# LONG-TERM PROTECTION OF FRESHWATER RESOURCES

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## Abstract

The subsurface geologic storage of carbon dioxide ($CO_2$) represents a primary option for achieving reduced greenhouse gas emissions to the atmosphere. Two factors are important to successful commercial deployment: 1) good site selection and 2) implementation of both conventional and innovative monitoring methods, which will ensure that active carbon capture and storage (CCS) operations are performing properly. Equally important to commercialization is the ability to provide assurances that negative impacts to human health and the environment will not occur in the future.

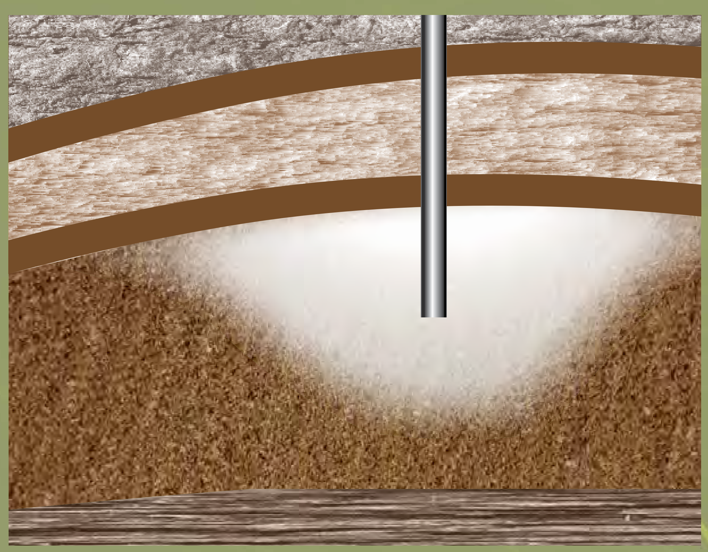
The Regional Carbon Sequestration Partnerships' (RCSPs') Water Working Group (WWG) has been using knowledge and experience gained from the RCSPs to understand how $CO_2$ containment in the subsurface can be achieved while ensuring protection of freshwater resources. Research conducted by the RCSPs has provided insight both on the types of $CO_2$-trapping mechanisms prevalent in $CO_2$ storage reservoirs as well as strategies to make use of these mechanisms in storage formations across the United States. These mechanisms include structural/stratigraphic, hydrodynamic, mineral, residual-phase, and solubility trapping. WWG is also identifying best practices for water management during CCS, including the long-term protection of freshwater resources. WWG has produced a fact sheet that highlights these efforts to aid in making all stakeholders of the CCS industry aware of work that is currently under way. WWG is also partnering with the IEA Greenhouse Gas R&D Programme to issue a special edition of the *International Journal of Greenhouse Gas Control* focused on water and CCS issues, to be published in 2016.

## Mechanisms for the Subsurface Storage of $CO_2$

Target rock formations for geologic storage, such as depleted oil and gas reservoirs and deep saline formations, are much deeper than any usable groundwater and are separated from that groundwater by thick barriers of impervious rock. Generally, these formations have already proved their effectiveness in containing $CO_2$ by keeping highly saline water separate from usable groundwater for millions of years.

Following $CO_2$ injection into the subsurface, several physical and chemical mechanisms actively store $CO_2$ and have the potential to ensure that the subsurface movement of $CO_2$ does not occur beyond the boundaries of the storage system. These "trapping mechanisms" include structural/stratigraphic, hydrodynamic, residual-phase, solubility trapping, and mineral. Each of these mechanisms is briefly described below.

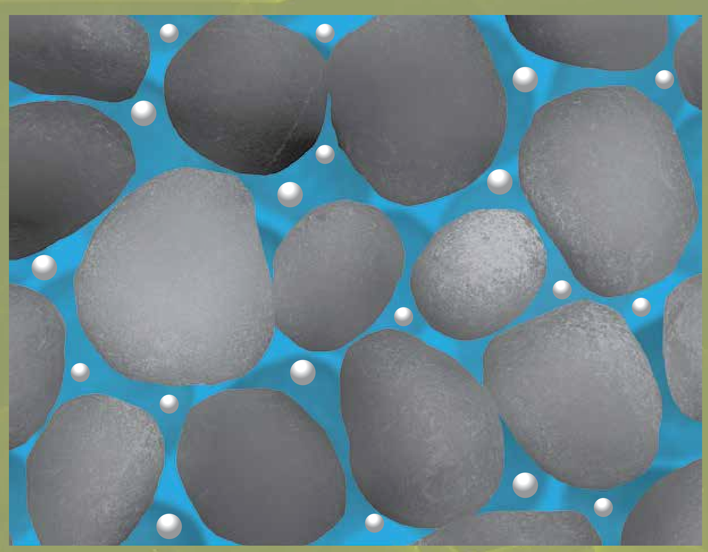

*Geologic storage of $CO_2$ occurs deep below the surface and is separated from freshwater resources by thousands of feet of rock and impermeable barriers (modified from Peck and others, 2012).*



### Structural/Stratigraphic Trapping

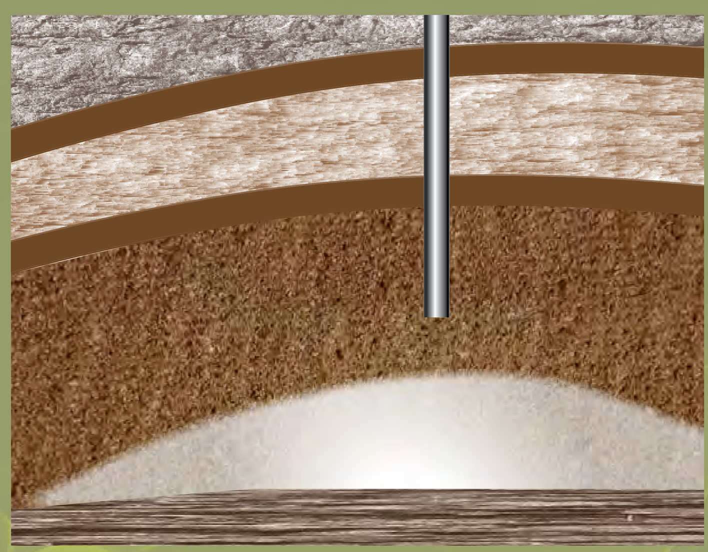
*In a structural/stratigraphic trap, $CO_2$ is physically trapped at the top of an anticline or in a tilted fault block. It is kept from further upward movement by the sealing rock (or cap rock).*

*A related trapping mechanism, known as **hydrodynamic trapping**, results when the travel time of $CO_2$ in low-permeability storage aquifers is on the order of thousands to millions of years.*



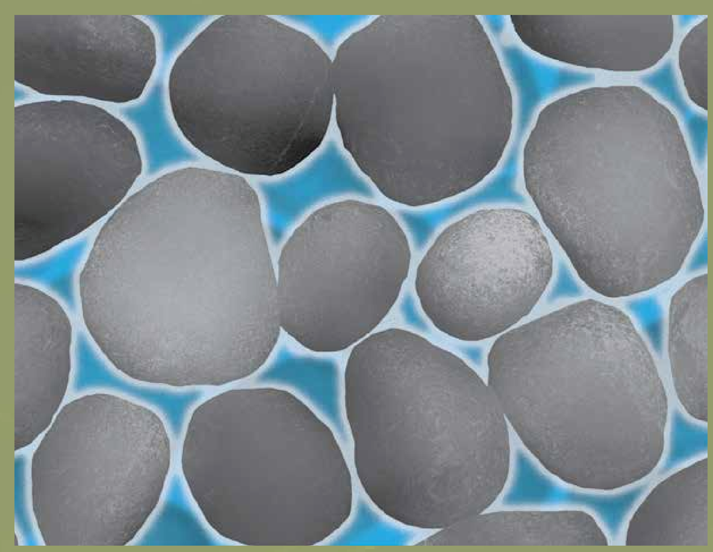
### Residual-Phase Trapping

*When free-phase $CO_2$ migrates, it forms a plume. At the tail of this plume, the concentration of $CO_2$ decreases, and it becomes trapped in the pore spaces between the rock by capillary pressure from the water, which stops its movement. Over time, this residually trapped $CO_2$ can dissolve into the formation water, promoting even more secure mineral trapping.*



### Solubility (dissolution) Trapping

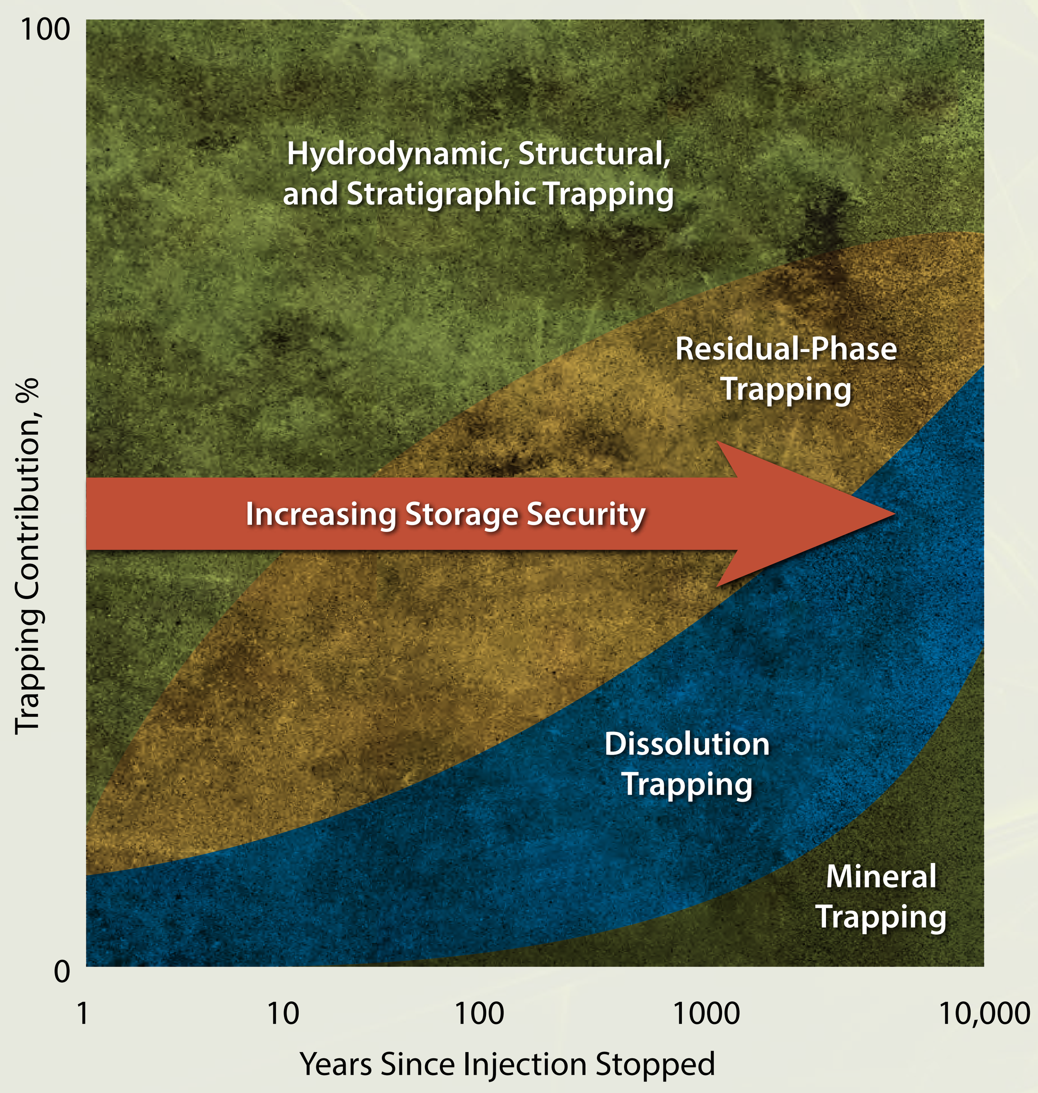
*The solubility of $CO_2$ in water increases with increasing pressure and decreases with increasing temperature and increasing water salinity. As the dissolution of $CO_2$ in water takes place, the water becomes denser and begins to sink downward. This allows the $CO_2$ to become more dispersed in the water, and the amount of $CO_2$ dissolved in the water can increase, promoting even more secure mineral trapping.*



### Mineral Trapping

*When dissolved $CO_2$ reacts with the reservoir rock, carbonate minerals can form and precipitate, trapping the $CO_2$ in stable chemical forms. The rate and extent of these reactions depend on the composition of the reservoir rock, the temperature and pressure of the reservoir, the chemical composition of the water, the water–rock contact area, and the rate of fluid flow through the rock. Mineral trapping is considered the most secure stage of $CO_2$ trapping.*

The way in which $CO_2$ is injected and flows through the storage reservoir, together with the time the $CO_2$ remains in storage, determines the relative proportion of the above trapping mechanisms that occur in a storage system over time. In turn, the movement of $CO_2$ in the reservoir depends on the geologic structure of the reservoir and the composition of the storage rocks and formation waters.




*The relative impact of trapping mechanisms over increasing timescales (modified from Intergovernmental Panel on Climate Change, 2005).*

## Understanding Long-Term Protection Through Proactive Research Programs

The U.S. Department of Energy (DOE) is proactively conducting fundamental and applied research to quantify the security of freshwater resources during subsurface $CO_2$ injection over a project's life cycle (including operational injection phase and site closure). This research is focused on developing a complete understanding of the trapping/storage mechanisms discussed here and incorporating this understanding into mathematical models capable of predicting subsurface conditions over hundreds of years.

Furthermore, these efforts will be combined with the results of other research initiatives to define "best practices" that can be applied at the preinjection, active, and postclosure stages of $CO_2$ geologic storage operations. Before injection, protective actions emphasize proper site selection and the presence and thickness of impermeable cap rocks. Proper site selection includes analysis of factors such as pore space volume, injectivity, and formation porosity and permeability, to name a few. The selection of potential sites for $CO_2$ injection also excludes areas with groundwater containing less than 10,000 milligrams per liter of dissolved solids, since these sources of groundwater are considered protected freshwater by the U.S. Environmental Protection Agency. Research into appropriate preinjection steps is complemented by investigating the real-time monitoring of the surface, near-surface, and subsurface environments during active operations to assess system performance and ensure the protection of water resources. This will help ensure the protection of freshwater resources, as well as compliance with the evolving regulatory framework during and following the widespread deployment of geologic storage of $CO_2$.

RCSP Water Working Group

Acknowledgment

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References

Intergovernmental Panel on Climate Change, 2005, IPCC special report on carbon dioxide capture and storage: Prepared by Working Group III of the Intergovernmental Panel on Climate Change, Metz, B., Davidson, O., de Coninck, H.C., Loos, M., and Meyer, L.A., eds., Cambridge, United Kingdom, Cambridge University Press, 442 p.

Peck, W., Buckley T., Battle, E., Grove, M., Riske, J., Gorecki, C., Steadman, E., and Harju, J, 2012, Plains $CO_2$ Reduction (PCOR) Partnership atlas (4th ed.): Grand Forks, North Dakota, Energy & Environmental Research Center, 124 p.