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CO_2 Geological Storage: Research, Development and Deployment (RD&D) Issues

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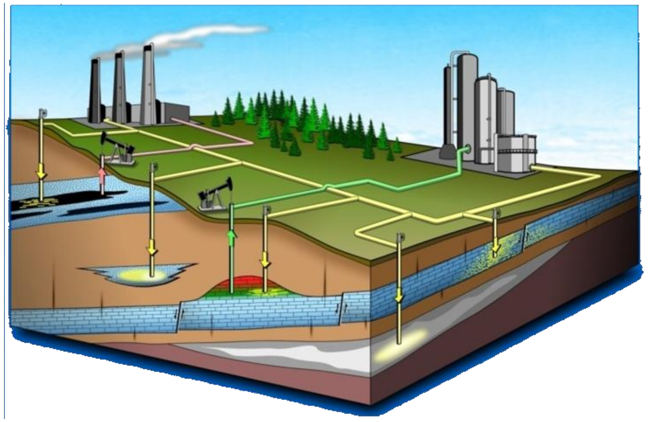
We need to demonstrate CO_2 storage safety and security for the time-scale of interest (centuries to millenia) considering all relevant processes, consequences and costs in a proper legal and regulatory framework that will convince the public to support it



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Key Elements of a CO_2 Storage Operation

- Long-term Liability ?
- Financial Responsibility ?
- Regulatory Oversight ?
- Remediation ?
- Monitoring √ & ?
- Safe Operations √
- Storage Engineering √
- Site Characterization and Selection √
- Fundamental Storage √ and Leakage Mechanisms ?

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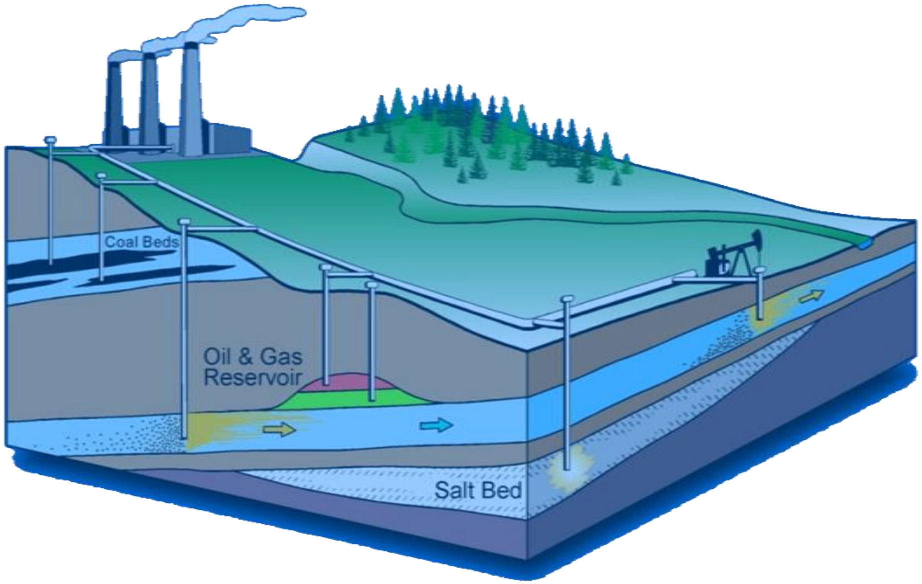
What are the Scientific and Technical Issues and Barriers to Deployment?



CO_2 Storage Capacity

- What media are suitable for CO_2 storage, meeting the conditions of capacity, injectivity and confinement (security)
  - Deep saline aquifers and hydrocarbon reservoirs √
  - Coal beds and shales **?**
  - Basalts**?**
- What is the global and regional size and distribution of the existing storage capacity (resource)
- What is the accessibility and economics of the existing storage capacity (reserve)
- Matching large CO_2 sources with appropriate CO_2 sinks

CO_2 Storage in Oil and Gas Reservoirs

- Geomechanical effect of pressure decrease during production and build-up during storage on reservoir and caprock integrity
- Effect of water invasion in aquifer-supported reservoirs
- Multi-phase flow effects (oil, gas, CO_2, water)
- Storage efficacy
- Time of reservoir availability (depletion)
- Optimization of oil recovery and CO_2 storage

CO_2 Storage in Deep Saline Aquifers

- Real storage capacity and efficiency
- Long term fate of the injected CO_2 and displaced formation water (brine)
- Are geochemical reactions and effects quick or slow, are they important?
  - If yes, how do they affect:
    - Flow (porosity and permeability)
    - Storage integrity and security (caprock integrity)
    - Storage capacity
  - If yes, how to get the data needed for assessment and modeling (e.g., mineral composition, contact area)
- Relative permeability
- Geomechanical and seismic effects on storage integrity (fracturing, ground heaving)

Injection and Pressure Build-up Effects

- Induced micro-seismicity
- Size and spread of the pressure build-up beyond the CO_2 plume
- Surface effects due to ground heaving
- Fate of the displaced formation water (brine)

Modeling

- HTMC Processes:
  - Hydraulic (pressure and fluid flow)
  - Thermal (difference in temperature between injected CO_2 and the fluids and rocks in the storage unit
  - (Geo) Mechanical as a result of pressure increase
  - (Geo) Chemical as a result of CO_2-water-rock interactions
- Models of coupled processes
  - Can we model them?
  - Do we have/can we get the data
- How do we validate the results of modelling?

Effects of Impurities in the Injected CO_2 Stream

- On storage capacity and injectivity
- On caprock and wells integrity
- On other resources, particularly groundwater, in case of leakage
- On life in case of leakage to the surface or seabed

Risk Issues

- Assessing the risks of CO_2 storage in the case of leakage:
  - To equity (other underground resources)
  - To potable groundwater
  - To soil and vegetation
  - To life
  - To property
  - Financial
  - Economic
- Developing appropriate risk models

Monitoring

- Various monitoring technologies work in different environments and with different accuracy and resolution
- No single technology or techniques works universally everywhere
- Since monitoring is based on detection of CO_2 at detectable compositions, no quantification as required by regulators and the public is possible without broad assumptions and calculations

Summary Regarding Technical and Scientific Challenges

- There are still many unanswered questions, but they should not be barriers to CCS deployment
- Implementation in the next few years of large-scale demonstration projects will help in answering many of the remaining scientific and technological challenges

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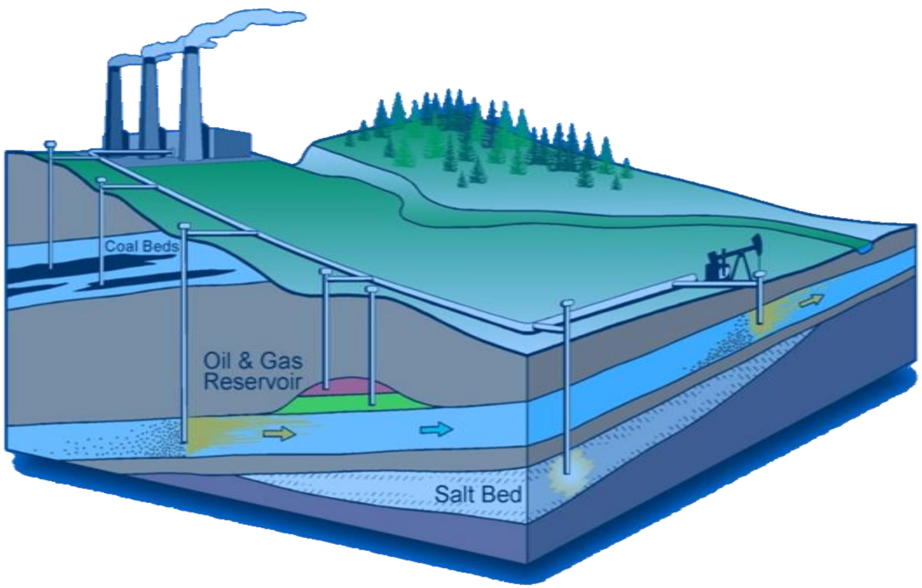
Non-Technical Barriers to CCS Deployment



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Barriers to CCS Deployment

- Lack of certainty regarding government policies regarding GHGs
- Lack of economic incentives ☺ or regulatory requirements ☹
- Risk identification and mitigation to increase investor and public confidence
- Lack of financing
- Lack of public awareness and acceptance
- Lack of human capacity in executing CCS projects
- High cost of capture (energy penalty)
- Identification and characterization of suitable and safe storage sites
- Absence of legislative and regulatory framework regarding CO_2 storage, including the issue of long-term liability for the stored CO_2

Political Trends

Public acceptance issues are broader than just local safety; they include the whole philosophy of energy and climate change

There is need to demonstrate on a large scale and in a variety of geological environments that CCS is a near-term viable and safe option for reducing anthropogenic CO_2 emissions into the atmosphere

The convergence of the geological, scientific and political trends leads to the need of demonstrating large-scale CO_2 storage in deep saline aquifers; however, the high cost and lack of incentives and policy lead to “Utilization” (CO_2-EOR) first

Concluding Remarks

- Large scale implementation of CO_2 geological storage is feasible with current technology
- Public safety must be paramount in developing CCS projects
- There is need to demonstrate the feasibility of fully-integrated “cradle-to-grave” CCS projects
- The public needs to be convinced that CCS operations are safe, and the industry needs convincing and support to do it

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