Carbon Management

Carbon Management offers solutions to leverage existing infrastructure and processes while preventing emissions by making use of carbon that would otherwise be emitted to the atmosphere.

Carbon Management Methods: Capturing Carbon

Direct Air Capture (DAC)

Direct air capture systems pull CO_2 out of atmospheric air, differing from point-source capture, which requires a high-concentration source of CO_2 such as exhaust from fuel combustion. Direct air capture can be applied in a wider range of applications, but it is still an emerging market. With DAC, CO_2 is captured as a gas and can be either used on-site, stored, or transported for use. Potential uses include combining captured carbon with renewable hydrogen to produce renewable natural gas (CH_4).[1] Many facilities have already implemented DAC, and its simple design allows flexibility in terms of the industries that can take advantage of the technology. DAC equipment requires water, electricity, and a source of heat (typically fuel combustion) to operate and extract CO_2. DAC devices can potentially be used to offset carbon emissions due to their ability to extract CO_2 from any air source. This may make DAC attractive to companies looking to become net zero or simply reduce their emissions. However, extracting carbon from air is currently more expensive than extracting it from concentrated sources of CO_2.[2]

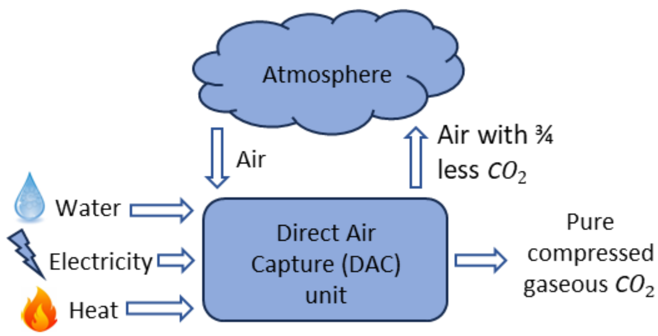

Figure 1: Simplified Diagram of Direct Air Capture (Source: ICF)

Chemical Absorption

One of the oldest and most widely used methods for capturing carbon, this process involves a chemical solvent that is used to bind directly with CO_2. While chemical absorption can be used as part of direct air capture, it is typically applied post combustion, at the site of fossil fuel combustion. As fuels are combusted, they create flue gas, which contains a very high concentration of carbon dioxide. This is known as "point source" capture, where a gas containing a high concentration of pollutants is captured before entering the atmosphere. When chemical absorption is applied properly and efficiently, up to 90% of CO_2 can be captured from its emissions source.[3] This technology has been available for decades, but solvents with lower costs and lower emissions are being continually developed, and certain companies are liquifying the captured CO_2. Liquification, while expensive,

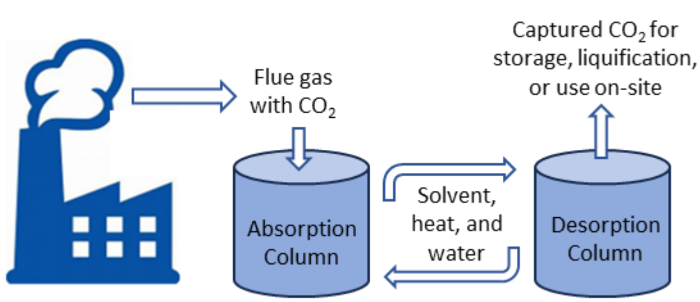

Figure 2: Representation of Chemical absorption using flue gas (Source: ICF)

[1] How does direct air capture work? | World Economic Forum (weforum.org)
[2] Direct Air Capture - Energy System - IEA
[3] The Chemistry of Carbon Capture – Hadron (imsa.edu)

adds the benefit of high transportability. There are currently feasible large-scale installations in Europe with planned sites in North America.[4]

Direct Separation

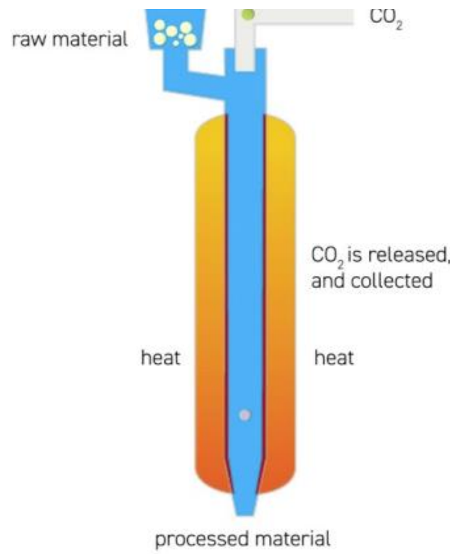

Figure 3: Direct Separation for cement
Source: Carbon Capture and Utilization Training Manual, Energy Solutions Center, Feb 28, 2023

The cement industry is responsible for 7% of total carbon emissions[5] and emits somewhere between a half and a full ton of CO_2 per ton of cement created. Many methods of carbon capture have been piloted for cement manufacturing, but direct separation has shown the most potential, with high efficiencies and low operating costs. The process separates CO_2 from flue gas emissions using waste heat from the cement manufacturing process. Limestone used in cement production is simultaneously heated and combined with the CO_2 to capture the carbon in the porous rock. Direct separation requires no chemical solvents and gas is never mixed with other combustion gases. Some studies show direct separation as having the potential to reduce CO_2 emissions from cement manufacturing by up to 60%.[6]

Other Methods

While the methods above show the most promise in terms of their potential and current use industrially, there are other methods of carbon capture that are in development or current use at a smaller scale One promising application takes CO2 directly from the exhaust of buildings' heating systems or water heaters and makes pearlash, a solid form of carbon. This technology can be easily implemented at a smaller commercial scale in most buildings as the units are smaller and more manageable than industrial carbon capture technologies. Pearlash production may also be intriguing as it utilizes excess heat from the reaction for heating or power, saving buildings on energy costs.[7]

Chemical looping, specifically with calcium, also shows potential. This process involves a simple compound such as CaO that binds with CO_2 to form a carbonate, which is then heated to release a high purity stream of CO_2 for compression or sequestration. Other methods such as membrane separation and bioenergy (algae) capture are also under development. For most potential carbon capture technologies, capital costs are the greatest barrier. Companies across the world are racing to create more efficient technologies to capture and sequester carbon at lower costs. The societal cost of emitting CO2 will continue to rise, and future policies against emitting greenhouse gases could help close the gap between theory and feasibility for many projects.

Carbon Management Methods: Utilizing Captured CO2

Carbon capture and sequestration (CCS), typically storing CO2 underground, is often discussed as a potential way to mitigate carbon emissions. However, utilization in the production of valuable substances and products can also provide a mitigation pathway. Carbon utilization is especially important in areas with high fossil fuel

[4] Home – Aker Carbon Capture
[5] Concrete: the world's 3rd largest CO2 emitter (phys.org)
[6] Simulation of direct separation technology for carbon capture and storage in the cement industry - ScienceDirect
[7] CleanO2

usage, as well as those areas where geography doesn't support sequestration. Additionally, there is an existing global market for CO_2 of around 130 million tons per year for the production of urea alone, an important chemical used for a variety of applications such as fertilizer and plastics.[8] This doesn't take into account the numerous other uses for captured CO2, including building materials, food and beverage production, enhanced oil recovery, and stimulating plant growth. The total estimate for CO2 utilization is 230 million tons worldwide and will continue to rise.[9]

Mineralization

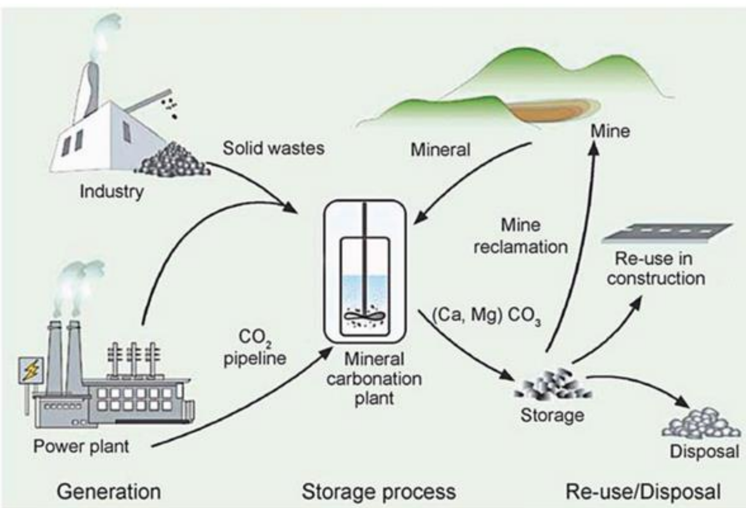

Figure 4: Depiction of mineralization and its associated markets
Source: Climate-policy-watcher.org

Mineralization processes convert CO_2 into solid minerals through exposure to certain types of rocks. Mineralization is said to be the only utilization method that completely eliminates carbon emissions, with carbon being stable in its mineral form for hundreds of years.[10] Large economic value is tied to carbon credits that can be produced from these minerals, ranging from baking soda and hydrochloric acid to crop enhancements and limestone for concrete, which could be a $1.3 trillion global market.[11]

While there are several types of mineralization, a common type is the production of pearlash, a solid carbon substance that can be used for soaps, detergents and cleaning. It also has the added benefit of permanently sequestering CO2, never allowing it to become gaseous again.[12] Another closely related concept uses fly ash, a byproduct of coal combustion. The black substance is capable of sequestering carbon through mineralization in the construction industry as well as enriching soil with nutrients.[13]

Cement and asphalt production have high potential for CO2 use as carbon dioxide aids in the efficiency of the process as well as the durability of the concrete, all while permanently storing the CO2, even after the concrete is destroyed. The primary mechanism for this type of mineralization involves the formation of calcium carbonate within the concrete, making the process require less virgin material and resulting in a stronger final product.[14] There are numerous ways that CO2 can be used in concrete, but the most promising designs permanently sequester carbon, reduce material, and increase concrete strength by 10%.[15]

[8] Energy Solutions Center Carbon Capture and Utilization (CCU) Training Manual for ESC members
[9] Putting CO2 to Use – Analysis - IEA
[10] Energy Solutions Center Carbon Capture and Utilization (CCU) Training Manual for ESC members
[11] These Companies are Turning CO2 into Concrete. Could it be the Solution to Construction's Emissions Problem? | This Is Construction
[12] CleanO2
[13] Coal Ash Reuse | US EPA
[14] Tracing Captured CO_2 From Source to Storage in Concrete - CarbonCure
[15] These Companies are Turning CO2 into Concrete.. Could it be the Solution to Construction's Emissions Problem? | This Is Construction

Greenhouse gassing

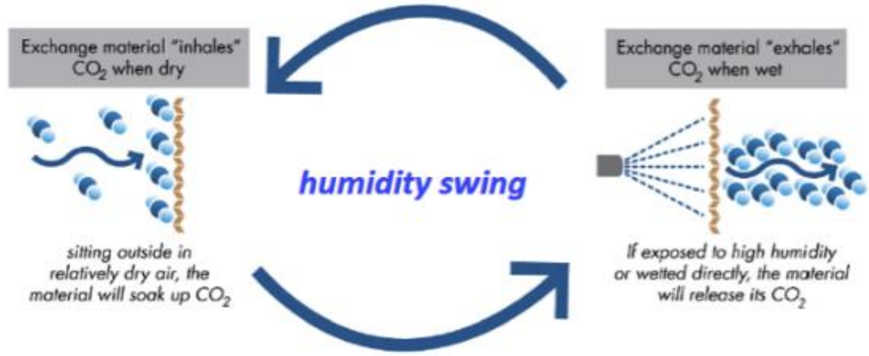

Figure 5: Direct air capture to utilize carbon in greenhouses. *Source: Carbon Capture and Utilization Training Manual, ESC Feb 28, 2023*

Greenhouse gassing methods use captured CO2 for greenhouses, enhancing plant growth rates. This can be achieved simply by adding air from the atmosphere with a fan (DAC) or spreading the captured CO2 via pipeline, oftentimes directly from boiler exhaust or nearby combined heat and power (CHP) system. Direct pipelines yield higher CO2 concentrations but are often more energy intensive. This Direct Air Capture design utilizes a sorbent material that takes in CO2 when dry and discharges it to a nearby greenhouse when saturated, requiring far less energy and zero combustion as compared to other greenhouse gassing practices that require concentrated CO2.

Production of Fuels

When combining hydrogen with captured carbon dioxide, future fuels ranging from kerosene and methane to jet fuel can be synthesized and produced with reduced carbon intensity. There is a cost barrier compared to producing traditional natural gas, but as the production of green hydrogen becomes more affordable, the usage of fuel production by combining H_2 & CO_2 will rise. This incentivizes methods to create clean, renewable hydrogen in a more cost-efficient manner, as it is estimated that hydrogen production accounts for 60% of the costs associated with generating fuel.[16]

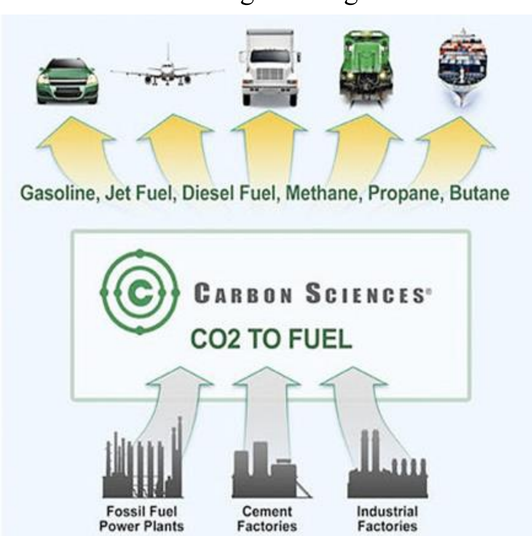

Figure 6: Using CO2 for fuel. *Source: inhabitat.com*

One noteworthy method for hydrogen production is known as the thermal process, and it uses two furnaces to separate natural gas into hydrogen and carbon black – a solid substance that can be used in various applications including the reinforcement of materials. While one furnace separates hydrogen from natural gas, the other combusts the hydrogen to provide steam for power. Because the furnaces rotate the two roles above and exhaust is re-used, the emissions are exceptionally low. There is also the added benefit of a usable byproduct in carbon black.[17]

The readiness level of these technologies vary by fuel type, with methane (Natural gas) being feasible but still slightly more expensive than mining for new fossil fuels. Other types of fuel such as diesel and gasoline still require some technological advancement to lower costs.

[16] Energy Solutions Center Carbon Capture and Utilization (CCU) Training Manual for ESC members

[17] AP-42, CH 6.1: Carbon Black (epa.gov)