Carbon Capture and Storage – How It Works

Keeping Industrial CO₂ Out of the Atmosphere

Carbon capture and storage (CCS) is a means to address the threat of climate change by capturing CO₂ from human (anthropogenic) activities instead of releasing it to the atmosphere. CCS involves the capture of CO₂ and transport to an appropriate location where it is injected deep underground for permanent geologic storage. CCS is best suited for use in large stationary facilities, like fossil fuel-based power stations, ethanol plants, oil- and gas-processing facilities, cement plant, and factories. Other names for CCS include carbon capture, utilization, and storage, or CCUS, and geologic sequestration.

Fossil Fuel-Based Power Stations

For most of the world’s electricity generation, coal, natural gas, or oil are burned to heat water to produce steam to drive a turbine to produce electricity. Burning any carbon-based fuel produces CO₂ and water. According to the IPCC (2014), these anthropogenic sources of CO₂ make up about 65% of our global carbon footprint.
Site Selection

Picking the right geologic location (configuration of rock layers at the right depth) is critical to the safe, permanent storage of CO₂. Successful storage requires that CO₂ stay in the injection layer, also known as storage layer.

Promising sites must have:

- **Capacity**: enough space in the storage zone to hold all of the CO₂ to be stored.
- **Containment**: overlying seals or cap rocks above the storage zone.
- **Geologic Stability**: no geologic faults in the surrounding rocks.
- **Depth**: ample barriers between the storage zone and sources of drinking water (typically deeper than 3000 feet (~800 meters)).
- **Chemistry**: rock content compatible with CO₂ injection and storage.

Identifying suitable sites involves many steps of data collection, analysis, and evaluation. Luckily, this is not a new concept. CCS builds on knowledge and technologies from the oil and gas industry. The oil and gas industry has already permanently stored millions of tons of CO₂ deep underground as part of nearly 50 years of CO₂ enhanced oil recovery (e.g., Weyburn, Bell Creek).¹

Technical information comes from many existing and new sources. These include historical drilling records, existing rock samples and well data, new exploratory holes, geophysical surveys (think sonograms of the earth), and other available geologic data. Scientists use these data to build computer models of a promising storage target to run simulations to predict CO₂ movement in the storage zone over time.

The U.S. Department of Energy’s (DOE) CarbonSAFE Initiative is looking at several potential sites. One site is in North Dakota and is called North Dakota CarbonSAFE project.

CO₂ Capture

CO₂ capture can be defined as the separation of anthropogenic CO₂ from the exhaust gas of an industrial process. CO₂ makes up a relatively small fraction of the exhaust gas mixture, but at a utility or industrial scale, the amount of CO₂ can be quite large. Because it involves complex chemistry and specialized equipment, capturing CO₂ is expensive.
The separation process consists of several steps. In the first step, pollutants such as sulfur oxides and nitrogen oxides, as well as particulate, are removed. These components would make the chemicals and materials used to separate the CO₂ much less efficient. Even though it adds cost to the process, their removal means that the gases coming out of the chimney are cleaner. The second step consists of the actual separation of CO₂ from the exhaust gas. This is usually done by absorbing the CO₂ in a liquid called a solvent and then heating the CO₂-laden solvent to remove the CO₂ from the solvent. This nearly pure CO₂ stream is saturated with water. The water is removed from the CO₂ stream to protect transport, storage, and other infrastructure from corrosion. Once dry, the CO₂ is compressed to a dense phase (much like a liquid) for transport.

CO₂ can be captured from refineries, natural gas-processing plants, cement plants, ethanol plants, power plants, and other industries. Some CO₂-emitting facilities include CO₂ separation as a part of normal processing, while for others, capture has been applied at least at a research scale. **Boundary Dam Station** in Estevan, Saskatchewan, Canada, is the site of the first commercial-scale capture facility for a coal-fired power plant.

### CO₂ Transportation

Following capture, CO₂ must be compressed to a dense phase (about 1200 to 1500 psi) for transport to a permanent storage site. Compression is energy-intensive, so improved methods of compression are being developed.

Given the quantities of CO₂ to be captured from industrial sources, pipelines are the most likely mode for transporting the captured gas to geologic storage sites. Pipelines are a proven method to safely transport CO₂. They have been used to safely transport industrial quantities of CO₂ for over 40 years. CO₂ pipelines are similar in design and operation to natural gas pipelines, although the higher pressures needed for CO₂ transportation require construction using thicker-walled carbon steel pipe. More on CO₂ pipeline infrastructure.

More than 5000 miles (7200 km) of CO₂ pipeline is in service in the United States alone, with additional pipelines planned or under construction. One example is the **Greencore Pipeline** that delivers CO₂ from gas-processing plants in Wyoming to the **Bell Creek** oil field in southeastern Montana.
Permanent Storage

Many suitable areas across the globe have the capacity to hold anthropogenic CO₂ emissions safely and securely deep underground. These formations exist in sedimentary basins and include oil and gas fields, saline formations, and unminable coal seams. What all of these formations have in common is a porous and permeable storage layer sealed by impermeable cap rocks.

Permanent storage can occur in two scenarios:
- Dedicated storage projects
- Storage that happens as part of CO₂ enhanced oil recovery (EOR)

When CCS projects are designed for dedicated storage, CO₂ is injected into a carefully selected storage formation with the intention of permanently storing it underground.

When CCS occurs as part of an EOR project, the CO₂ is injected into an existing oil-bearing reservoir to increase oil production. During the life cycle of the EOR process, more than 90% of CO₂ stays trapped as a secondary benefit, producing greener oil.

Monitoring

All CCS projects have a comprehensive monitoring plan approved by a regulatory authority. The plan:
- Ensures that injected CO₂ is safely and permanently stored deep underground.
- Confirms that the CO₂ does not migrate out of the storage zone.
- Ensures that potable groundwater and ecosystems are protected throughout the life of the project.

Many technologies are used to monitor the site before, during, and after CO₂ has been injected. Surface monitoring such as soil gas and groundwater sampling are carried out during all stages of the project and aim to assure operational safety and environmental protection as well as detect any potential anomalies early. Subsurface monitoring begins with the actual CO₂ injection. Surface and downhole sensors allow direct measurement of CO₂ concentrations and collect real-time data such as injection pressure and temperature. These and other subsurface tools are used not only to monitor...
conditions in key formations (e.g., storage and overlying seals), but also the flow of CO\(_2\) once it has been injected into the storage layer.

Monitoring technologies have advanced over the last decade through small- and large-scale research projects. The tools and protocols developed by this research have led to an approach called **monitoring, verification, and accounting (MVA)**. MVA recognizes that part of CCS is verifying that permanent storage has occurred and determining how much CO\(_2\) has been trapped. These aspects are critical to any system encouraging CO\(_2\) emission reductions—whether for regulatory or economic drivers. Whereas the unique aspects of each potential CCS project dictate the specific tools and protocols, the MVA approach is effective at validating the CCS project for regulators and supports emission reduction credits.

### CCS Regulatory Authority: U.S. EPA’s Underground Injection Well Program or North Dakota DMR

The **U.S. Environmental Protection Agency (EPA)** has the ultimate authority to permit and regulate all injection wells in the United States as a means to protect drinking water resources. This authority covers **six types or classes of injection wells**. As this is an onerous task, EPA grants primary regulatory authority to states where the state regulators have petitioned and proved competency to be at that authority by having established regulations that meet or exceed EPA standards. Such permission is called “primacy” and must be sought for each class of wells.

As of January 2020, the North Dakota Department of Mineral Resources (NDDMR) Division of Oil & Gas (under the Industrial Commission of North Dakota) is the only **state regulator** that has received authority from the EPA to permit and regulate CO\(_2\) injection wells for geologic sequestration (Class VI). This is official recognition by EPA that the NDDMR’s comprehensive regulations for dedicated permanent CO\(_2\) storage wells meet or exceed EPA’s standards and that entities that want to develop CCS sites can work directly with the regulators most familiar with the geology and environmental conditions in North Dakota. The outcome is anticipated to be a faster process—i.e., CO\(_2\) emissions eliminated sooner—more reliable for industrial partners, and more accessible with more direct oversight for human safety and environmental protection.

### Notes and References


3. Siting Carbon Dioxide Pipelines. 


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