Geological Sequestration of CO2

An overview from geological site selection to monitoring

By

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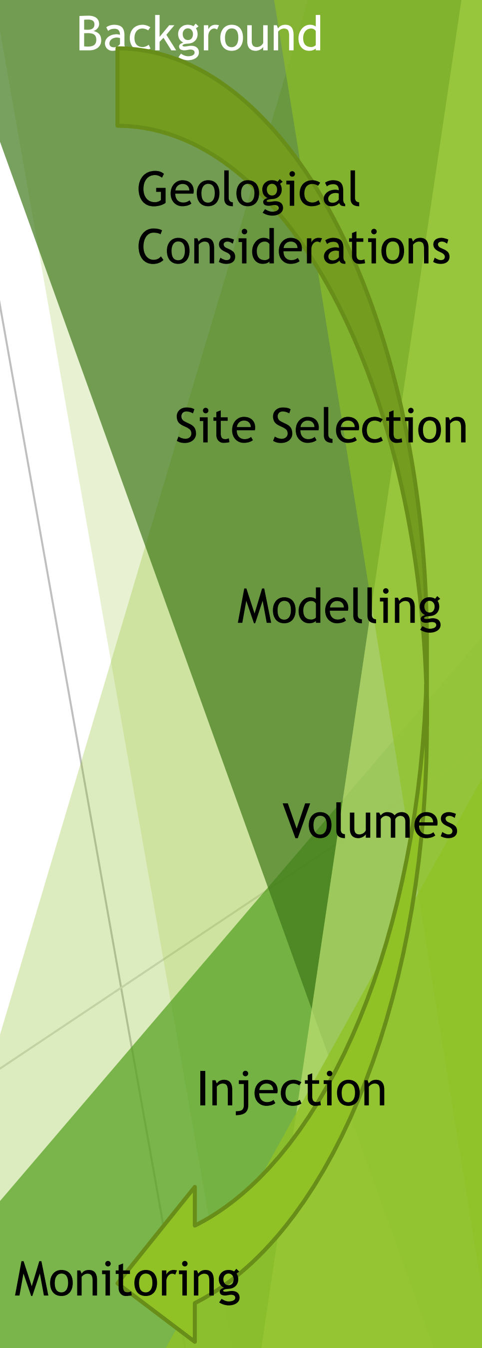
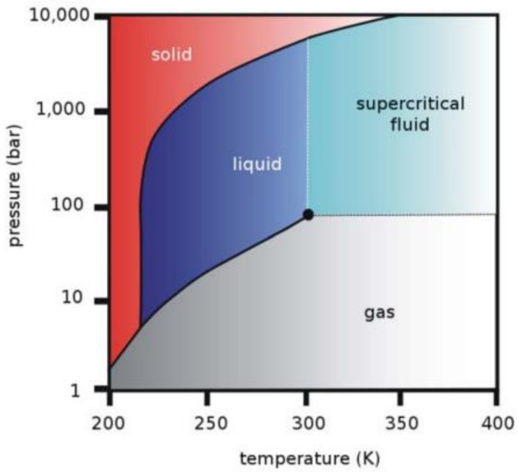
AGENDA

- Background & Nomenclature
- Geological Considerations
- Site Selection
- Modelling
- Volumes
- Injection
- Monitoring



Nomenclature/Units/Facts



- 1 car emits 4.6 T CO2 per year
- 1 Ton CO2 = 556.3 m3 = 20 MSCF

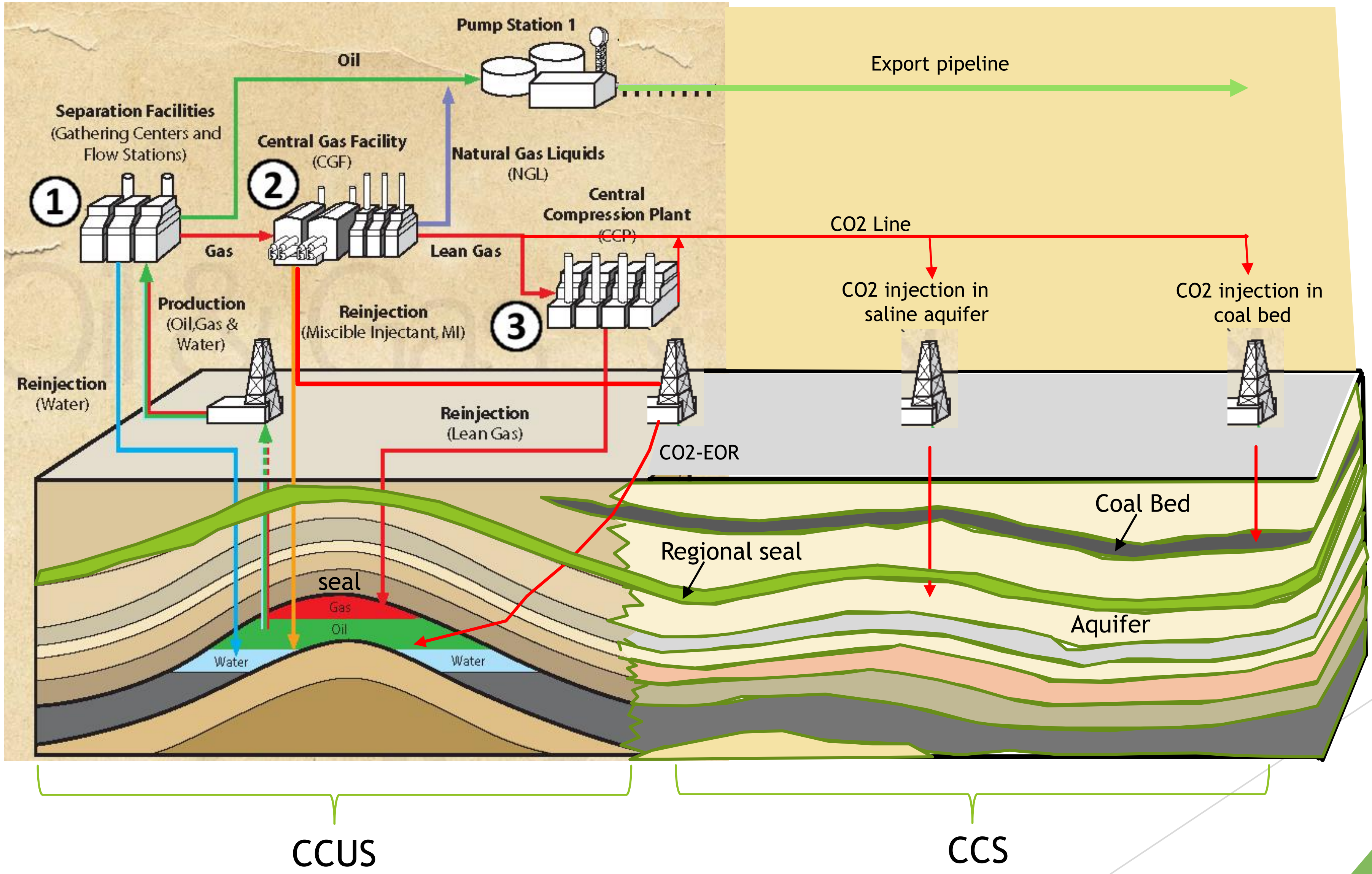
- 3 billion tones of CO2 emissions in 2020
- G20 countries produce 80% of CO2 emissions

- Ultimate goal is the development of green energy sources, effective measures are required in the short term

- CCS – Carbon Capture and Storage
- CCUS – Carbon Capture Utilization an Storage – not in public favour
- EOR – Enhanced Oil Recovery

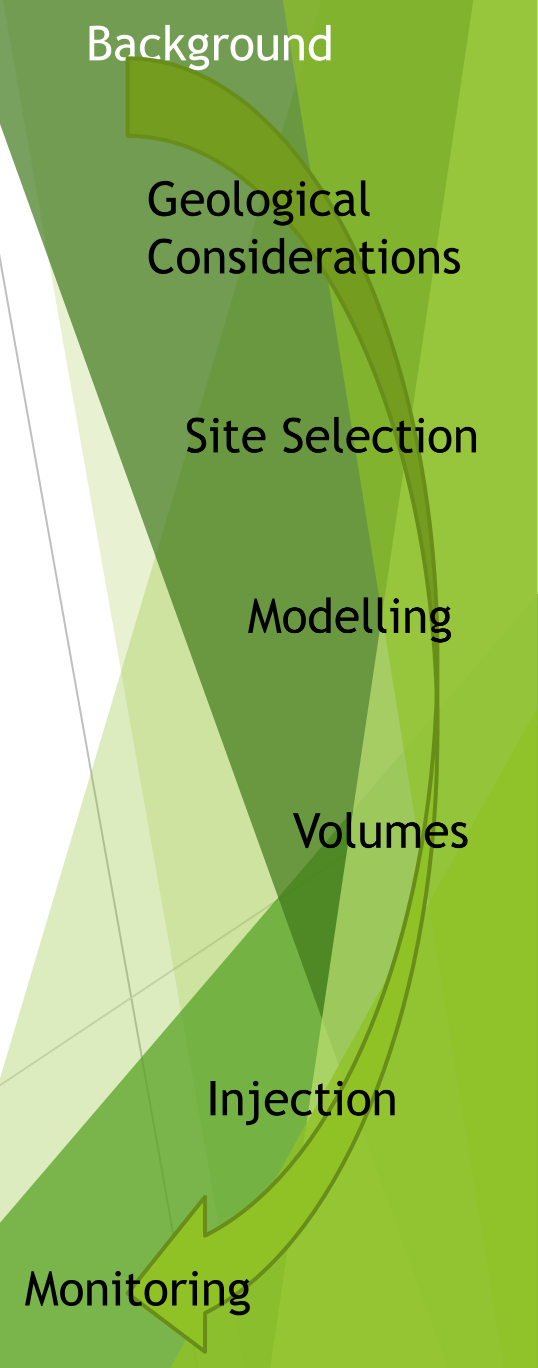
} Mitigation of Global Warming

Geological Options for CO2 Sequestration



CO_2 Sequestration: Recap

- Natural CO_2 sequestration into carbon sinks: Forests, soils and oceans
- Induced CO_2 sequestration into geological structures: Depleted reservoirs, aquifers (CCS) and EOR processes (CCUS).
- Both CO_2 Sequestration processes reduce CO_2 emissions in the planet – reduce green house effects
    - CCS in Europe: mostly offshore
  - CCUS: Make EOR projects economically attractive and contribute to sustainability

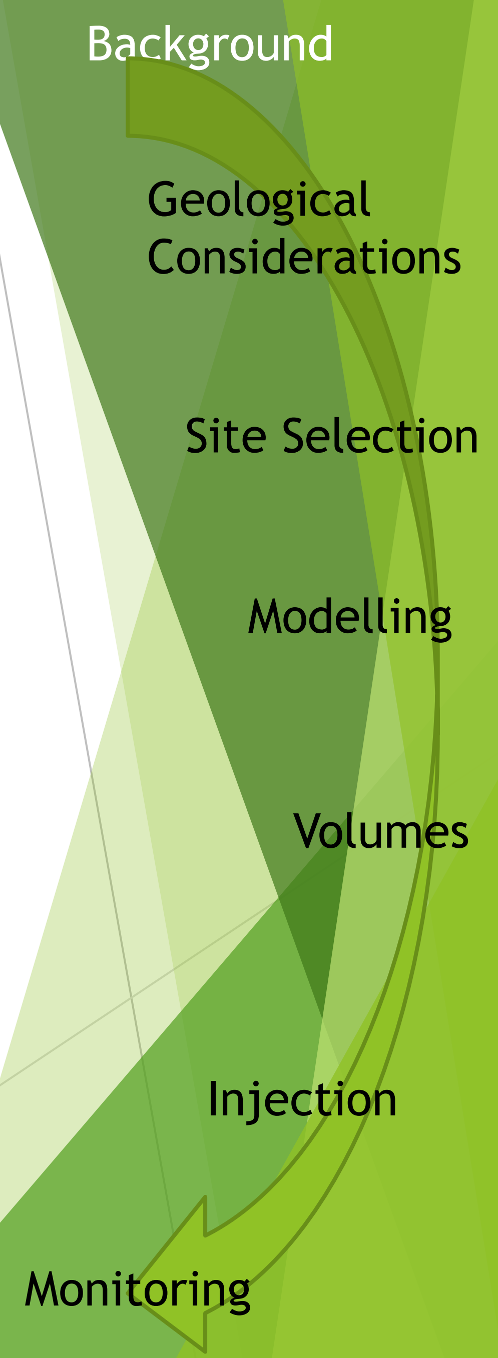


CCS Projects in the World

Project/Country/Year	Storage	Injection	Comments
Sleipner, Norway, 1996	Aquifer (sand)	0.9 MMT/Yr; 16.5 MMT until 2015	Low cost of separating CO2 from produced gases & tax reduction
Frio Pilot, USA, 2002	Aquifer	1600 T, for 10 days	Monitor plume to validate models
Cranfield, ISA, 2009	Depleted oil field	Cumulative 2015 = 5 MMT	5 MMT monitored; validate models
Decatur, USA, 2011	Aquifer (sand)	1000 T/daily over 3 yrs	CO2 from industrial processing Ethanol plant; completed in 2014
Ketzin, Germany, 2004	Aquifer(sand)	630 m aquifer	pilot terminated in 2017
Otway, Australia, 2008	Depleted gas field	150 T daily	2 Km TVD
Gorgon, Australia, 2012	Aquifer	2000 m below res.	14% CO2 from producing gas field
Salah, Algeria,2004	aquifer in field	1.2 MMT/Yr,	10% CO2 from produced gas

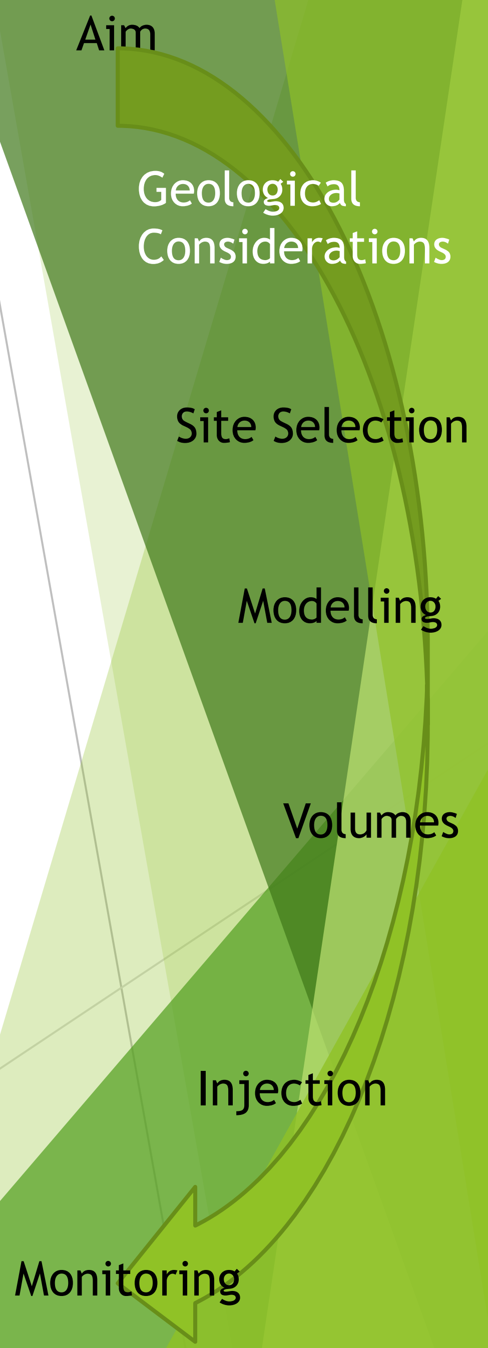
Largest CCUS (CO2-EOR) Operators in USA

- In US 80%+ of CO2 for EOR projects comes from natural sources; Mississipi, CO2 purchases cost $5-$12 Ton
- 1st, 2nd and 3rd Largest CO2 operators in US (Oxy, Kinder Morgan, Denbury):
  - Oxy's high CO2 utilization factor – they recycle their CO2 40x to get the NET utilization factor down.
  - Permian Basin, miscible CO2 floods, gross total gas injected utilization 7-20 Mscf/BO and net utilization of 3-15 MScf/BO; net being total injected gas less recycle injected gas.
  - Mississipi, utilizations much higher 20-35 Mscf/BO with net 10-20 Mscf/BO
  - To go for CO2 EOR projects with high utilization factor, we need cheap CO2 and tax incentives.
- CO2-EOR in Weyburn fractured carbonate, Canada, 2000, 320 km CO2 pipeline – 130 MMbbls incremental oil.
- CO2 tax in Europe is 40 Euro/Ton



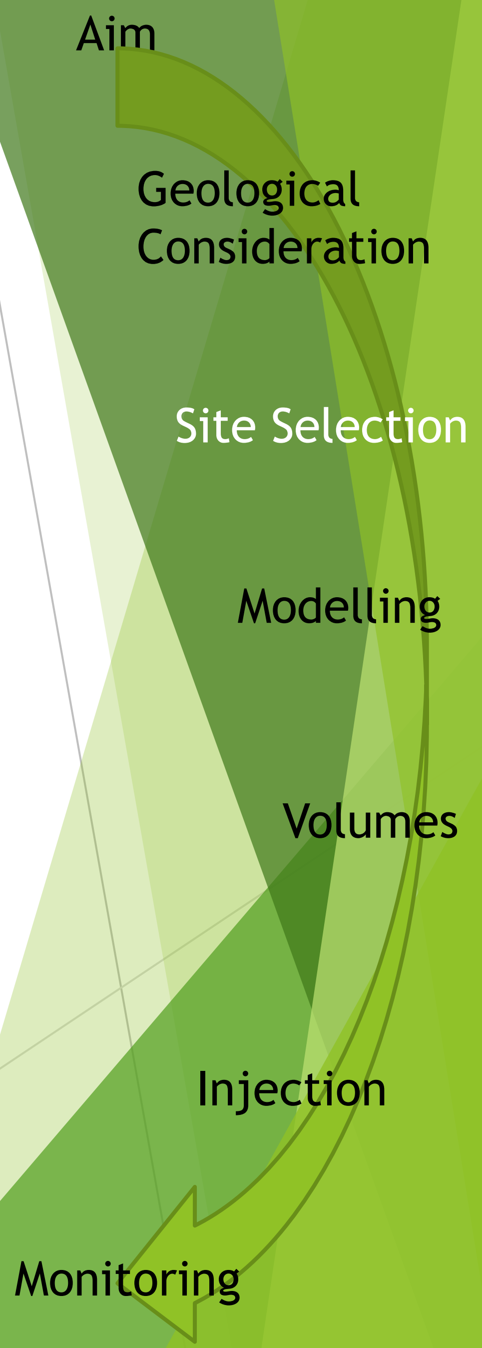
Geological Considerations for CO_2 storage

- Geological storage considerations:
  - Structure & Volumes
    - Depleted oil/gas reservoirs
    - Aquifers
    - Coal beds
    - Salt caverns
  - Cap rock extension and integrity
  - Depth (compression requirements)
  - Surface constraints
  - Distance from source



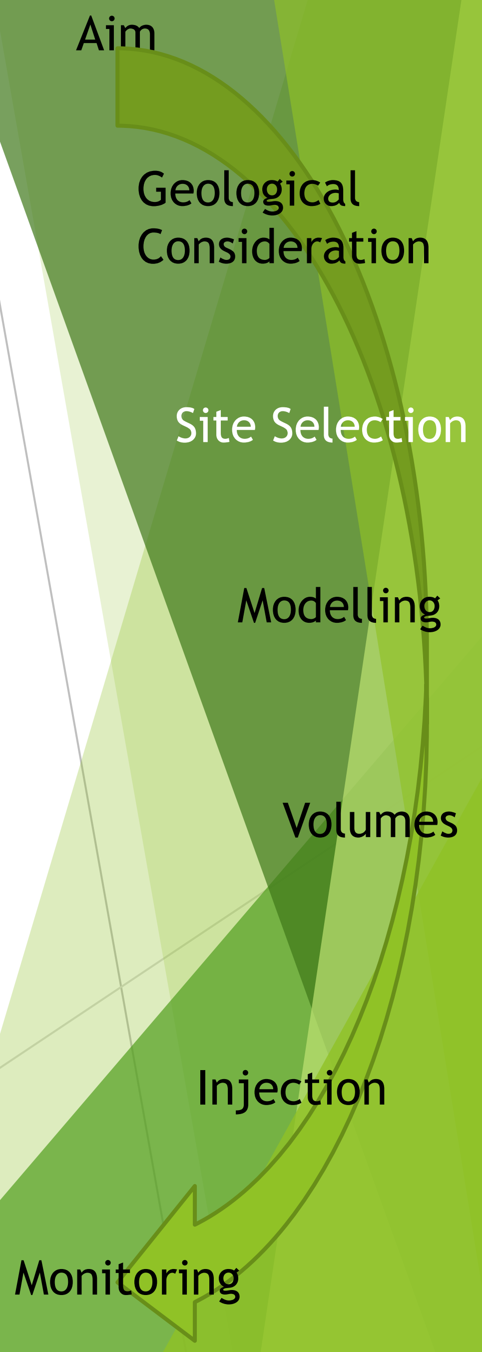
Site Selection – Depleted Reservoirs - Pros & Cons

- Depleted Reservoirs
  - Pros
    - Geological and petrophysical information is favourable
    - Volumes are well known
    - Cap rock integrity has been proven
      - Geological containment demonstrated over geological time
    - Existing wells could be used for monitoring
  - Cons
    - Well Integrity Issues; can we P&A old wells safely ? OH vs CH completions ?
    - Completion materials:
      - CRA; Carbon steel controlled hardness F22 and corrosion inhibitors to deal with H_2S cracking corrosion – if injected sour gas with 5% H_2S and 5% CO_2
      - Cladded material or made of Nickel alloy 28.
    - Cement quality – cross-flow behing pipe



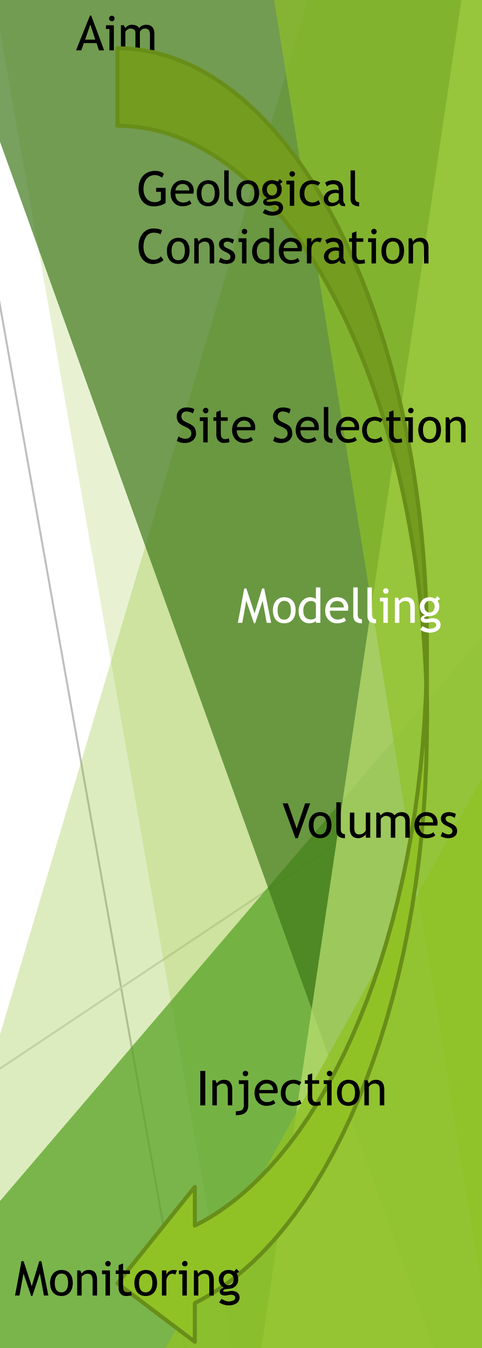
Site Selection – Aquifers - Pros & Cons

- Aquifers
  - Pros
    - No well integrity issues
    - No volume issues for large aquifers
  - Cons
    - Geological uncertainties
    - Faults and fractures
    - Cap rock integrity
    - Lack of high resolution seismic data



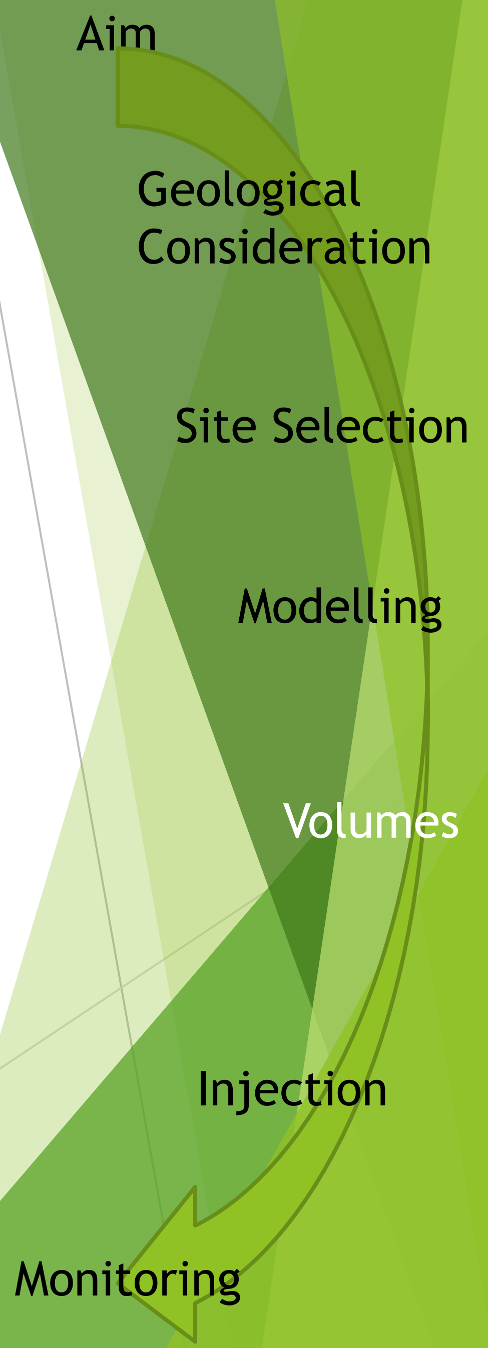
Geological Modelling for CO_2 storage

- Static Modelling – similar to any static modelling workflow – Petrel/RMS etc
- Softwares for dynamic modelling
  - Eclipse 300, CMG (GEM)
  - MRST with CO2 Lab Module
  - Stanford University code
  - GPU with parallel processing
- Key topics to be considered in modelling
  - Aquifers: Large size – many grid blocks
  - Depleted reservoirs: possible cross-flow in existing wells
  - CO2 injection pressure – not to exceed frac gradient
  - SCAL/PVT properties – from lab measurements or analog reservoirs
  - Use of 3D seismic to understand structural elements
    - Seismic inversion for porosity modelling



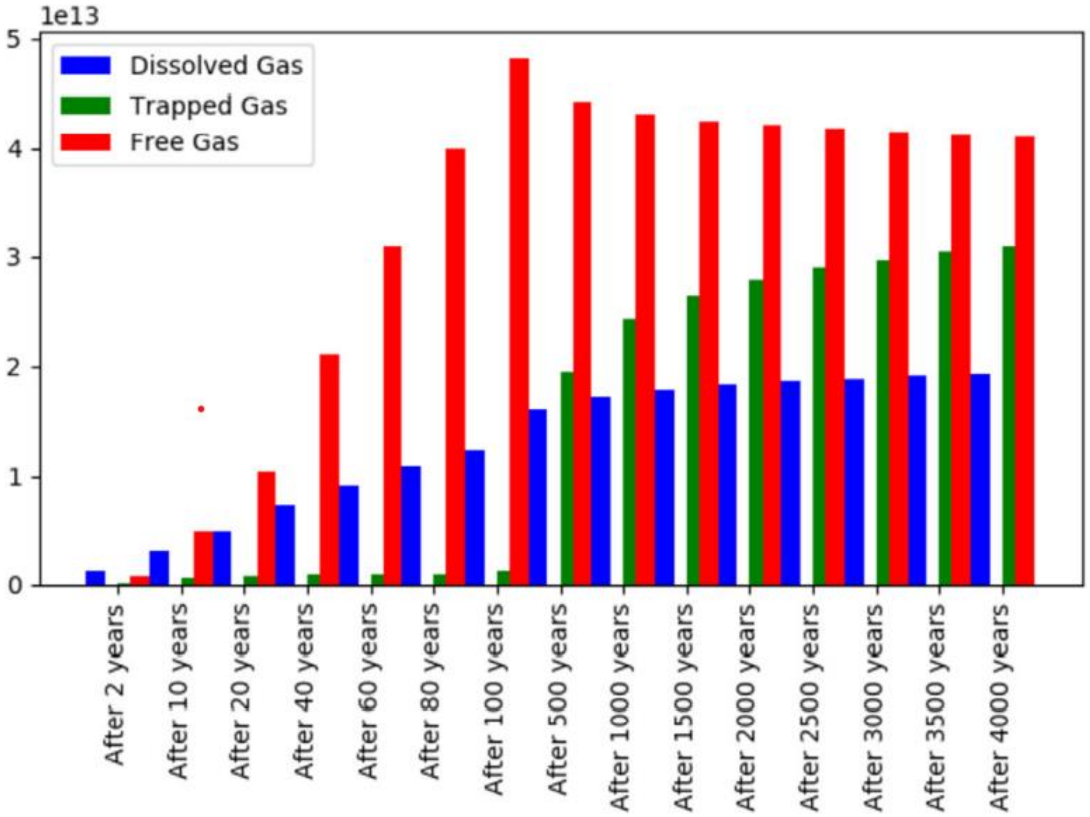
Volumetrics for CO_2 storage

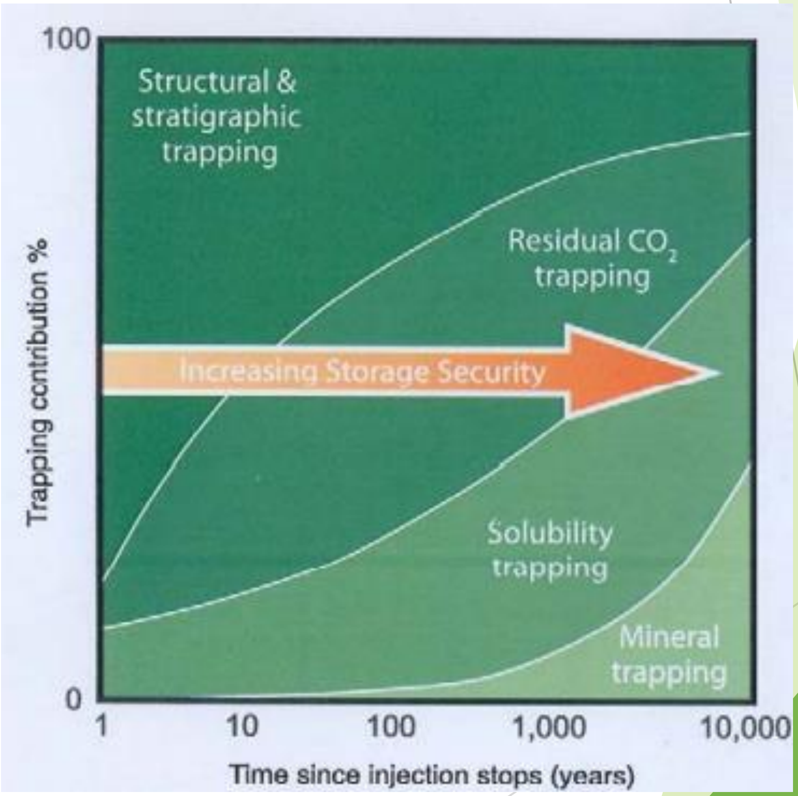
- **Static: Volumetric approach**
  - Aquifer with open boundaries
    - Pressure is not considered in this formulation
    - Considers only pore volume, density and capacity coefficient
      - Capacity coefficient: depends on trap heterogeneity, buoyancy of CO2 and sweep efficiency
  - $M_{CO2} = A.h.\Phi.\rho(1-S_{wirr}).C_c$
- **Static: Compressibility approach**
  - Aquifer with closed boundaries
  - pressure will be expected to increase in the aquifer during injection of CO2
  - $M_{CO2} = (B_p+B_w).\rho.V_p.Dp_{max}$
- **Dynamic: Simulation**
- Volumetric capacities could be improved by the extraction of in-situ brine from the aquifers



Trapping Mechanisms

- **Simulation Results (left figure); Concept (right figure)**





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Geological Consideration

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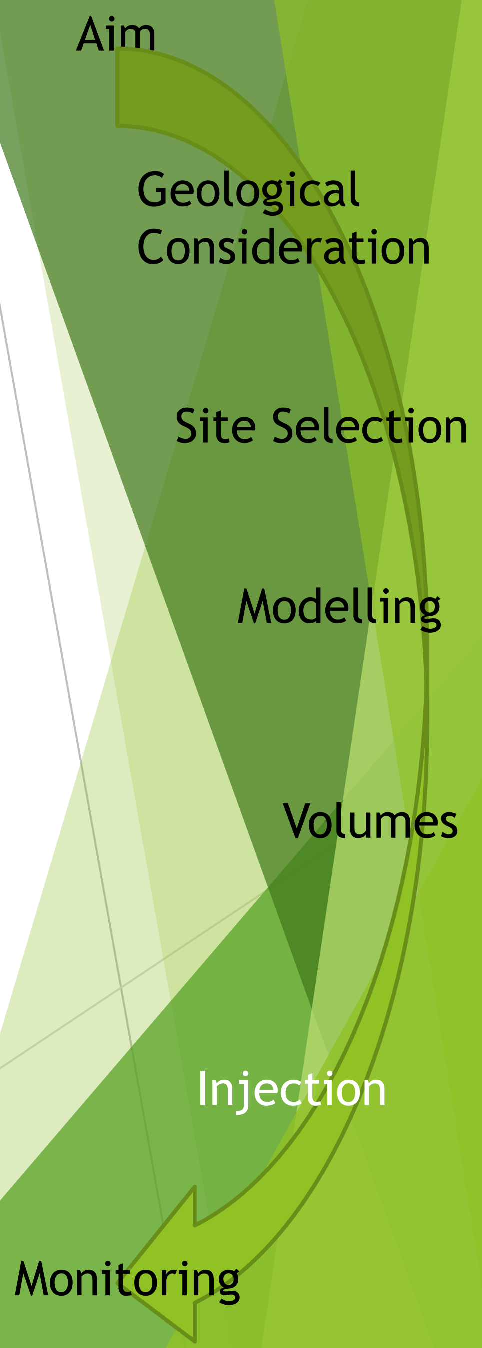
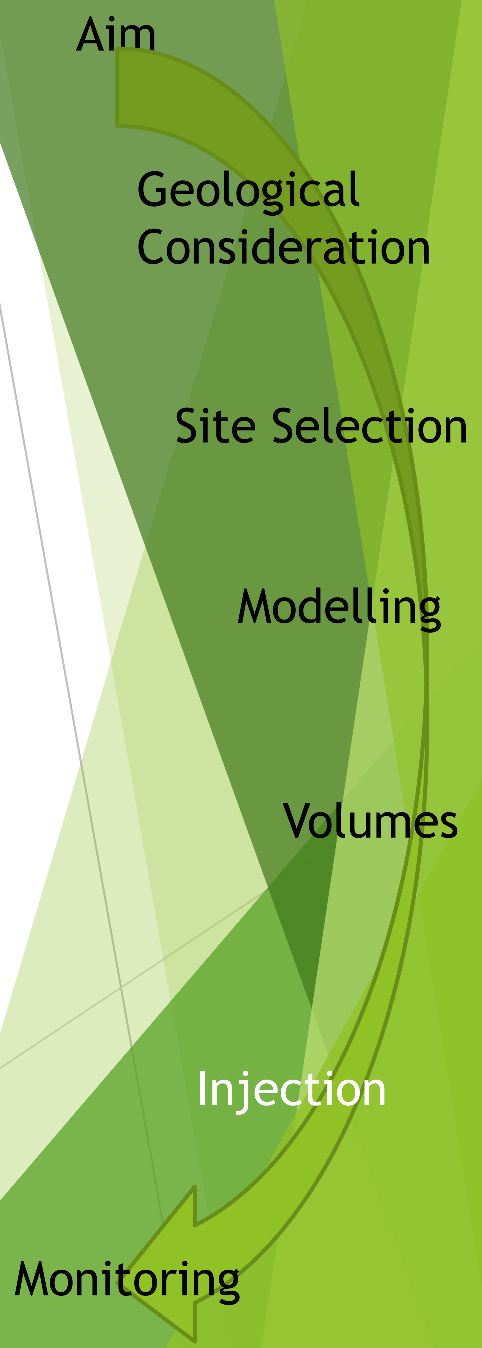
CO2 Injection: Geomechanical Considerations

- Dry CO2 to be injected:
  - Permian Basin: supercritical dense phase (1900-2100 psi); just have booster pumps (much cheaper than compression).
  - Dry CO2 minimizes corrosion
  - Some operators get CO2 at ambient pressure (anthropogenic origin – CO2 captured) – need big compressors if reservoir pressures are high.
- 30F temperature drop expected by CO2 injection
  - Implications on well design; Thermal fracturing
- Injection pressures & geomechanical considerations:
  - Consider poro-elastic effects; Min horz stress (SHmin) = frac gradient
  - Exceeding SHmin results in cap rock breach (SPE 108528)
  - Are faults and fractures at stable condition ?
  - If failure line is above Mohr Circle is stable



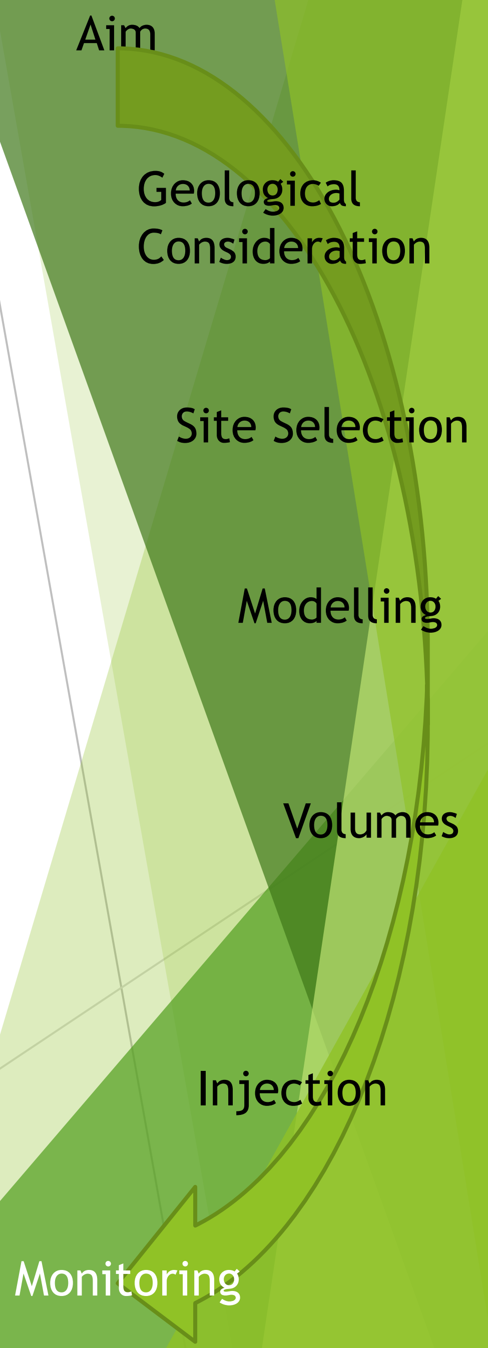
CO2 Injection: Geochemical Considerations

- Geochemical considerations:
  - Rock dissolution and erosion under injection scenarios
  - PVT SIM NOVA software
  - CO_2 is solid free, no erosion issues
- Cap rock geochemical considerations:
  - Calcite -> highest reaction rate
  - Experiments indicate 5% porosity becomes 5.0032% after CO_2 injection
  - Experiments indicate 1% porosity becomes 1.0006% after CO_2 injection
  - Each liter of water with CO_2 is capable of dissolving 0.64 cc of rock
  - Geochemical integrity & monitoring

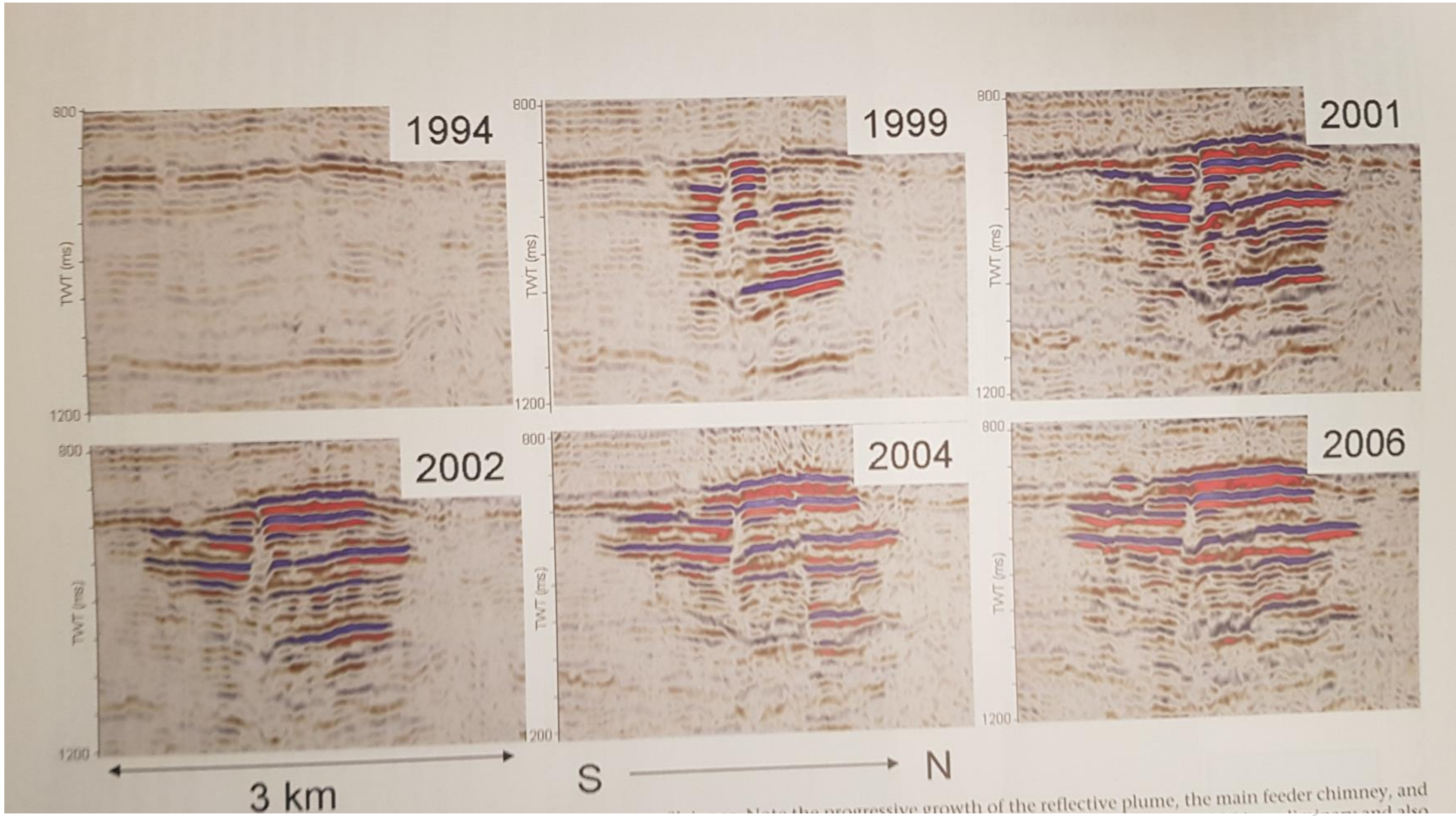


Monitoring CO_2 storage – Example of Lacq TOTAL

- Monitoring wells to be located above and within the cap rock to monitor cap rock leakage
- CCS site in Lacq, 3.5 Km from Pau (France)
  - Buried geophones to minimize noise; capture small micro seismic events
  - Differentiate between real seismicity and CO2 micro seismic activity
  - 7, 200 m shallow wells with 4 triaxial sensors each
  - SBA – Shallow Buried Array; 1 SBA per 4km2 for fault monitoring
  - Deploy SBA 6 months prior to CO2 injection
  - Deploy 1 deep borehole tool per injection well.
  - Geophones buried 30 years ago
  - CO2 injection well at 4500 m TVD
- Other monitoring techniques: Gravimetry, time lapse seismic and resistivity, soil sampling, perflurocarbons etc



Monitoring CO_2 in Sleipner using time-lapse seismic



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Key References (Books)

- Baines, S. J. & Worden, R.H. (eds) 2004. Geological Storage of Carbon Dioxide, publication by Geological Society of London, Special Publication 233.
- Grobe, M. & Pashin, J. C., Dodge, R.L.(eds) 2009. Carbon Dioxide Sequestration in Geological Media – State of the Science. AAPG Studies in Geology 59

Thank you – Obrigado

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