Potential Impacts of CO$_2$ Storage on Groundwater Resources

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Lead by BRGM

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Content of Presentation

- Potential Overlap of Resources
- Classification of potential impacts and overlap
- Potential Leakage Mechanisms
  - Chemical Effects
  - Physical Effects
  - Analogues
  - Modelling Studies
- Regulations
- Mitigation and Remediation
Potential Overlap of Resources

- Consideration of groundwater protection in site selection
- Global distribution - GIS based approach
- WHYMAP – world hydrological mapping and assessment programme
  - Lack of depth data
- Storage Maps - Globally, only limited data are available - Regional Approach used
  - Geocapacity
  - NatCarb
  - Other less detailed maps e.g. China
Combining GEOCAPACITY data on DSF both (pink) with WHYMAP thematic layers representing large, uniform freshwater aquifers (blue). Combining GEOCAPACITY data on DSF(pink) with WHYMAP thematic layers representing areas with complex hydrogeological structure (green).
Combining data on DSF from the Carbon Sequestration Atlas (pink) with WHYMAP thematic layer representing large, uniform freshwater aquifers (blue)

Combining data on DSF from the Carbon Sequestration Atlas (pink) with WHYMAP thematic layer representing areas with complex hydrogeological structures (green)
Typologies/Mapping Scenarios

- Areas with potential DSF storage overlain by:
  - Large, uniform freshwater aquifers
  - Complex hydrogeological structures where productive potable aquifers (including karst) may occur in close vicinity to non-aquifers
  - Localised/very shallow aquifers
  - Formations containing saline groundwater
  - Over-exploited groundwater resources
- Areas with no DSF suitable or identified for CO$_2$ storage
Typology Map

**Blue:** large and uniform freshwater aquifers (Type a).

**Green:** complex hydrogeological structures (Type b).

**Brown:** areas with local/shallow aquifers (Type c).

**Grey:** areas with no deep saline formations suitable for CO₂ storage (Type f).

**Orange:** Areas with saline surface waters

**Red symbols** - areas of heavy groundwater abstraction with overexploitation.
Impact Mechanisms

Potential Impacts of CO₂ Storage on Shallow Groundwater

Media & Cause
- CO₂ + impurities
- Brine
- Immiscible Hydrocarbon
- Pressure Effects

Affect
- Rocks
- Groundwater
- Biota

Impact on
- Groundwater availability
- Groundwater quality
Potential Leakage Pathways

Schematic Diagram – not to scale

Fresh groundwater levels and pressures, may rise (particularly where confined) and spring flows increase. In coastal areas saline intrusion may be controlled by increased pressure head. Effects may be transient during injection until equilibrium is re-established. Deeper wells may be contaminated by displaced fluids.

Open system DSF. CO₂ plume may be contained in geological structure but pressure dissipation and impacts felt further afield. CO₂ and brine may leak through confining layers or deep wells (active or abandoned), accompanied by lateral movement of brine through displacement.

Isolated system DSF. Increased pressure could lead to leakage of brine and CO₂ through confining layers or deep wells (active or abandoned). Pressure relief brine wells may be required to discharge at surface or, possibly, other brine filled aquifers.
Natural Analogues

• Pressure effects
  – Natural gas storage

• Chemical effects
  – Lab experiments
    • limited use. Reaction rates several orders of magnitude higher compared to field conditions
  – Industrial Analogues
    • Acid-gas injection, CO$_2$-EOR, brine injection
  – Natural Analogues – CO$_2$ accumulations
    • Mostly volcanic and fractured - not good CO$_2$ storage analogue, but potential analogue for leakage into groundwater
Modelling Studies

• Review of modelling studies
• Basin Scale modelling Hydrodynamics
  • Single phase approach
  • Reservoir Flow Simulator
  • Analytical Modelling
• Geochemical models take into account
  • initial mineralogy
  • possible thermochemical reactions
  • kinetic rate of the reactions and surface complexation.
• Chemical impacts considered
  • Acidification and release of solutes
• Limited number of studies - effect on groundwater
Pressure effects
displacement of brine in ‘open’ aquifers

- faults, abandoned wells
  - characterization and monitoring of pathways
Pressure Effects

- Hydrodynamic models show effect of pressurisation over much larger area than associated CO$_2$ plume
- **Pressure pulse** will rapidly attain a large extent (up to 100 or 200 km) within the storage formation.
- Pressure pulse is largely controlled by the amount of injected CO$_2$ and the permeability of the sealing rock.
- Pressure in the vicinity of the injection well can reach values of several tens of bars, while the impact on the head pressure in surface outcrops is much less.
Effect of Seal Permeability

Pressure build-up after 30 years of injection for different seal permeabilities – adapted from Birkholzer et al, 2009
Potential Chemical Processes

• Modifications in flow
• Migration of dissolved organic compounds
• Mineral dissolution
• Precipitation of carbonates / other secondary minerals resulting from rock alteration
• Co-precipitation and sorption of metals
• Changes in microbiological activity
• Aqueous complexation of cations that can promote solubility
Regulations

• Regulations from different countries reviewed
• Some measures particular to groundwater protection
• Existing groundwater protection rules
  – could be some legal barriers against the storage of CO$_2$ in deep saline aquifers.
  – Amendments needed to allow injection of CO$_2$ such as in the European Directive for CO$_2$ storage. Or injection likely to depend on authorisation/permit by authorities in charge of the protection of groundwater.
Mitigation

• Reduction of pressure in the storage reservoir – Brine/CO₂ extraction
• Interception and extraction of CO₂ plume followed by reinjection
• Increase of pressure in the formation into which leakage is occurring.
• Isolation (shut-off) of CO₂ leaks in identified and accessible locations
Summary

- Areas of geographical overlap between potential DSF CO₂ storage and overlying potable aquifers identified – WHYMAP and regional storage maps.
- Classification scheme developed for various geological settings in which conflicts could occur - tested for Europe.
- Two approaches have been used to address potential impact mechanisms of CO₂ storage projects on the hydrodynamics and chemistry of shallow groundwater.
  - natural or industrial analogues; laboratory experiments.
  - hydrodynamic and geochemical models,
- Possible mitigation options assessed include
  - Extraction of CO₂ / brine from the storage/ overlying formations.
Thank You / Questions

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