

The Importance of Carbon Capture and Storage: A Focus on Geological Storage

Abstract

Carbon Capture and Storage (CCS) is an essential strategy in the global effort to mitigate climate change by reducing net greenhouse gas emissions. This white paper highlights the critical role of geological storage as a cornerstone of CCS, detailing its technical viability, economic potential, and environmental importance. By storing carbon dioxide (CO₂) in underground geological formations, such as depleted oil and gas reservoirs, deep saline formations, unmineable coal seams, and sandstone reservoirs, CCS can help achieve net-zero emissions while supporting energy security and industrial growth.

1. Introduction

The increasing concentration of CO₂ in the atmosphere is driving climate change, that is arguably already resulting in severe environmental and socio-economic impacts which are expected to dramatically worsen if this continues. To limit global warming to 1.5°C above pre-industrial levels, as outlined in the Paris Agreement, drastic reductions in net CO₂ emissions are necessary. While renewable energy and energy efficiency measures are critical, CCS offers a complementary solution by addressing emissions from very hard-to-abate sectors such as cement, steel, and petrochemical industries.

Geological storage is the process of injecting captured CO₂ into deep subsurface formations for long-term containment. This approach leverages the natural ability of geological structures to trap gases securely over time scales beyond that of the human species.

2. Context: Global Emissions Forecast

According to the International Energy Agency (IEA), global CO₂ emissions reached over 36 billion tons in 2021, with the combustion of fossil fuels accounting for the majority. Emissions from power generation, industry, and transportation sectors are projected to remain significant contributors through to the mid-century, even under ambitious climate policies. Without significant intervention, global emissions are expected to rise further due to population growth and economic development in emerging markets.

Key projections include:

- **Baseline Scenario:** Under current policies, CO₂ emissions could exceed 40 billion tons annually by 2050.
- **Net-Zero Scenario:** Achieving net-zero emissions by 2050 requires reducing annual emissions to approximately 12 billion tons, with remaining emissions offset by carbon removal technologies.

The Intergovernmental Panel on Climate Change (IPCC) emphasizes that limiting warming to 1.5°C requires reducing emissions by 45% from 2010 levels by 2030 and achieving net-zero by

2050. CCS, particularly geological storage, is integral to bridging the gap between current trajectories and climate goals.

3. The Science of Geological Storage

Geological storage relies on the interplay of physical and chemical mechanisms to ensure CO₂ remains securely contained:

- **Structural Trapping:** CO₂ is confined by impermeable cap rocks that act as barriers to upward migration.
- **Residual Trapping:** Small amounts of CO₂ are immobilized in pore spaces of the reservoir rock through capillary forces.
- **Solubility Trapping:** CO₂ dissolves in formation water, reducing its buoyancy and mobility.
- **Mineral Trapping:** Over longer time frames, CO₂ reacts with minerals in the rock to form stable solid carbonates.

These mechanisms collectively provide robust containment, minimizing risks of leakage.

4. CO₂ Storage in Coal Seams

Coal seams present a unique opportunity for geological storage due to their natural capacity to adsorb CO₂. This process involves the molecular bonding of CO₂ to the surface of coal, effectively trapping the gas in a sponge-like fashion. The key advantages of CO₂ storage in coal seams include:

- **Enhanced Storage Potential:** Unmineable coal seams can act as highly effective storage sites for very large quantities of CO₂, especially in regions where other geological formations may be limited.
- **Improved Recovery of Methane:** In some cases, CO₂ injection into coal seams can displace methane, enabling its recovery for energy use (a process known as Enhanced Coalbed Methane Recovery, or ECBMR).
- **Cost-Effective Deployment:** Shallow coal seams often require lower drilling, completion and operating costs compared to deeper formations.

In practice, CO₂ storage in coal seams involves injecting the gas into unmineable seams through a closed-loop system. Water and CO₂ are injected into the coal seam via one well, and water is extracted from another well. The CO₂ is adsorbed by the coal while clean water is recovered as a by-product. This approach has been successfully demonstrated in pilot projects in the USA.

The long-term viability of coal seams as storage reservoirs depends on the permeability of the seam^[NY1], the integrity of overlying rock formations, and ongoing monitoring to ensure containment. By advancing this technology, CCS can unlock significant storage capacity in coal-rich regions worldwide.

5. CO₂ Storage in Sandstone Reservoirs

Sandstone reservoirs represent one of the most promising options for geological CO₂ storage. These formations, for CCS purposes generally found at depths greater than 800 meters, offer significant advantages due to their high porosity and permeability, which allow for the efficient injection and containment of CO₂. Key aspects of CO₂ storage in sandstone reservoirs include:

- **Large Storage Capacity:** Sandstone reservoirs, especially those associated with saline formations, can hold vast quantities of CO₂, making them ideal for large-scale storage projects.
- **Proven Technology:** Numerous projects, such as the Sleipner and Quest initiatives, have demonstrated the effectiveness of sandstone formations in securely storing CO₂.
- **Long-Term Stability:** Over time, CO₂ trapped in sandstone reservoirs undergoes processes like solubility and mineral trapping, further enhancing containment.

In sandstone formations, CO₂ is injected as a supercritical fluid, allowing it to occupy less space and flow more efficiently. The impermeable cap rock above the reservoir acts as a seal, preventing the upward migration of CO₂. Monitoring through seismic surveys and well logging serves to demonstrate the integrity of the storage site.

The global distribution of sandstone reservoirs and the historical data collection thereon from oil and gas activities, combined with advancements in injection techniques and monitoring technologies, positions them as a cornerstone of CCS strategies. Their successful deployment will play a critical role in reducing industrial emissions and meeting climate goals.

6. Benefits of Geological Storage

- **Permanent CO₂ Removal:** Geological formations can securely store billions of tons of CO₂, offering a long-term solution to emissions.
- **Facilitating** the ongoing existence of the “hard to abate” sectors which are cornerstones of modern life.
- **Versatility:** This approach is adaptable to various geological settings globally, enabling widespread deployment.
- **Economic Opportunities:** CCS projects create jobs in construction, operation, and maintenance while driving innovation in carbon management technologies.
- **Support for Industrial Decarbonization:** Geological storage enables industries to continue operating while reducing their carbon footprint, maintaining economic stability.

7. Case Studies

- **Sleipner Project, Norway:** Operating since 1996, this project has successfully stored over 20 million tons of CO₂ in a saline aquifer, demonstrating the feasibility and safety of geological storage.
- **Quest Project, Canada:** This initiative has captured and stored over 6 million tons of CO₂ from oil sands operations, showcasing its application in the energy sector.

8. Challenges and Solutions

Despite its potential, geological storage faces challenges:

- **High Initial Costs:** Investments in infrastructure, such as pipelines and injection wells, are significant. Cost reductions can be achieved through economies of scale and technological innovation.
- **Public Perception:** Misunderstandings about safety and efficacy can hinder acceptance. Transparent communication and successful pilot projects can build trust. Misunderstandings also exist about the true extent of the challenges facing the energy transition, particularly in the hard to abate sectors, which basically require CCS to offset their emissions.
- **Regulatory Frameworks:** Clear policies and incentives are essential to encourage adoption. Governments must establish comprehensive legal frameworks to govern CCS operations.

9. Future Outlook

Geological storage is poised to play a central role in achieving net-zero emissions. Emerging technologies, such as direct air capture (DAC) combined with storage, promise to enhance its effectiveness. As international collaboration and investment in CCS grow, geological storage is becoming a critical tool in the fight against climate change.

10. Conclusion

The urgency of addressing climate change necessitates a multifaceted approach. Geological storage, as part of a comprehensive CCS strategy, offers a proven, scalable solution to reducing CO₂ emissions. By investing in this technology, we can secure a sustainable future while maintaining economic resilience.

References

1. IPCC Special Report on Carbon Dioxide Capture and Storage, 2005.
2. Global CCS Institute, "The Global Status of CCS 2023".
3. International Energy Agency, "World Energy Outlook 2022".
4. Sleipner CO₂ Injection Project, Norwegian Petroleum Directorate.
5. Quest Carbon Capture and Storage Project, Shell Canada.

This expanded white paper provides added context regarding forecast global emissions, CO₂ storage in coal seams and sandstone reservoirs, and underscores the importance of geological storage in achieving climate goals.