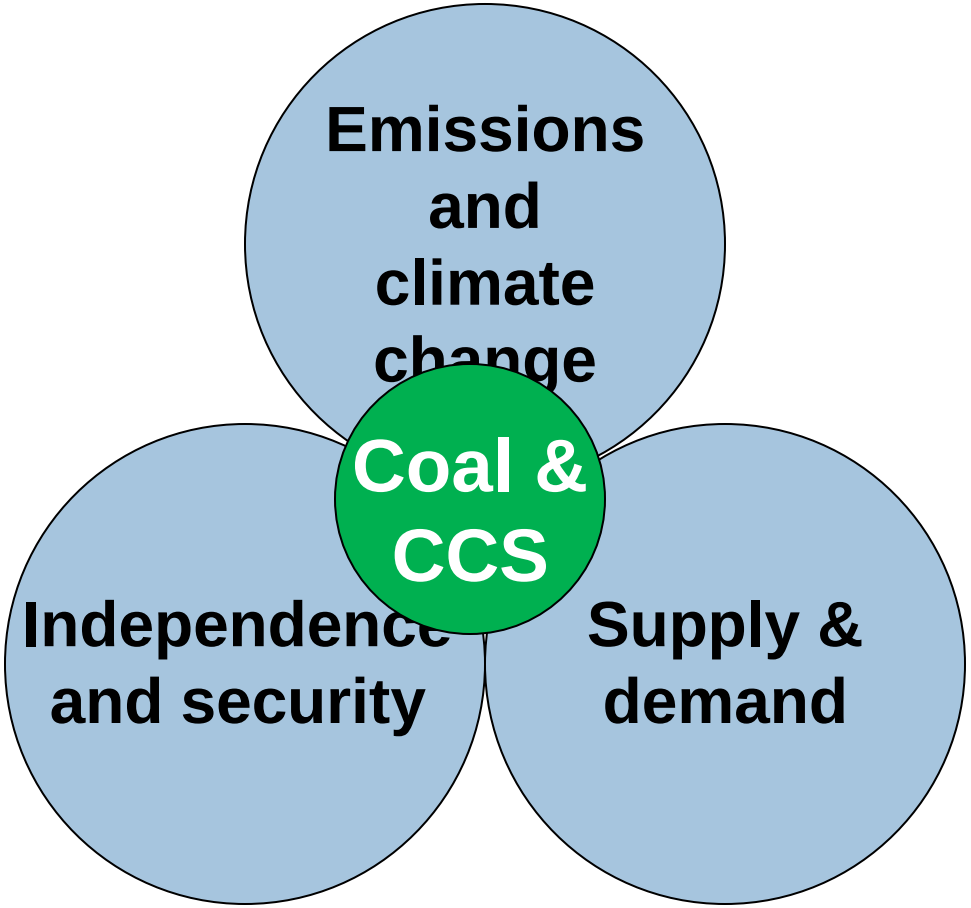
Energy – a three part problem



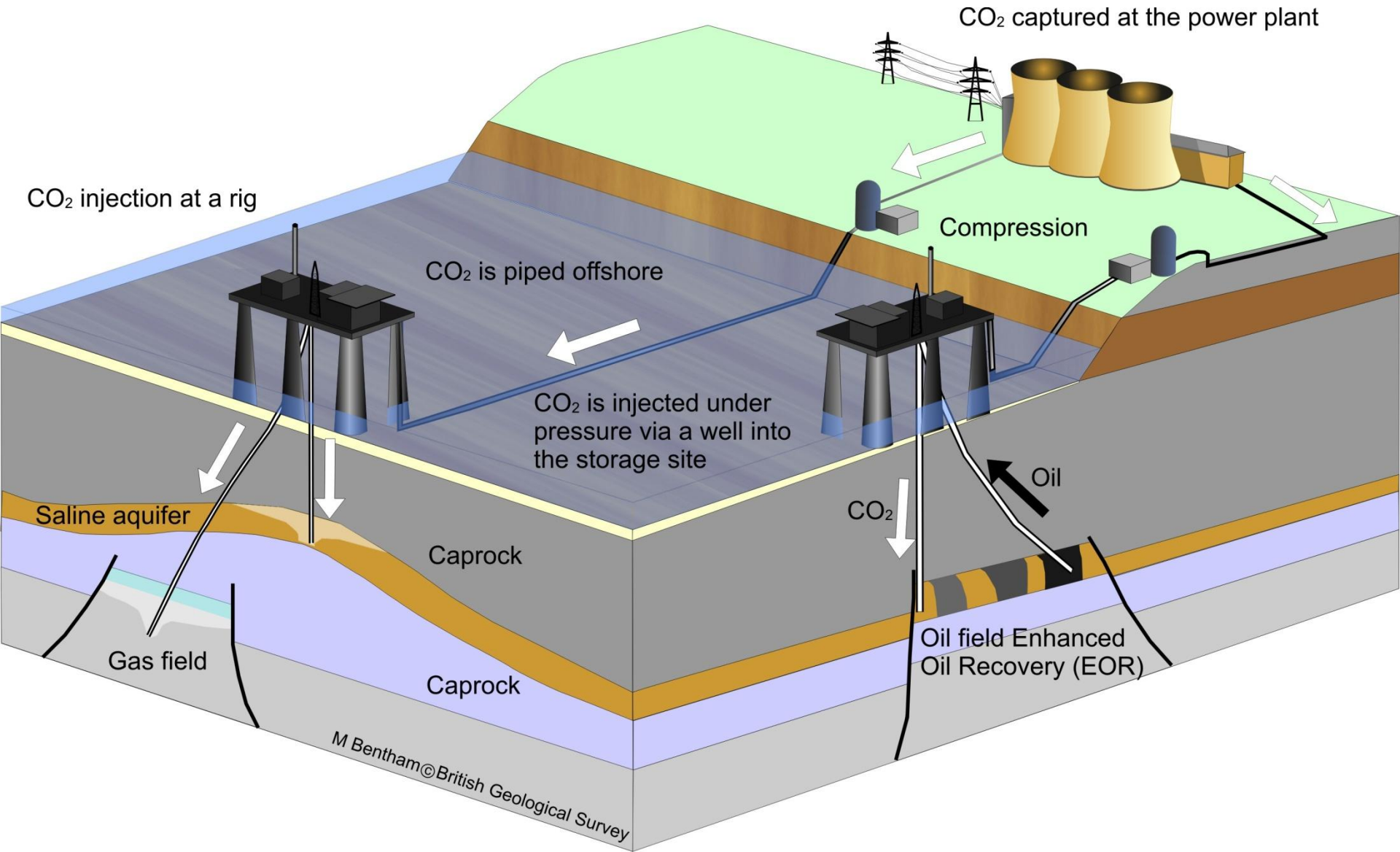
Energy – a three part problem



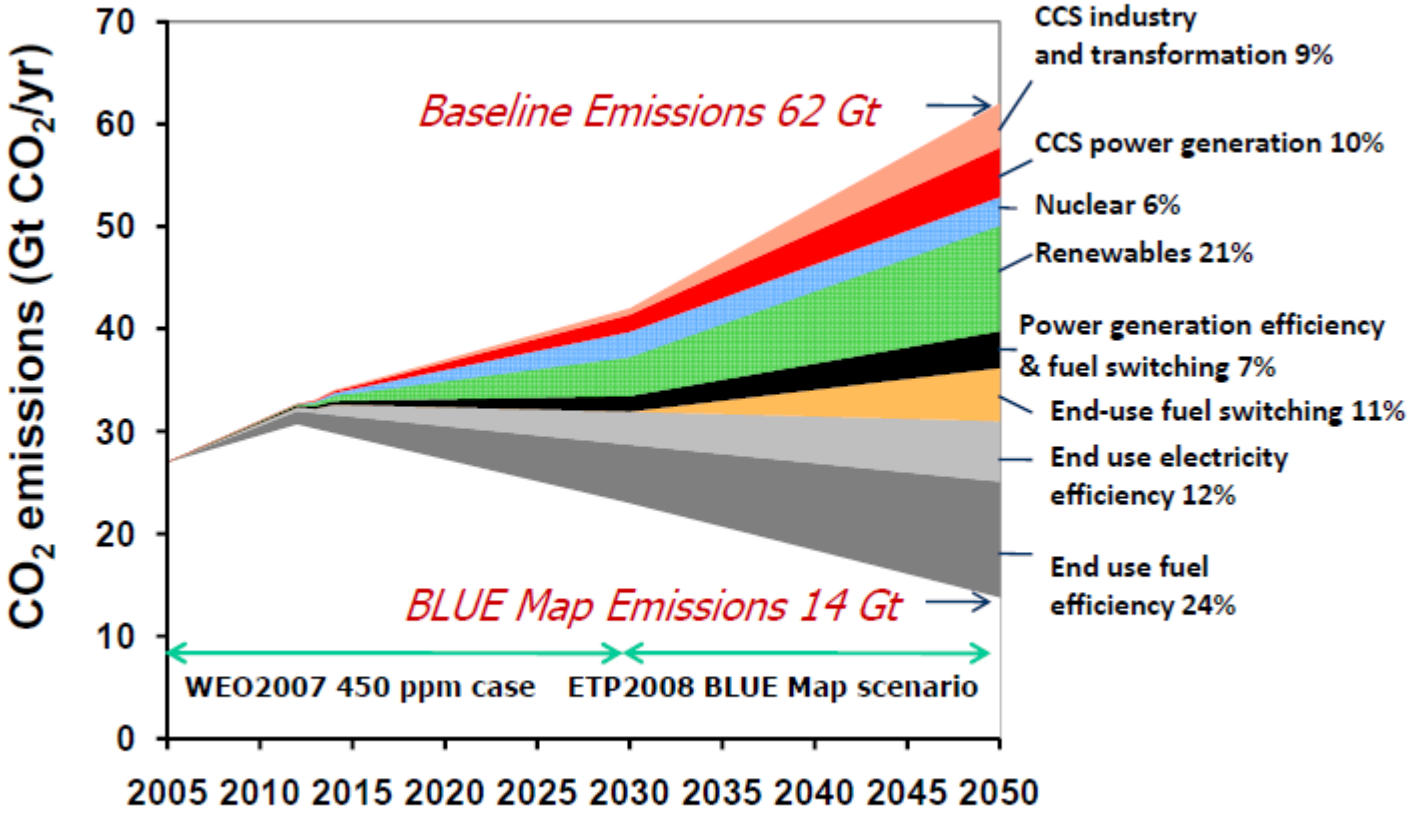
Energy – a three part problem



Carbon Capture & Storage



CCS – part of the solution



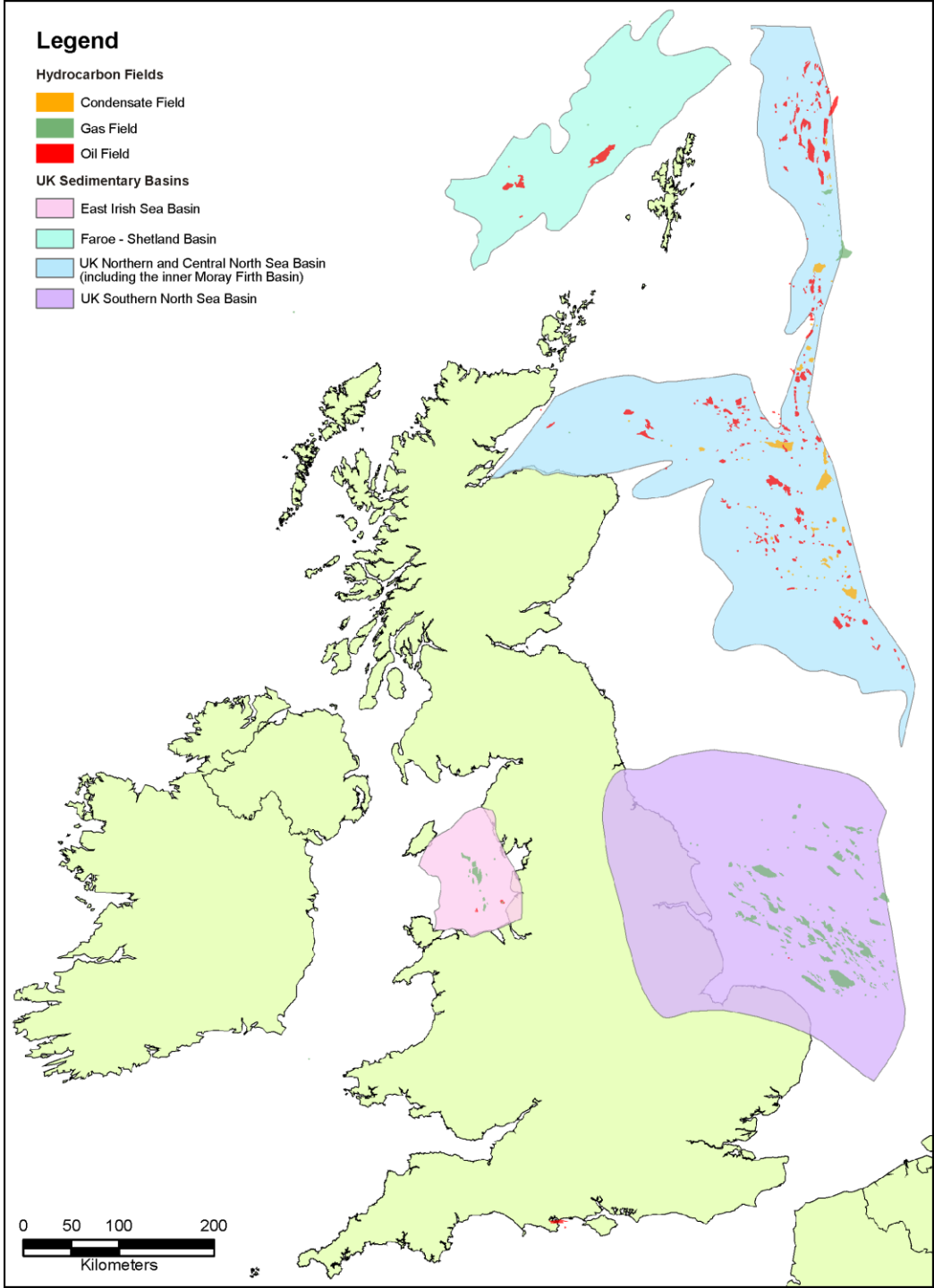
IEA BLUE Map, Energy Technology Perspectives 2008

UK CO_2 Sources

- Total UK emissions c. 560 million tonnes (Mt) CO_2
- Emissions from industrial point sources = 283 Mt CO_2
- Of the 20 largest emitters, 17 are power plant, 3 are integrated steel plants and 1 is a refinery /petrochemicals plant
- Emissions from 20 largest power stations = 132 Mt CO_2
  - If emissions from these could be reduced by 85-90%, UK emissions would be reduced by 18-20%

UK storage potential

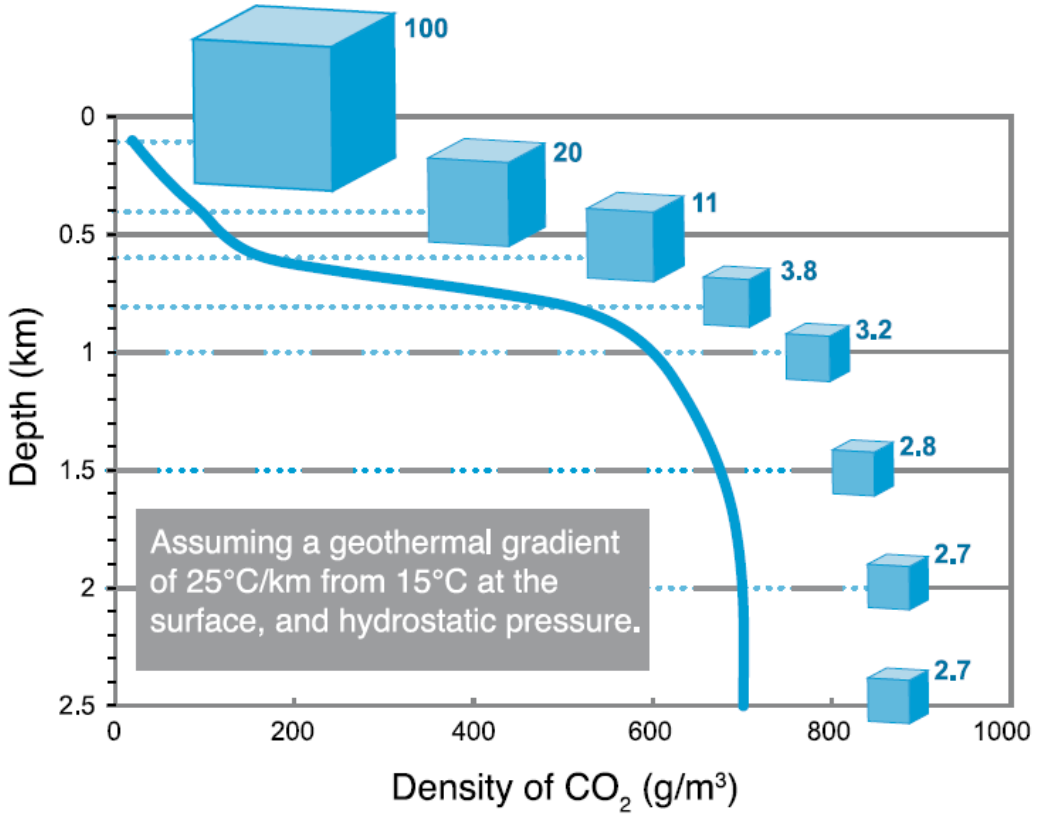
Category	Estimated CO2 capacity (Mt)
Oil fields	1175
Gas fields	5140
Gas/ condensate fields	1200
Southern North Sea basin saline aquifers	Up to 14250
East Irish Sea basin saline aquifers	Up to 630
North and central North Sea	Not quantified fully but potentially large
Total	**22395**



BGS 2006

Storage in saline aquifers

- Inject CO_2 into porous, permeable rocks.
- CO_2 injected and stored as dense phase to maximise efficiency.



IPCC 2005

Storage in saline aquifers

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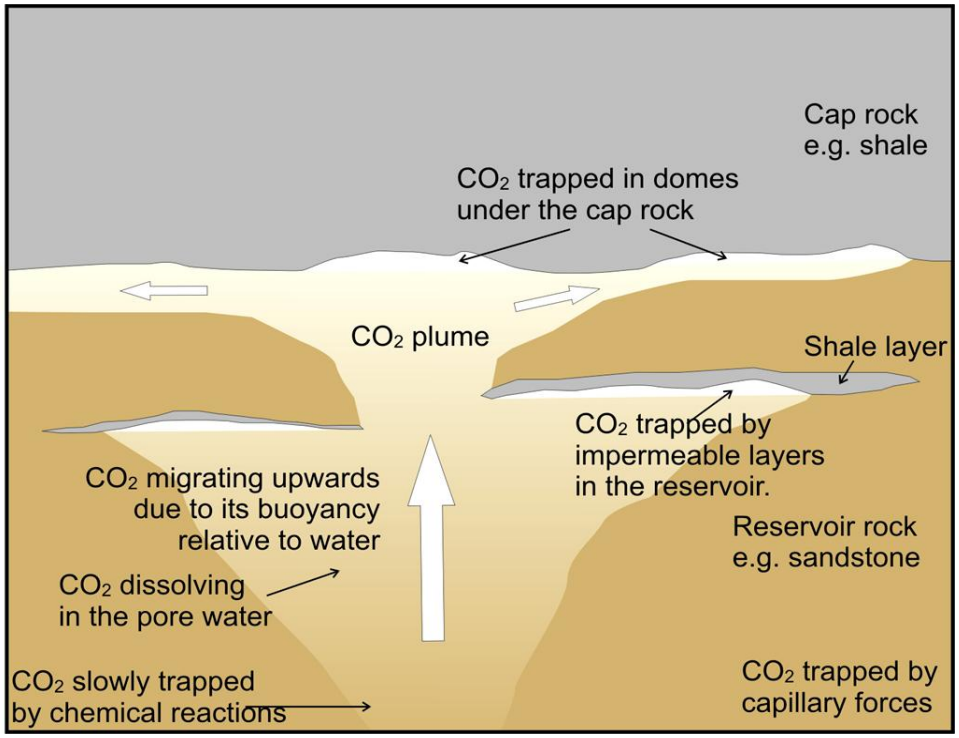

Storage in saline aquifers

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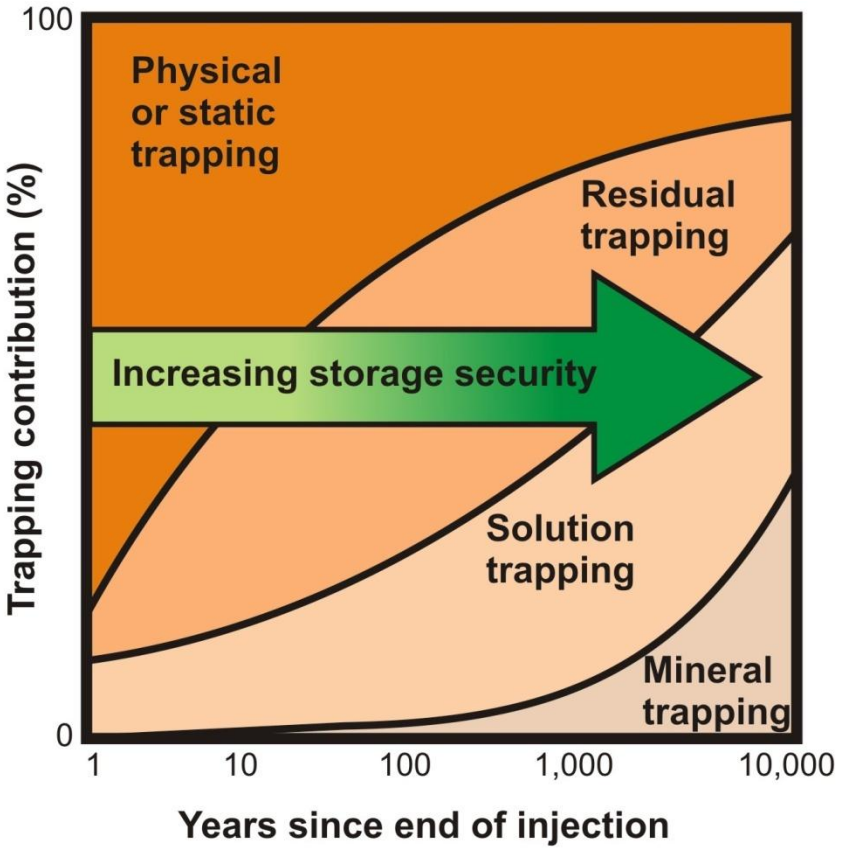
- CO_2 injected and stored as supercritical, dense phase to maximise efficiency.
- CO_2 is trapped by a number of mechanisms.
- Storage needs to be effective for ‘00s to ‘000s of years.



IPCC 2005

Reservoir geology

- Clean, clastic formations (sandstones)
- Porosity >10%
- Depth >800 m
- Thickness >20 m
- Permeability >200 mD
- Salinity >30,000 mg/l
- Ideally has structures suitable for physical trapping (anticlines, domes)

Caprock geology

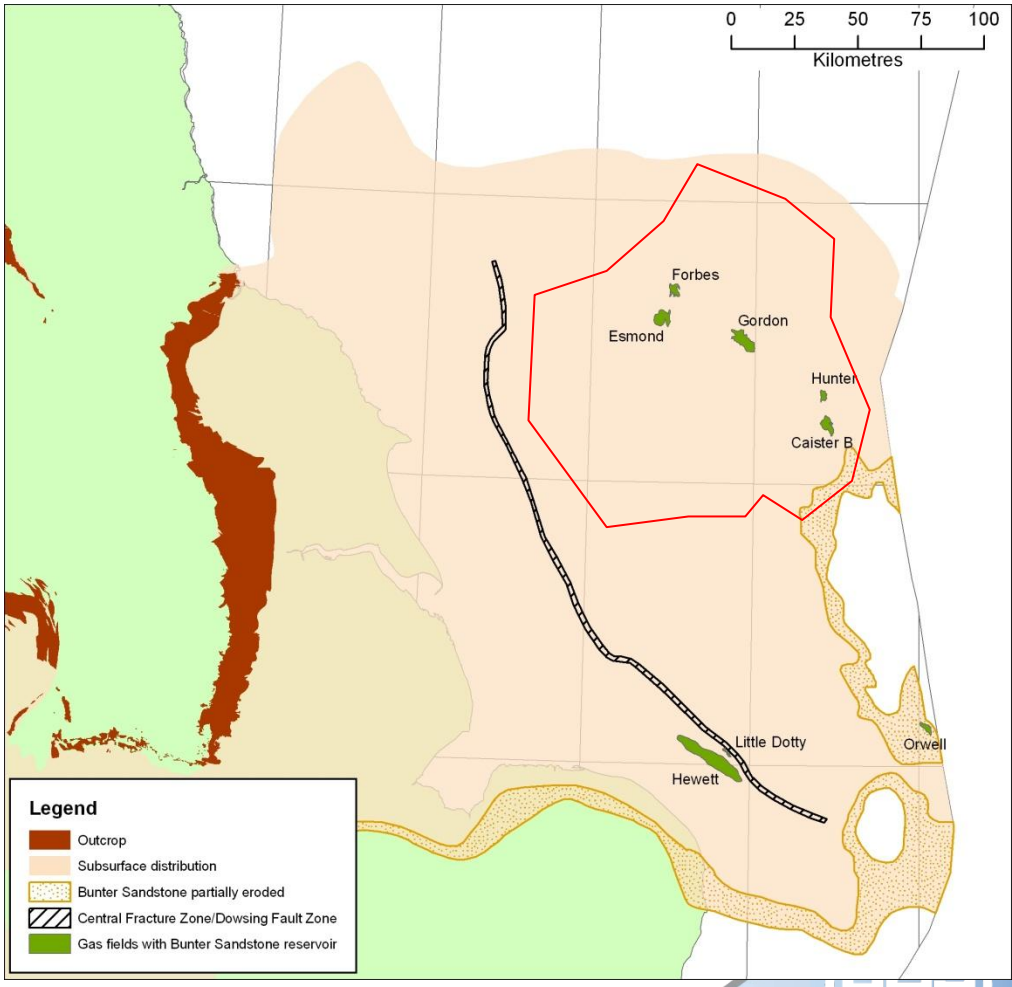
- Shale, evaporites, and dolomites are good caprock candidates.
- Needs to form an effective capillary barrier to CO_2.
- Needs to be capable of withstanding greater pressures / buoyancy forces.
- Needs to resist chemical degradation by carbonated brine.
- Ideally have multiple trapping horizons between storage reservoir and surface / any groundwater resources.

Pressure and boundary conditions

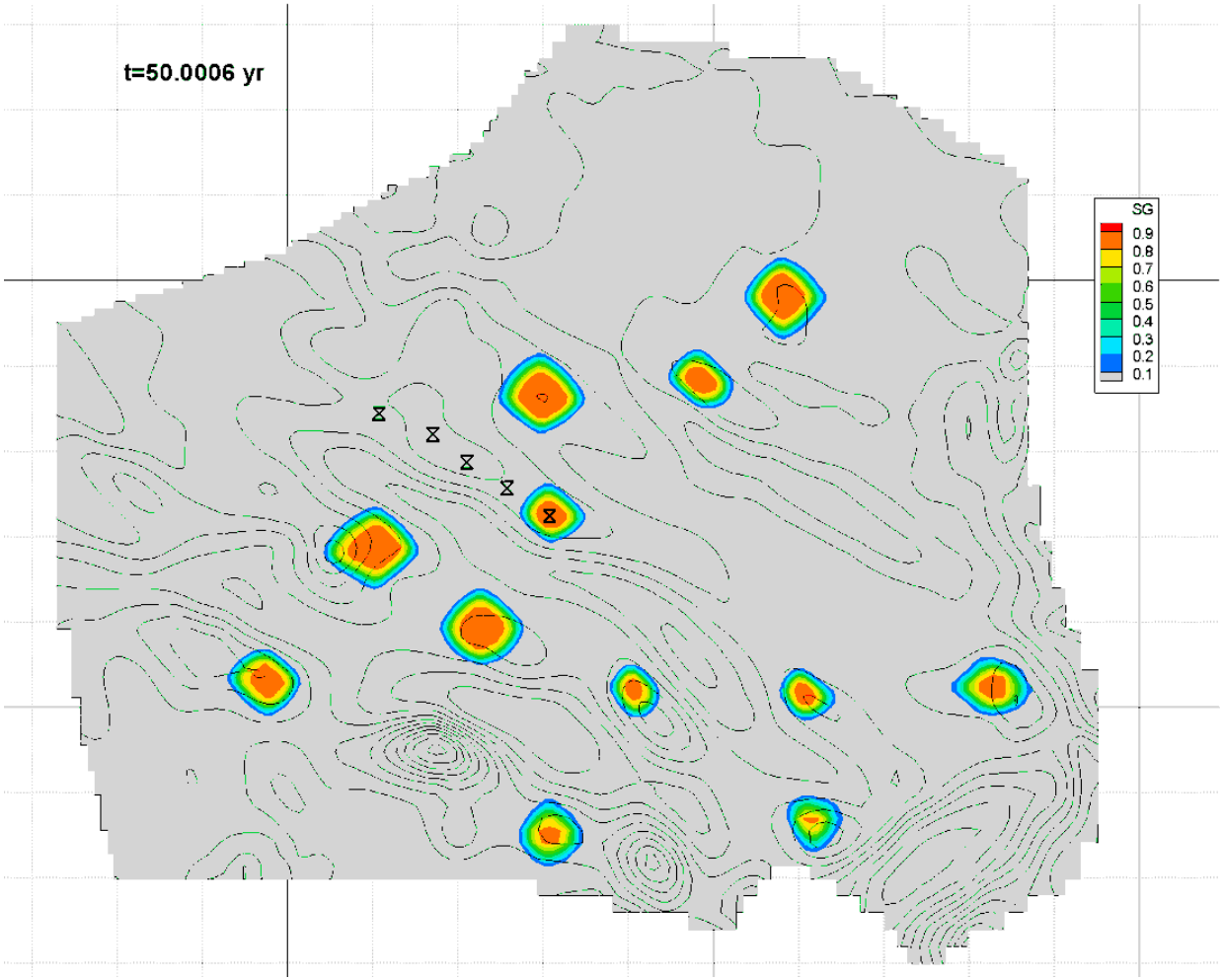
- Boundary conditions of aquifer affect the pressure build-up during injection, and capacity.
- Capacity is derived by displacing water out of reservoir pore volume and replacing with CO_2 (open system) or by compressibility of fluids and formation under increased pressure.
- Understanding pressure build-up is important in closed or partially closed aquifers.

Boundary conditions - Bunter

- Subset of Bunter Sandstone Formation is bounded by pinch out, major fault zones and salt walls.
- Degree of pressure and fluid communication across boundaries is unknown.
- No known internal permeability barriers.
- Total pore volume 350 km^3.
- CO_2 density taken as 700 kg/m^3 at initial P–T conditions.

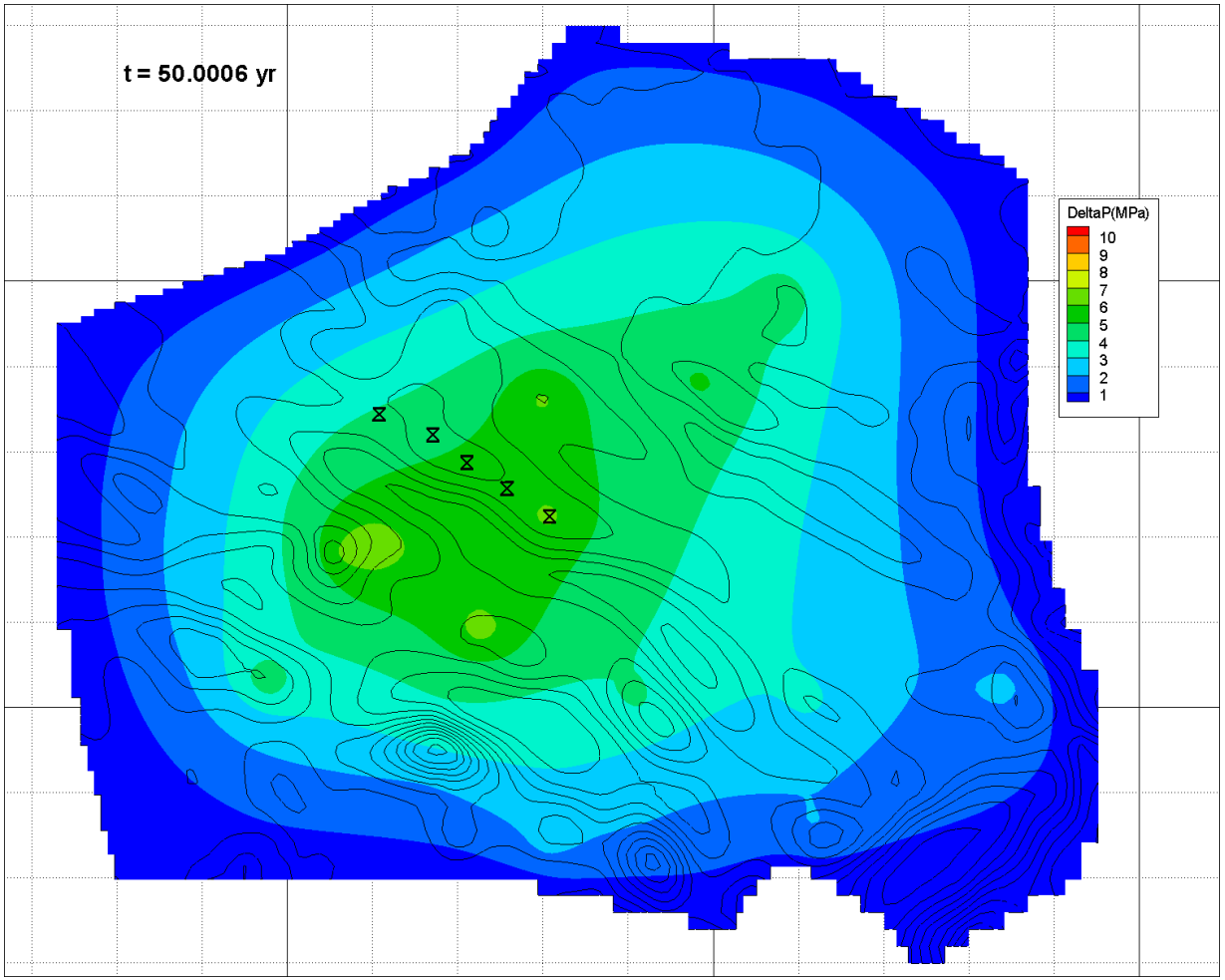


CO_2 distribution



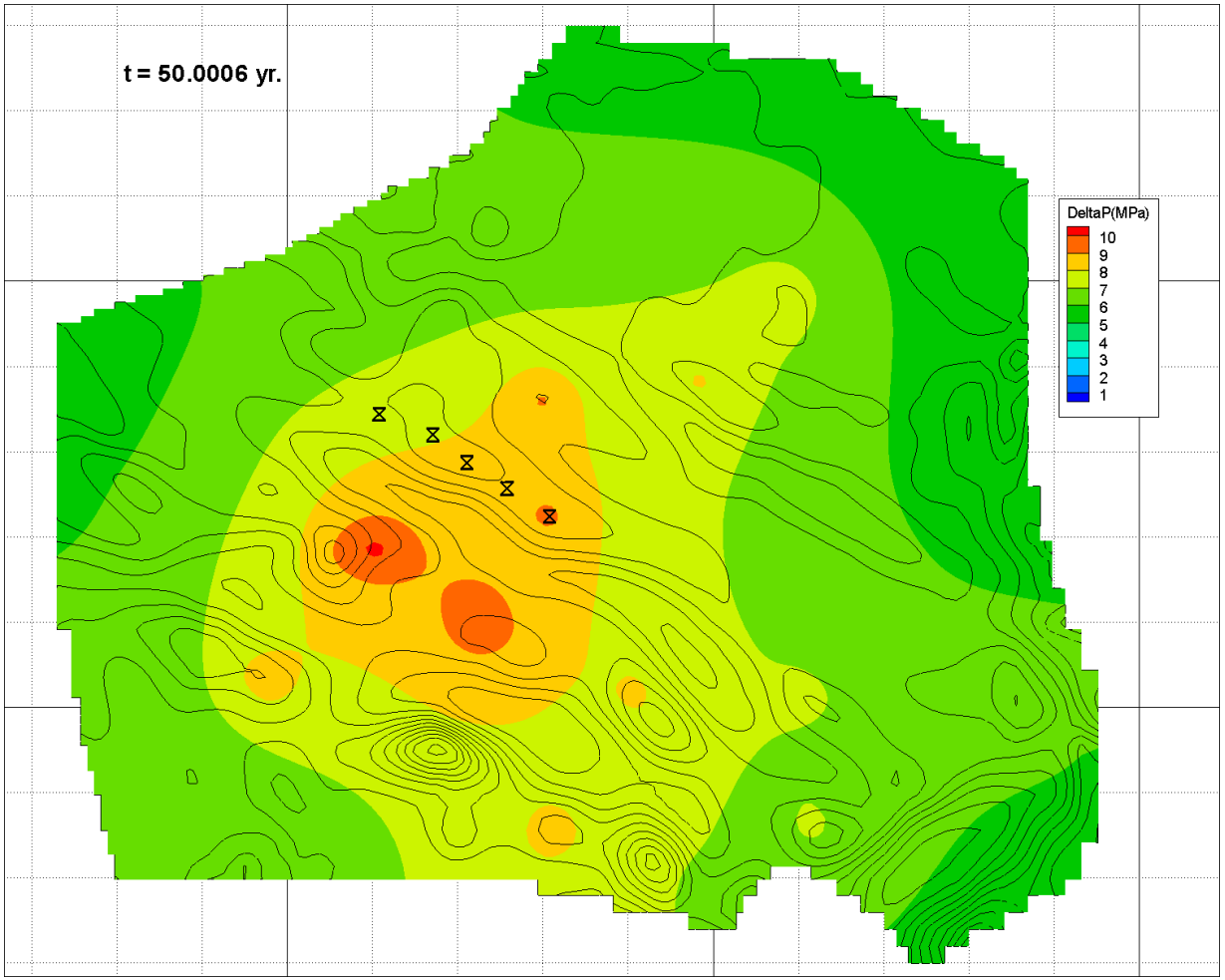
- Shows CO_2 saturation after 50 years of injection
- @ 33 Mt CO_2 yr^{-1}

Dynamic model – open system



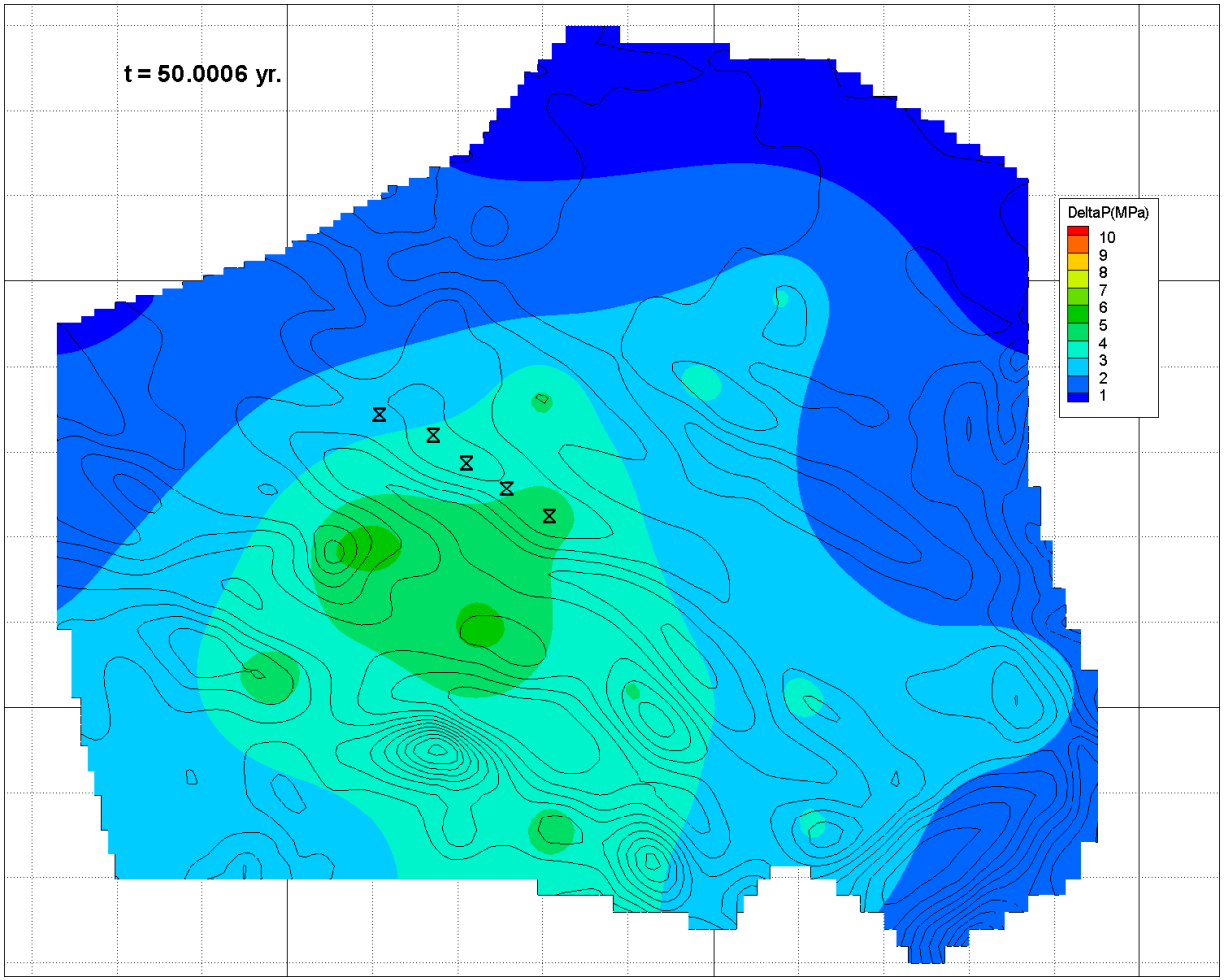
- Plot of ΔMPa
- 500 m thick overburden with permeability of 10^{-25} m^2
- Pressure high where wells more closely spaced.

Dynamic model – closed system



- Plot of ΔMPa
- 500 m thick overburden with permeability of 10^{-25} m^2

Closed system with low permeability overburden

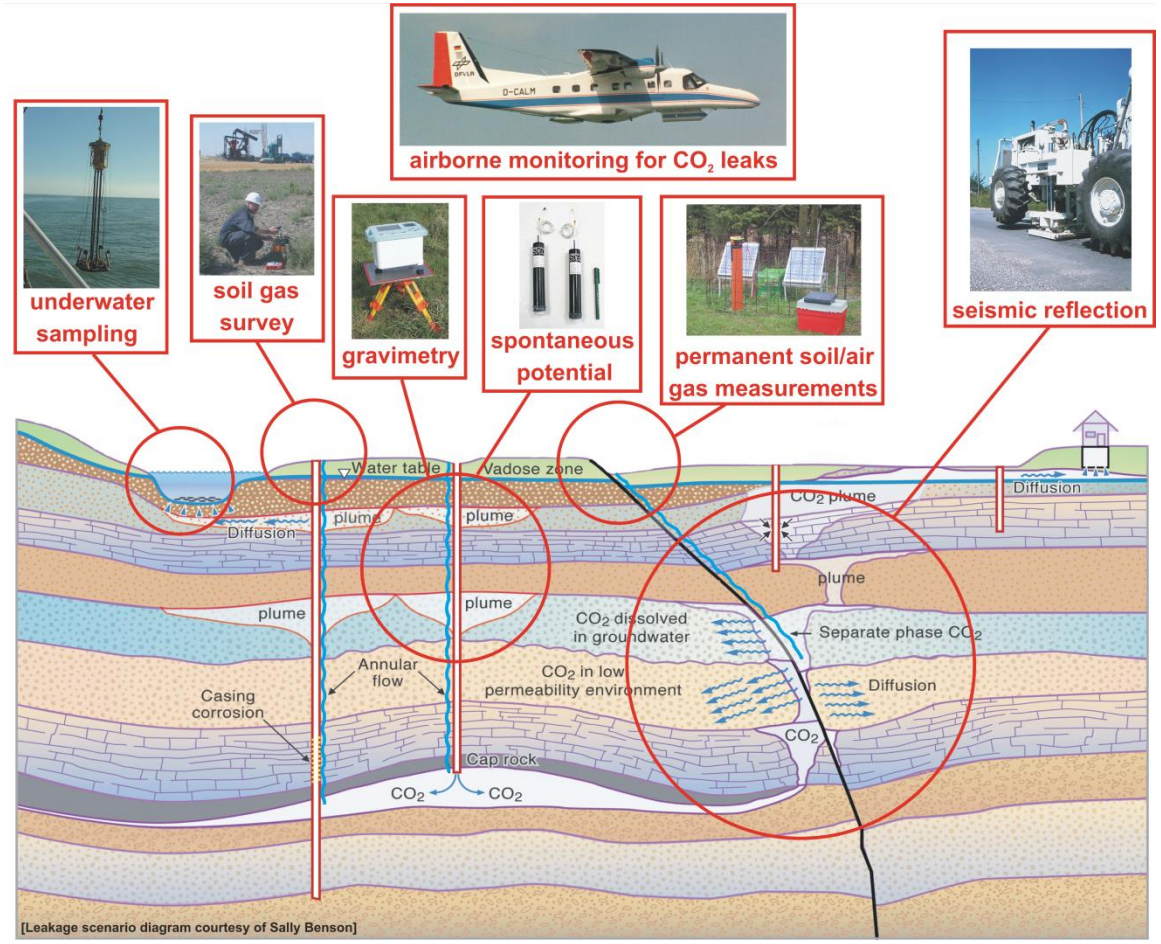


- 500 m thick overburden with permeability of 10^{-17} m^2 **(0.01 mD)**

Geochemistry

- Introduction of CO_2 and impurities can affect pH, Eh, mineral saturation, alkalinity, etc.
- In general, kinetics are slow.
- Water-rock reaction with carbonated (acidified) water in aquifers may release metals and semi-metals (As, Pb, Cd...) via carbonate breakdown, cation exchange, absorption/ desorption with clays, Fe hydroxides, amorphous silica.
- Ultimately mineral carbonates form to permanently store carbon.

Monitoring and verification



- Need to verify storage, and identify and quantify leakage.
- Applicability of techniques is site specific
- Storage integrity is critical – leakage undermines economics, public acceptance and environmental benefits (although contrast local impacts with wide scale benefits).

Issues and barriers - costs

Chain	Cost $US per tonne CO_2
CAPTURE (inc. compression)	15 – 75
TRANSPORT	
Pipe	1 – 6 /tCO_2 / 250 km
Ship	10 – 15
STORAGE	
Geological formations	0.5 – 9 (including monitoring)
Ocean Injection	6 – 31
Mineralisation	50 – 100

Approximate costs from IPCC 2005

Issues and barriers - public acceptance

- Little public awareness given its state of development
- Very few people in the UK have heard of CCS
- Climate change “scepticism”
- CCS as “coal enabler” and “business as usual”

NIMBY and NUMBY

- Protests halted Vattenfall CCS scheme in Denmark.

the COPENHAGEN post Online

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CO2 storage protests

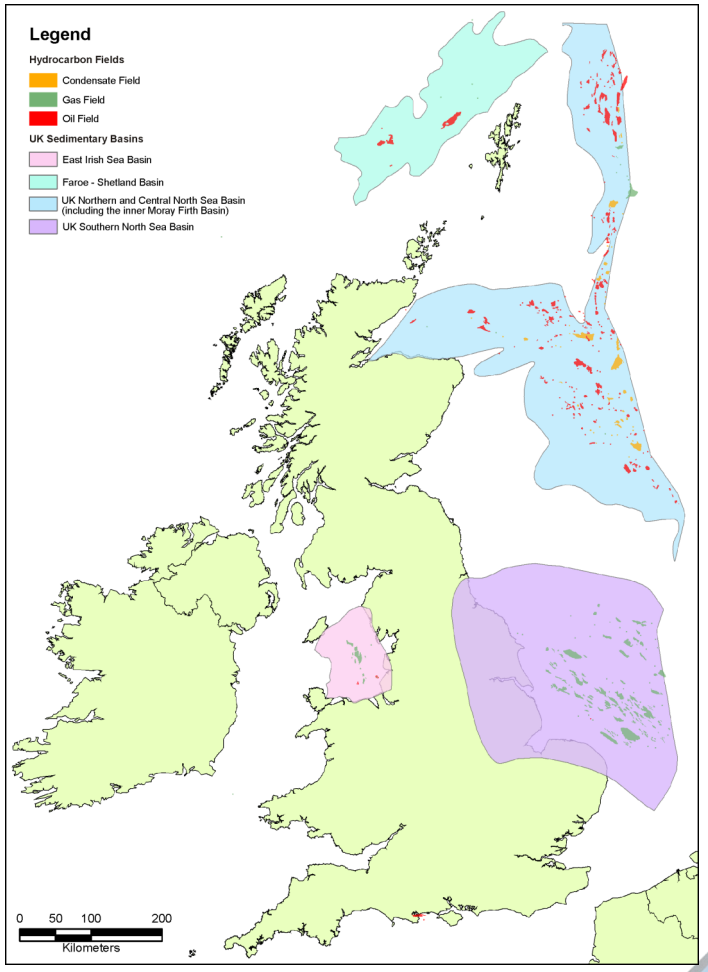
WEDNESDAY, 05 AUGUST 2009 09:45 | RC NEWS

Strong opposition to a underground carbon dioxide 'capture chamber' in the north of Jutland

A group of landowners in northern Jutland have collectively dug in their heels to stamp out a power company's plans to establish a giant underground carbon dioxide storage chamber in Jammerbugten.

NIMBY and NUMBY

- Protests halted Vattenfall CCS scheme in Denmark.
- Offshore storage eases issues...



NIMBY and NUMBY

- Protests halted Vattenfall CCS scheme in Denmark.
- Offshore storage eases issues...
- But not for plant & pipe construction

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Page last updated at 10:00 GMT, Thursday, 8 October 2009 11:00 UK

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New Kingsnorth coal plant delayed

Controversial plans to build a new coal-fired power station at Kingsnorth in Kent have been put on hold for up to three years, energy firm E.On has said.

Kingsnorth would be the UK's first new coal-fired power station for 30 years

It said it would be delayed until about 2016 because electricity demand had fallen during the global recession.

The site has been a high-profile target for environmental protests by groups that argue a new plant

Active CO_2 storage operations

- **Sleipner** (northern North Sea) has injected >12 $MtCO_2$ since 1996. (Statoil).
- **In Salah** (central Algeria): CO_2 stripped from natural gas prior to export; 3 Mt injected to date. Active since 2004 (BP, Statoil, Sonatrach).
- **Weyburn** (Saskatchewan, Canada): Enhanced Oil Recovery (EOR) operation, started in 2000. Greater than 12 $MtCO_2$ stored to date (EnCana Resources).

Summary I

- CCS represents a bridging technology allowing us to “decarbonise” fossil fuel power generation in the transition to renewables.
- CCS allows necessarily CO_2 emitting industries to “decarbonise” – e.g. cement production.
- Storage in saline aquifers allows for CO_2 to be safely stored for hundreds to thousands of years in otherwise unused geological formations.
- Potential storage sites must fulfil a number of geological criteria, and require careful characterisation to ensure storage security, integrity, feasibility and cost-effectiveness.

Summary II

- Pressure, and related displacement of saline water require simulations to predict response to CO_2 injection.
- Comprehensive monitoring programs are needed to ensure continued safe storage and compliance with regulations.
- A number of active storage operations demonstrate effectiveness and allow for considerable R&D activity.