CCS

inFocus

Carbon Capture & Storage

Underground CO_2 Storage: A Reality?

CAPTURING AND STORING CARBON DIOXIDE (CO_2) UNDERGROUND IS NOT A NEW OR EMERGING TECHNOLOGY — IT IS ALREADY A REALITY ON A SMALL SCALE. THERE ARE LARGE CARBON DIOXIDE STORAGE RESERVOIRS THROUGHOUT THE WORLD THAT EXPERTS BELIEVE CAN ACCOMMODATE CENTURIES WORTH OF INJECTED CO_2. ADDITIONALLY, THE VARIOUS TECHNICAL COMPONENTS OF CARBON CAPTURE AND STORAGE (CCS) HAVE BEEN SEPARATELY PROVEN. BUT USING THE TECHNOLOGY ON THE COMMERCIAL SCALE NECESSARY TO IMPACT GLOBAL CLIMATE CHANGE REMAINS PROHIBITIVELY EXPENSIVE. CONTINUED RESEARCH IS NEEDED TO LOWER COSTS OF THE TECHNOLOGY ITSELF AND CONFIRM ALL ASPECTS OF GEOLOGIC STORAGE, INCLUDING RESERVOIR SIZE, SAFETY, AND RELIABILITY.

OVERVIEW

There are decades of operational experience from CCS projects, including underground CO_2 injection for enhanced oil recovery (EOR) and the use of technologies analogous to carbon capture and storage, such as acid gas injection and natural gas storage. Three large-scale storage projects — injecting 1 million to 2 million tonnes of CO_2 annually — have been operating for several years, and five smaller projects are now actively capturing and storing carbon dioxide. There are also capture-only projects for industrial use. These industrial-level experiences are complemented by numerous research-scale CCS projects, intergovernmental and industry partnerships, research programs, and stakeholder networks. **No adverse safety, health, or environmental effects have ever resulted from any of these operations**.

Scientists believe the earth has extensive capacity for storing injected carbon dioxide. The United Nations Intergovernmental Panel on Climate Change (IPCC) estimates the world's potential capacity at 2 trillion tonnes, although there could be a "much larger potential."[1] The bottom line is that many pieces of the CCS puzzle have been deployed and verified separately but no commercial-scale power plants using the technology have yet been constructed. This is an essential step before CCS can be deployed commercially. Meanwhile, existing projects and research initiatives are helping researchers and operators acquire the real-world experience and data needed to advance the technologies, lower costs, and validate CCS potential and storage capabilities.

> **Did You Know?**
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> **In the United States, CO_2 has been injected underground for enhanced oil recovery operations for decades; about 63 million tonnes of mostly naturally produced CO_2 are injected annually for this purpose.**
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> U.S. Department of Energy, National Energy Technology Laboratory, "The Role of Underground CO_2 Accumulations in the Emergence of CO_2 Enhanced Oil Recovery," June 2011, Executive Summary, 1.

[1] U.N. IPCC, "Special Report on Carbon Dioxide Capture and Storage: Summary for Policymakers," 2005, 12.

What is a geologic formation and how does it sequester CO_2?

The concept involves storing CO_2 deep underground (typically at depths greater than 800 meters, or more than 2,600 feet) in geologic formations [2] with characteristics that would trap large volumes of CO_2 and not allow it to leak. Some of these characteristics include tiny microscopic spaces generally filled with salty water, known as **porosity**; sufficient connection between the open spaces so that CO_2 can flow sideways or move around within the formation, known as **permeability**; and a confining layer that can "**cap**" the upward flow so that CO_2 is trapped underground.

Many types of geologic formations have these features, such as sandstones and limestones, and some geologic formations are tens to hundreds of feet thick and may extend laterally for miles.

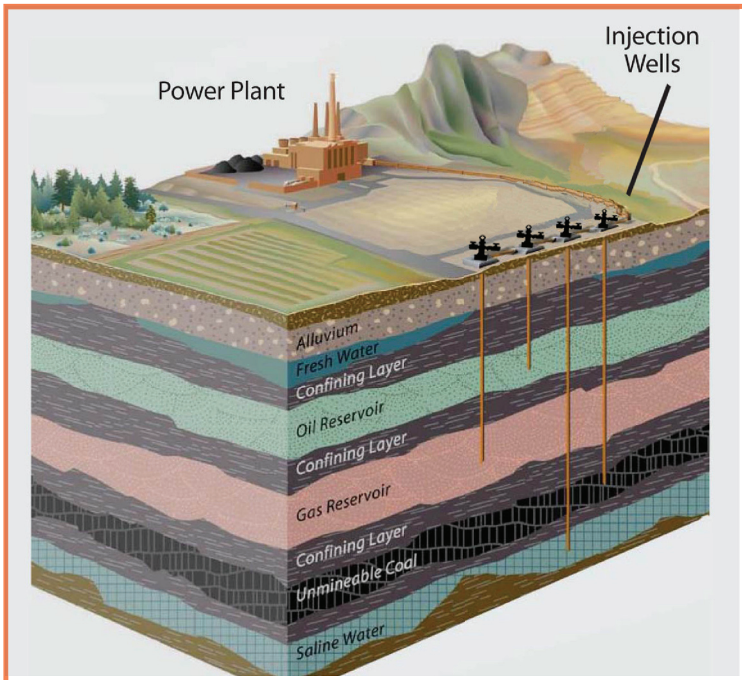
Geologic formations that are potential CO_2 reservoirs are the same as reservoirs that trap oil and gas and naturally occurring CO_2. Oil and gas can be found in sandstones, limestones, and other permeable formations, trapped for millions of years until tapped by wells drilled from the surface to extract the oil.

An overlying layer of low permeability rock, commonly referred to as a **caprock** or geologic seal (such as shales or siltstones), prevents oil and gas from traveling out of the permeable formation. Similarly, a caprock or geologic seal would be expected to trap CO_2 and prevent it from migrating upwards.

How is CO_2 injected underground and why does it stay there?

CO_2 is compressed into a dense fluid then pumped — via one or more wells — into a porous geological formation. At first, being more buoyant than water, the CO_2 rises to the top of the formation, where it becomes trapped beneath a confining layer of impermeable caprock (see description above) which acts as a seal: Caprocks have trapped oil, gas, and CO_2 underground for millions of years.

However, it is not long before other trapping mechanisms also start to take effect: during injection, and as the CO_2 shifts within the formation, some of it becomes trapped in the tiny pore spaces of the rocks and does not move. The CO_2 also starts dissolving into the saline formation (the way sugar dissolves in hot tea) and being heavier than the water around it, the carbonated water sinks to the bottom of the formation, trapping it indefinitely. Finally, the dissolved CO_2 reacts chemically with the rocks to produce minerals, much like shellfish use calcium and carbon from seawater to form their shells. Depending on the chemistry of the rocks and water, this process can be very rapid or very slow, but it effectively binds the CO_2 to the rocks.



Schematic illustrating the process of carbon capture and storage (also known as sequestration). Adapted from Energy and Geosciences Institute, The University of Utah illustration.

[2] To classify and map layers of rock, geologists created a basic unit called a formation. A formation is a rock unit that is distinctive enough in appearance that a geologic mapper can tell it apart from the surrounding rock layers. It must also be thick enough and extensive enough to plot on a map.

Why are scientists so optimistic that geologic CO_2 storage will work?

No emissions control technology, including carbon capture and storage, is risk-free. But several projects are already successfully storing millions of tonnes of CO_2 underground. To date, five large-scale CO_2 storage projects (greater than 1 million tonnes of CO_2 per year — enough to fill the Empire State Building — over the storage period) are underway worldwide — two in Norway, and one each in Algeria, Canada, and the United States.

The Sleipner Project, located approximately 150 miles (241 kilometers) off the coast of Norway in the North Sea is storing more than 2,700 tonnes of CO_2 per day, injected 2,600 feet (792 meters) below the seabed. Over the lifetime of the project, more than 20 million tonnes of CO_2 are expected to be injected into the saline formation, which is sealed at the top by an extensive and thick shale layer. Monitoring surveys of the injected CO_2 indicate that over the past 13 years, the gas has spread out over nearly two square miles underground without moving upwards or out of the storage reservoir. Long-term simulations also suggest that over hundreds to thousands of years the CO_2 will eventually dissolve in the saline water, becoming heavier and less likely to migrate away from the reservoir.

Additionally, oil and natural gas companies have more than 40 years of experience storing natural gas deep underground and using injected CO_2 to "push" oil toward producing wells (i.e., EOR). According to the International Energy Agency (IEA), the success of these projects, as well as the increasing number of research demonstrations, provides "growing confidence in the potential to store large quantities of CO_2 underground — safely and securely."[3]

The IPCC notes:

> **"Information and experience gained from the injection and/or storage of CO_2 from a large number of existing enhanced oil recovery (EOR) and acid gas projects, as well as from the Sleipner, Weyburn, and In Salah projects, indicate that it is feasible to store CO_2 in geological formations as a CO_2 mitigation option. Industrial analogues, including underground natural gas storage projects around the world and acid gas injection projects, provide additional indications that CO_2 can be safely injected and stored at well-characterized and properly managed sites."[4]**

Globally, there are currently more than 8,100 large CO_2 point sources (accounting for more than 60 percent of all anthropogenic CO_2 emissions) that could conceivably adopt CCS technologies as a means for delivering deep and sustained CO_2 emissions reductions.

"Carbon Dioxide Capture and Geologic Storage," Global Energy Technology Strategy Program, April 2006, 8.

Did You Know?

Where would large amounts of CO_2 likely be stored?

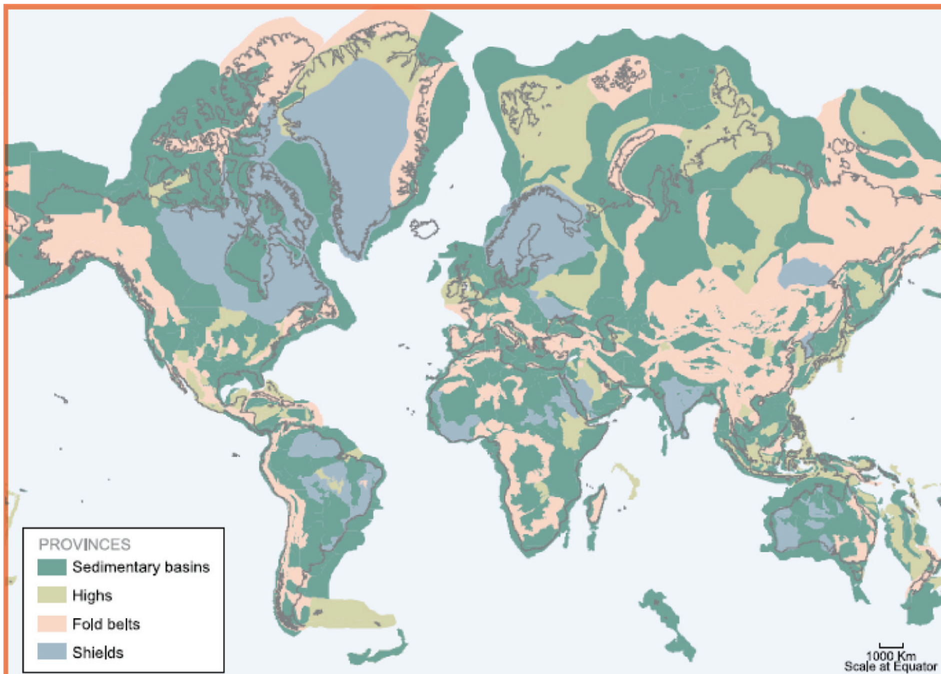
The IPCC has identified prospective areas in sedimentary basins (see map) where saline formations, or oil, gas, and coal fields potentially suitable for CO_2 storage are located.[5] These formations are widely distributed around the world and many are near large groupings of power plants and other industrial facilities.

[3] IEA Greenhouse Gas R&D Programme, "Storing CO_2 Underground," 2007, 2.

[4] U.N. IPCC, "Special Report on Carbon Dioxide Capture and Storage," 2005, 197.

[5] U.N. IPCC, "Special Report on Carbon Capture and Storage: Summary for Policymakers," 2005, 9.

Rocks in deep sedimentary basins are suitable for CO_2 storage



IPCC, "Special Report on Carbon Capture and Storage," 2005, Figure 5.14, "Distribution of Sedimentary Basins Around the World," 214.

Depleted oil and gas fields, deep saline formations, and unmineable coal seams have been suggested as favorable CO_2 geological storage sites. Here, various physical (e.g., highly impermeable caprock) and geochemical trapping mechanisms would prevent the CO_2 from escaping to the surface. In the future, companies may be able to inject CO_2 into coal seams and produce natural gas from the seams as an added benefit.

Saline formations contain highly mineralized brines (or very salty water) that are unsuitable for agriculture or human consumption. Saline formations have been used for storage of chemical waste in a few cases. The main advantages of saline formations are their large potential storage volume and their common occurrence. Other possibilities include deep basalt formations and shales.

How much CO_2 can be stored underground?

As scientists work to refine methodologies, estimates of global geologic storage capacity can be highly variable. Nevertheless, numerous studies suggest there is extensive worldwide potential for permanently storing large quantities of CO_2 in geological formations.

As previously noted, the IPCC has identified a technical potential of at least 2 trillion tonnes of worldwide CO_2 storage capacity in geological formations and they also note: "There could be a much larger potential for geological storage in saline formations, but the upper limit estimates are uncertain due to lack of information and an agreed methodology."[6]

A more recent report prepared by the United States Department of Energy (DOE) has documented between 1.85 trillion and 20.5 trillion tonnes of CO_2 storage potential in oil and gas reservoirs, coal seams, and saline formations across the United States and Canada. Preliminary estimates suggest the availability of centuries worth of CO_2 storage for the United States and Canada in these geologic formations.[7]

A preliminary estimate by scientists at DOE's Pacific Northwest National Laboratory (PNNL) indicates there is nearly 11 trillion tonnes of potential global deep geologic storage capacity, "which, assuming other advanced energy technologies (such as nuclear and renewables) are developed and deployed along with CCS, should be more than enough to address global CO_2 storage needs for this century."[8]

[6] U.N. IPCC, "Special Report on Carbon Dioxide Capture and Storage: Summary for Policymakers," 2005, 12.

[7] National Energy Technology Laboratory, "Carbon Sequestration Atlas of the United States and Canada — Third Edition, 2010, page 155.

[8] James Dooley, Robert Dahowski, and Casie Davidson, Pacific Northwest National Laboratory, "CCS: A Key to Addressing Climate Change," Chapter 4 in "Fundamentals of the Global Oil and Gas Industry," 2007, vol. 2007, 67–69.

carbon sequestration leadership forum

In Europe, the EU project GESTCO estimated the CO_2 storage capacity in oil and gas fields in and around the North Sea at 37 billion tonnes, which would enable this region to inject CO_2 for several decades once the fields are depleted.[9]

One report notes: "In a world in which there is a broad portfolio of complementary carbon management technologies that can be drawn upon (e.g., energy efficiencies, renewable energy, nuclear power, etc.), it would appear that the deployment of CCS systems will not be constrained by a lack of overall storage capacity."[10] Meanwhile, as part of ongoing research, the Carbon Sequestration Leadership Forum (CSLF) is seeking to develop a clear set of definitions and methodologies to allow scientists to provide consistent assessments of worldwide CO_2 storage capacity.

It Seems Like Geologic Storage is Pretty Promising. Why is More Research Needed?

There is scientific consensus that CO_2 storage in deep underground geologic reservoirs has great potential as one of several climate change mitigation strategies. But there are substantial financial, institutional, regulatory, and technical challenges that need to be overcome before CCS can be widely deployed. One of these involves completing the database necessary to assure we can safely and effectively store the large volumes of CO_2 necessary to achieve significant emissions reductions from fossil-fuel power plants. Rapid progress is being made in this area, but continued field tests to fully characterize geologic storage sites, validate models and prior findings, and develop measurement, monitoring, and verification (MMV) instrumentation is essential.

"Observations from engineered and natural analogues as well as models suggest that the fraction (of stored CO_2) retained in appropriately selected and managed geological reservoirs is very likely to exceed 99 percent over 100 years and is likely to exceed 99 percent over 1,000 years."

IPCC, Special Report on Carbon Dioxide Capture and Storage, "Summary for Policymakers," 2005, 14.

Did You Know?

Sources for Additional Information

- United Nations Intergovernmental Panel on Climate Change, http://www.ipcc.ch/
- International Energy Agency, http://www.iea.org/
- World Coal Institute, http://www.worldcoal.org/
- The World Bank, http://www.worldbank.org/
- European Zero Emissions Platform, http://www.zeroemissionsplatform.eu/

Other inFocus Factsheets:

- Is Geologic CO_2 Storage Safe?
- Why Carbon Capture and Storage?
- CO_2 Capture — Does it Work?
- CO_2 Transportation — Is it Safe and Reliable?
- 10 Facts About CCS

[9] European Union Fifth Framework Programme for Research and Development, "Geological Storage of CO_2 from Combustion of Fossil Fuels," November 2004, 9.

[10] Global Energy Strategy Technology Program, "Carbon Dioxide Capture and Geologic Storage," April 2006, 8.