

Why Will CO₂ Stay Confined in Appropriate Geologic Formations?

The goal of carbon sequestration is to prevent CO₂ from being released into the atmosphere where it will contribute to global warming. Therefore, a carbon sequestration operator must ensure that the CO₂ will stay in the geologic reservoir into which it is injected, and that the injected CO₂ will remain confined to a well defined zone ensuring that it does not damage other subsurface assets—such as hydro-carbon or fresh water reservoirs. CO₂ will not remain confined everywhere in the subsurface. Carefully chosen CO₂ sequestration sites, however, have powerful physical attributes that ensure that the injected CO₂ will remain trapped for millions of years. The existence of buoyant fluids—such as oil, gas, and even natural CO₂—in geologic formations after millions of years proves that these trapping mechanisms work.

Trapping Mechanisms

Primary Trapping: Structural and Stratigraphic

The primary mechanism for trapping CO₂ or other fluids in the subsurface is through the existence of confining layers, or cap rocks, such as shale or salt beds, that are impermeable to the CO₂ or other fluid. Whereas a suitable reservoir layer for CO₂ injection may have a permeability of 10-1,000 milliDarcies, the cap rock will have permeabilities of at least 1,000 times less, measured in the microDarcies. Such low permeabilities prevent CO₂ migration into the confining layer. When a confining layer exists above as well as to all sides of a reservoir layer, the CO₂ will be prevented from migrating both vertically and laterally; it will be confined. Such subsurface orientations of reservoir and confining layers into trapping structures are the source of all the oil and natural gas that has been or will be recovered. Specifically, the geometry of the sub-surface traps take two dominant forms. The first type of trap—called a structural trap—is shaped as a dome or anticline (i.e., “upside-down bowl”), while the second called a stratigraphic trap—derives from lateral variations in rock type that result in the reservoir layer grading into adjacent confining layers.

Secondary & Tertiary Trapping: Residual, Solubility, and Mineral

Over time, certain physical and chemical mechanisms further trap the CO₂, thereby increasing the security of the reservoir. It must be noted, however, that these are secondary, and even tertiary trappings mechanisms; the structural and stratigraphic trapping are far more important.

As the CO₂ migrates through the pores in the reservoir layer, pockets of CO₂ will adhere to the rock grains, where they will remain due to surface tension effects; this is called residual or capillary trapping, and is the reason why primary and secondary oil recovery does not obtain more than about 2/3 of the original oil in place. Second, over many hundreds of years the CO₂ will dissolve into the brine, forming a CO₂-laden brine that is slightly denser than the original brine and will sink to the bottom of the aquifer. Third, over thousands of years, the CO₂ will precipitate out of the water

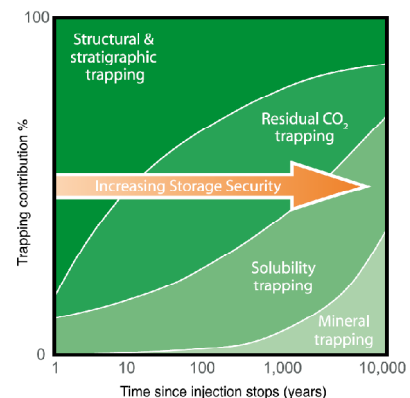


Figure 1: Schematic of the contributions of various trapping mechanisms over time. From IPCC, *Special Report on Carbon dioxide Capture and Storage*, 2005.

phase, forming stable carbonate minerals that are immobile. shows the contributions of the various physical trapping mechanisms over time.

Proof from the Confinement of Oil, Gas, and CO₂ in Reservoirs

Every year the oil and gas industry extracts billions of tonnes of hydrocarbons from the subsurface, which have been in place for tens to hundreds of millions of years even though they are more buoyant than the water in their geologic formations. Oil and gas deposits have remained in place due to the same trapping mechanisms that that will trap CO₂; virtually all oil and gas fields are found in structural or stratigraphic traps. The presence of so many oil and gas reservoirs provides an unambiguous existence proof that CO₂ will remain in appropriately chosen geologic reservoirs.

Oil and gas deposits are good analogues for CO₂ storage; however, a more similar set of analogues are natural CO₂ deposits. Natural CO₂ deposits, originating from volcanic activity or other processes, occur around the world (see Figure 2); a handful, such as the McElmo Dome, Bravo Dome, Sheep Mountain, and Jackson Dome, are exploited in the United States to obtain CO₂ for enhanced oil recovery. Natural CO₂ deposits develop near the source of CO₂, and thus do not have the advantage of careful site selection, with the result that many of the CO₂ fields have a slow, non-harmful leakage rate. Some fields, however, have developed in areas that are favorable for the secure accumulation of CO₂: the 200 Mt of CO₂ in the Pisgah Anticline (near Jackson Dome in Mississippi) has remained in place for 65 million years with no sign of leakage.

Proof from Engineered Reservoirs

Finally, engineers have extensive operating experience with the storage of natural gas and CO₂ in the subsurface. Natural gas storage, which involves the injection of natural gas into a subsurface reservoir during times of surplus so that it can be withdrawn when needed, has been performed for almost 100 years with a good track record. In the United States in 2005, 470 projects totaling over 160 Mt of storage capacity were operational. Again, natural gas storage sites are chosen because of their confining properties due to structural or stratigraphic trapping.

Several large CO₂ sequestration projects around the world have proven the security of CO₂ storage in the subsurface. The Sleipner and Snohvit projects, operating since 1996 and 2007, respectively, each inject ~1 Mt/yr of CO₂ into a sandstone formation in the North Sea; while the In Salah project, operating since 2004, injects ~1 Mt/yr into a depleted gas reservoir in Algeria. These projects have been carefully monitored and do not show signs of leakage.

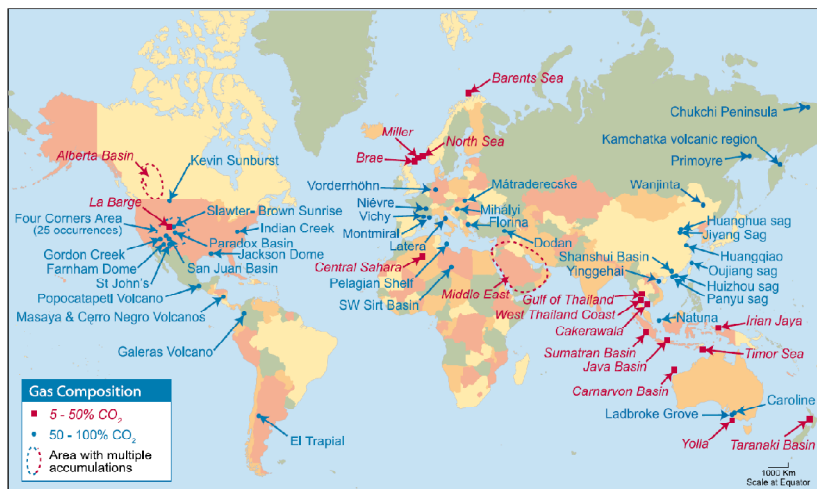


Figure 2: Examples of natural CO₂ deposits. From IPCC, 2005.

In summary, an appropriately chosen geologic reservoir will utilize powerful physical trapping mechanisms to trap CO₂ for millions of years, just as oil, gas, and natural CO₂ have been trapped.