What Is Carbon Capture and Storage?

Broadly, climate change results from human activity upsetting the long-standing balance of greenhouse gasses (GHG) in the atmosphere, leading to significant temperature increases and weather pattern shifts. According to the EPA, carbon dioxide (CO_2) comprises 76% of total US GHG emissions. Therefore, addressing the release of CO_2 is necessary to fight climate change.

To mitigate further CO_2 emissions, and even reverse their release, carbon capture storage (CCS) technologies are crucial. But what is CCS exactly, and how does it work?

What is Carbon Capture and Storage (CCS)?

Carbon capture and storage primarily refers to processes and systems used during industrial and other CO_2-releasing activities to inhibit further emissions.

Essentially, the use of CCS technologies is for the purposes of creating "closed systems," through which CO_2 emissions are captured before they can be released into the environment. Instead, the carbon captured via CCS is typically gathered, has its chemical properties altered, and is stored deep below ground within:

- Saline formations
- Oil and natural gas reservoirs
- Unmineable coal seams
- Organic-rich shales
- Basalt formations

These deep-ground locations act as safe storage for carbon emissions, preventing their release (or re-release) into the atmosphere.

Why is CCS Technology Necessary?

More GHG—CO_2 in particular—are released whenever we consume fossil fuels (e.g., oil, coal, natural gas). Current measurements place the atmospheric presence of CO_2 at roughly 420 parts per million (ppm), and it's increasing by roughly 2 ppm per year, pushing us further away from an identified safe threshold of 350 ppm.

CCS technology is necessary because we're often only performing an incomplete cycle, which significantly exacerbates climate change.

The Carbon Cycle

To continue the idea of a carbon cycle, fossil fuels such as oil, coal, and natural gas should similarly be viewed as deep-ground carbon storage before they're mined.

When we exhume and burn these fuels without returning the emitted carbon below ground, we're only moving it from one place to another. But, unfortunately, the place we're moving it to is the air around us, which leads to detrimental effects.

Consider a hypothetical situation where evaporated water never rained back down as part of the water cycle; we would gradually consume all water on Earth until none was left. In comparison, our fossil fuel consumption reflects the reverse process—we've traditionally ignored the release of GHGs, allowing them to steadily accumulate.

In effect, we're not taking the trash out, but merely letting it pile up around us at a rate that's accelerating our approach to disaster. In-air—rather than out-of-sight—and out-of-mind has been our default approach for far too long.

What is Direct Capture?

Since CCS with 100% efficiency would only stop the further release of CO_2, we also need to remove atmospheric GHG to reach that 350 ppm safe threshold. We've started taking out the trash and preventing further build-up, but we can't simply ignore what's accumulated.

Unfortunately, CCS applications don't currently extend to anything remotely approaching all fossil fuel consumption. And fossil fuels are projected to remain a dominant energy source for the next few decades.

According to the Intergovernmental Panel on Climate Change, per year CO_2 emissions across notable industries roughly amount to:

- Power generation – 10,539 metric tons (Mt)
- Cement production – 932 Mt
- Refineries – 798 Mt
- Iron and steel processing – 646 Mt
- Petrochemicals – 379 Mt
- Bioethanol and bioenergy – 91 Mt
- Oil and gas processing – 50 Mt
- Other sources – 33 Mt

In addition to integrating CCS technologies, we also need to utilize "direct capture" processes to extract the CO_2 that's already escaped into the atmosphere and will continue to do so.

What is CCUS?

CCUS—or "carbon capture, utilization, and storage"—refers to innovations and resultant processes that attempt to use the captured CO_2 as a beneficial or neutral input (e.g., in concrete) to provide additional safe storage repositories.

CCUS provides another means to recycle the carbon emissions we capture, rather than just storing them below ground.

How Does CCS Work?

CCS processes can be broken apart into two stages: the capture and then the storage of carbon.

Carbon Capture

In most instances, carbon capture requires systems and processes integrated with industrial activity that sequester CO_2 from other byproducts via solvents, sorbents, and membranes.

Three primary methods are used, with varying applications and benefits:

- **Post-combustion** – CO2 is removed from exhaust gasses (i.e., the "flue") after burning fossil fuels. The solution or membrane containing the CO_2 is mixed with steam to remove it, and then the GHG is sequestrated, compressed, and cooled into a liquid. This process is the easiest and most cost-effective for retrofitting older power and industrial plants.

- **Pre-combustion** – By partially burning fossil fuels via "gasification," CO_2 can be captured from the exhaust before using the energy source. While more efficient and cost-effective, pre-combustion cannot be retrofitted to existing industrial and plant operations. It's most commonly found in the production of power, chemical gasses, and fertilizers.

- **Oxyfuel combustion** – When fossil fuels are burned in pure oxygen (as opposed to all the elements that make up air), the easily captured flue byproduct is primarily composed of CO_2 and water vapor. Although it's the most efficient carbon capture process, oxyfuel combustion requires significant energy inputs to burn the oxygen used initially and cannot be retrofitted.

Each of these processes can be made even more sustainable by utilizing electrical energy from solar or wind sources (e.g., the creation of high-temperature steam).

Carbon Storage

Once captured and refined, the CO_2 is most often stored deep below ground as a "supercritical fluid." This means bringing the CO_2 to temperatures and pressures above 88^{o}F and 1,057 psi, respectively. In this state, the CO_2 takes up less volume and is dense enough to remain below the Earth's surface.

Trapping CO_2 in Storage

When CO_2 is buried deep enough underground, the natural temperatures and pressures will maintain the supercritical fluid state without any additional effort.

However, the density of CO_2 compared to other liquids that may be present deep below ground may be less, resulting in greater buoyancy and upward force. Therefore, to keep the supercritical CO_2 fluid stored, it must often be "trapped."

CO_2 trapping can be performed via:

- **Rock seals** – Also known as "structural trapping," naturally occurring impermeable rock layers can be used as caps or seals that prevent CO_2 from rising further.

- **"Sponges"** – Permeable rock layers can be used to absorb the supercritical CO2 fluid, much like a sponge. This is known as "residual trapping."

- **Dissolution** – The CO_2 can be dissolved if brine water is also present in permeable rock layers, which achieves "solubility trapping."

- **Carbonate materials** – If the solution of CO2 dissolved in brine water also reacts with the minerals present, they can form solid carbonate minerals. For example, bicarbonate (i.e., HCO_{3-}) is a weak acid that will react with magnesium to form MgCO3, a solid carbonate that will remain below ground through "mineral trapping."

With these different trapping methods, we can complete the "carbon cycle" that we've been ignoring for too long.

Barriers to CCS Deployment

While carbon capture and storage technologies provide an extremely promising pathway forward to address GHG emissions, there are still hurdles to overcome before widespread, efficient, and cost-effective adoption is achieved.

Per Resources for the Future, a Washington DC nonprofit, additional innovations will be needed across:

- **Cost barriers** – The systems and energy needed to perform CCS are not inexpensive. Furthermore, the only CCS process with widespread adoption that can be retrofitted to existing power and industrial plants is post-combustion capture—the least efficient of the three primary methods.

- **Output efficiency** – Much like adding emissions systems to automobiles, the energy consumption added by CCS to power and industrial plants results in "parasitic loss"—or less efficient output.

- **Infrastructure and transportation** – Safely transporting CO_2 requires significant pressurizing and cooling, which requires dedicated, specialty pipeline infrastructure. This adds further location and routing challenges concerning private property and ecological effects.

- **Education and public support** – If people don't know about the benefits of CCS technologies, they may be reluctant to support them in their area. Already present public antipathy for pipeline projects related to fossil fuels may dissuade local populations from supporting CCS projects, even if the infrastructure will be used to create a more sustainable future rather than increase GHGs. Education is necessary.

While CCS innovations have been especially promising and represent one aspect of a comprehensive strategy to combat climate change, innovations and information will be needed to further increase adoption and support.

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Reach out to discover how we can help you with carbon capture and storage—and all your other renewable energy infrastructure.

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