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The most effective way to combat the predicted impacts of climate change is to limit carbon dioxide (CO_2) emissions, particularly from coal-burning power plants which produce half the nation's electricity. Technologies such as carbon capture and sequestration (CCS) enable coal to be used while avoiding significant greenhouse-gas emissions. CCS is technically ready to be deployed now, but it is expensive. However if the current administration successfully passes and funds a climate bill, the market for carbon will be primed and CCS will achieve the incentive needed for commercialization.

The Intergovernmental Panel on Climate Change (IPCC, 2005) concluded that the local health, safety, and environmental risks of CCS are comparable to the risks of current activities such as natural-gas storage and enhanced oil recovery if there is "appropriate site selection based on available subsurface information, a monitoring programme to detect problems, a regulatory system and the appropriate use of remediation methods to stop or control CO_2 releases if they arise." Early sequestration projects combined with over 30 years of experience injecting CO_2 for enhanced oil recovery provide confidence that long-term sequestration is feasible in properly selected geologic formations

The Risks

What are the risks? Those most commonly cited include long-term leakage of CO_2 back to the atmosphere through an inadequate seal, a seal damaged through operation, or via well holes back to the atmosphere; localized, high-volume leaks to the atmosphere producing an asphyxiation hazard to people or ecosystems; and leakage to and contamination of groundwater by either CO_2 and its co-contaminants or by saline water forced upward by high CO_2 pressures.

Leakage: This is the most frequently voiced concern about CCS. For a confining layer to be effective, it must be laterally extensive and thick enough to counter total buoyant forces of CO_2 accumulation. Potential escape mechanisms include unplugged wells, faults, fractures, and insufficient impermeable caprock. These risks can be managed by demonstrating the effectiveness, lateral extent, and uniformity of the reservoir seal or confining layer before the site is selected, using standard structural geologic and geophysical studies that map fractures, faults, and quantify the potential for fault slippage. Injection pressure must be managed to avoid risk of tensile failure (fracturing of caprock) or sheer failure (reactivation of dormant faults).

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Current regulations tend to focus only on prevention of tensile failure. All wells in the surrounding area should be catalogued and properly sealed. Assessment of possible migration patterns can help determine where existing fluid could travel when displaced.

Opponents of CCS often cite a 1986 incident at Nyos Lake, Cameroon. In this volcanic lake, CO_2 accumulated gradually in the lower depths of the lake and then, triggered by a natural event, rose suddenly to the surface, emitting a large cloud of CO_2 that suffocated nearby people and livestock. While tragic, this situation is not an appropriate corollary to regulated CCS: a shallow, tectonically active volcanic crater would never be considered an appropriate sequestration site.

Contamination: A principal concern expressed about CCS is that CO_2 leaks could impact drinking-water aquifers. One regulatory proposal to guard against this is to prohibit any CCS activities above the lowest drinking-water aquifer. Aquifers are shallower than potential storage formations in most areas, but a potential conflict could arise where deep groundwater resources exist. In such areas, hydrologic studies and monitoring well protocols could be designed to ensure the protection of the drinking-water source and permit CCS.

Injected CO_2 can displace existing saline water far beyond the space occupied by the CO_2 plume. Regulations can be tailored to prevent this from posing a threat to underground drinking-water sources by requiring a containment zone that will retain displaced water pressure generated by the project. Hydrologic transport models that incorporate movement of both the CO_2 plume and formation fluid can assist with the evaluation. Remedial response protocols should be established if a drinking-water source is potentially endangered. If danger is detected, ceasing injection will quickly reduce pressure. Additional steps to reduce pressure or prevent migration to a water source can then be considered.

Finally, there is some concern that CO_2 injected into brine reservoirs could pollute future drinking-water alternatives. Presently, water with concentrations of up to 10,000 parts per million (ppm) total dissolved solids (TDS) is considered to be of drinking-water quality. In comparison, seawater has 35,000 ppm TDS. The water quality of the brine reservoirs under consideration for carbon storage has three times the concentration of the dissolved solids of seawater. Protecting deep sources of water with that level of TDS should not prohibit or limit CCS projects. However, consideration should be given to protecting groundwater just above 10,000 ppm TDS since such water may in fact be an important resource in the future.

How Are Risks Managed?

Perhaps the biggest tool to manage risk is the regulatory framework promulgated for CCS projects at the state or federal level. Regulations must be grounded in a thorough scientific understanding of the risks involved and ensure they are managed properly. Rules must be flexible, adaptive, performance-based, and include requirements for site characterization, site selection, and long-term monitoring.

Site selection is one of the most important aspects of a CCS project. The proposed site must have large capacity and retention capabilities, and geology that promotes both structural trapping and residual pore-space trapping. Rock chemistry that facilitates dissolution and mineralization to ensure permanence is also desirable. Under most circumstances, CO_2 will dissolve in water and lower pH. In a system containing reactive mineral phases, decrease in pH is buffered by dissolution of carbonate-bearing silicate minerals.

Once a project has begun, monitoring of groundwater quality, geochemical changes, and pressure changes should be performed above the confining zone to detect any problems before they become serious. Operators should have the flexibility to choose monitoring protocols as long as they meet overall requirements and cover the CO_2 plume, extent of injected or displaced fluids, and areas of increased pressure. Key monitoring parameters include pressure, temperature, and fluid chemistry in the injection reservoir and immediately above the primary confining zone. A variety of surface and downhole geophysical techniques can provide information on the location and geometry of the CO_2 plume and the integrity of the confining unit and wells. At the surface, soil-gas and surface-air monitoring can detect CO_2 leakage (WRI, 2008).

In summary, although CCS presents some challenges, environmental concerns can be mitigated through careful project planning and execution. Considering the urgency of climate change, the benefits of CCS far exceed the risk. ■

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References

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