VIEW POINT

EXPLORING THE HORIZONS OF CARBON CAPTURE - PART 1

Abstract

Climate change, driven by carbon emissions, is a critical issue. Comprehensive strategies, including emission reduction, energy efficiency, and renewable energy, are essential. Carbon capture, utilization, and storage (CCUS) technologies have significantly advanced, with 800 projects as of mid-2023. The International Energy Agency (IEA) predicts a 75% increase in storage and 40% in capture capacity by 2030. Current CCUS facilities capture 50 million metric tonnes of CO_2, only 0.2% of global emissions. Models from the IPCC and IEA indicate capturing 1.5 billion metric tonnes annually by 2030 is crucial.

This article examines the latest CCUS advancements, challenges, and future integration into carbon management policies to combat climate change.

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Understanding Carbon Capture

By 2030, the IEA wants to capture and store 1.5 billion metric tonnes of CO_2 annually, and by 2050, several billion tonnes, to prevent global warming from exceeding 1.5°C above pre-industrial levels. Despite significant emission reductions, heavy industries and aircraft will continue to generate CO_2, making it essential. Unavoidable emissions are decreased via carbon capture systems.

Exhausted gas and oil fields or deep saltwater aquifers are potential locations for CO_2 storage. The UK intends to capture and store 20-30 million tonnes of CO_2 annually in the empty oil and gas reservoirs of the North Sea by 2030. Both the United States and the European Union are making substantial investments in carbon capture. By 2030, the European Union aims to have a 50 million tonne capacity.

Current Technologies

1. Pre-Combustion Capture

Pre-combustion carbon capture is the process of capturing CO_2 from fossil fuels prior to combustion by converting them into syngas, a mixture of hydrogen and carbon monoxide. The hydrogen is subsequently removed from the CO_2, which can be used as a pure fuel.

Process Steps:

- **Gasification:** Fossil fuel (coal, natural gas) is partially oxidized with steam and oxygen at high temperatures and pressure to produce syngas.
- **Water-gas Shift Reaction:** Syngas undergo a reaction where carbon monoxide reacts with water to produce hydrogen and CO_2.
- **CO_2 Separation:** The gas mixture, rich in hydrogen and CO_2, is processed to separate the CO_2 using physical or chemical absorption methods.
- **Hydrogen Utilization:** Hydrogen generated can be used in other industrial operations or power generation as a clean energy source.

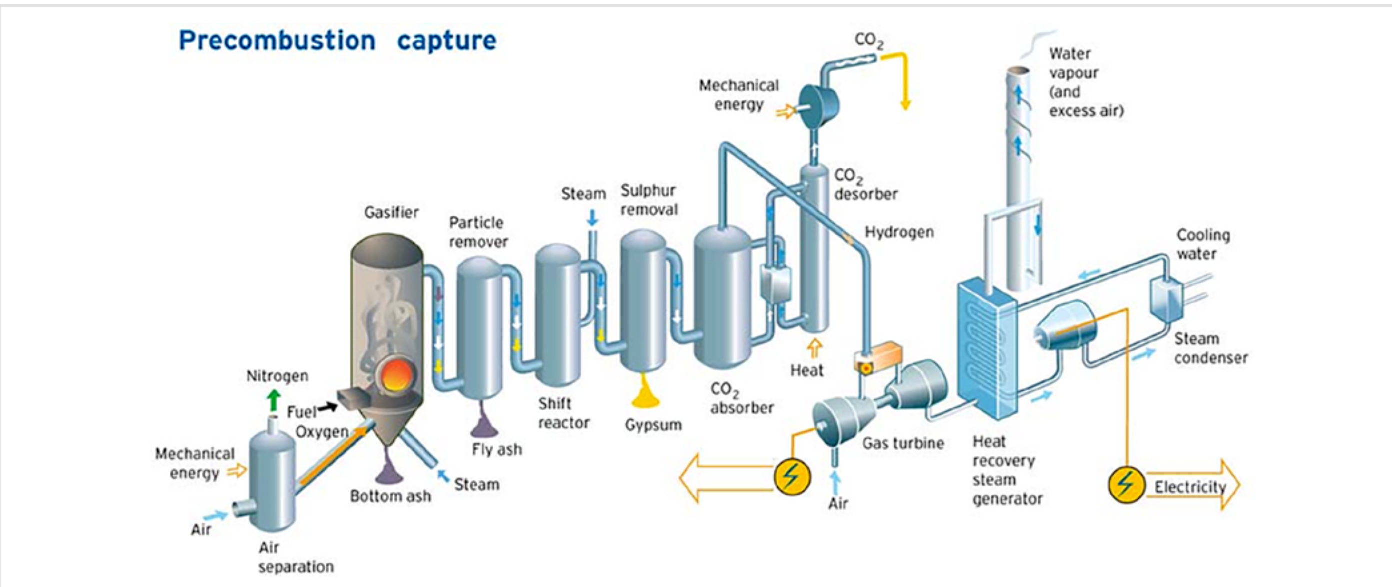


Figure 1: Pre-combustion capture system

Source: https://www.researchgate.net/profile/Muhammad-Arshad-43/publication/303785003/figure/fig21/AS:368965080633362@1464979538503/Pre-combustion-capture-system-Photo-Courtesy-of-wwwkjell-designcom-Vattenfall.png

Key benefits of technology

- **High Efficiency:** Achieves high CO_2 capture rates, reducing greenhouse gas emissions.
- **Clean Fuel Production:** Produces hydrogen, a clean and efficient fuel, reducing overall carbon emissions.
- **Versatility:** Can be applied to various fossil fuels, making it a versatile solution for different industries.
- **Scalability:** Can be scaled up for large industrial facilities, significantly reducing their carbon footprint.

Challenges:

- High initial capital costs and complex technology.
- Requires significant infrastructure for gasification and CO_2 transport.

Example Project:

Kemper County Energy Facility: Originally meant to use pre-combustion capture technology, this initiative sought to collect 65% of the CO_2 generated from coal gasification. The CO_2 captured was meant for EOR in nearby oil fields. Though technically and financially difficult, the project offered insightful analysis of the intricacies of large-scale pre-combustion capture.

2. Post-Combustion Capture (PCC)

After fossil fuel burning, PCC collects CO_2 from flue gases produced by industrial sites and power plants. Solutions like chemical absorption, physical adsorption, or membrane separation help to remove CO_2 from the exhaust gas.

Process Steps:

- **Combustion:** Fossil fuel (coal, natural gas) is burned in a boiler to produce heat, generating steam to drive a turbine and produce electricity.
- **Flue Gas Treatment:** Flue gas containing CO_2 is treated to separate CO_2 from other gases.
- **CO_2 Separation:** CO_2 is separated using a chemical solvent (e.g., amine) that absorbs CO_2, then regenerated to release the captured CO_2 for reuse.
- **CO_2 Compression and Storage:** Geological formations like exhausted oil and gas fields or deep saline aquifers are used to store compressed CO_2 that has been collected.

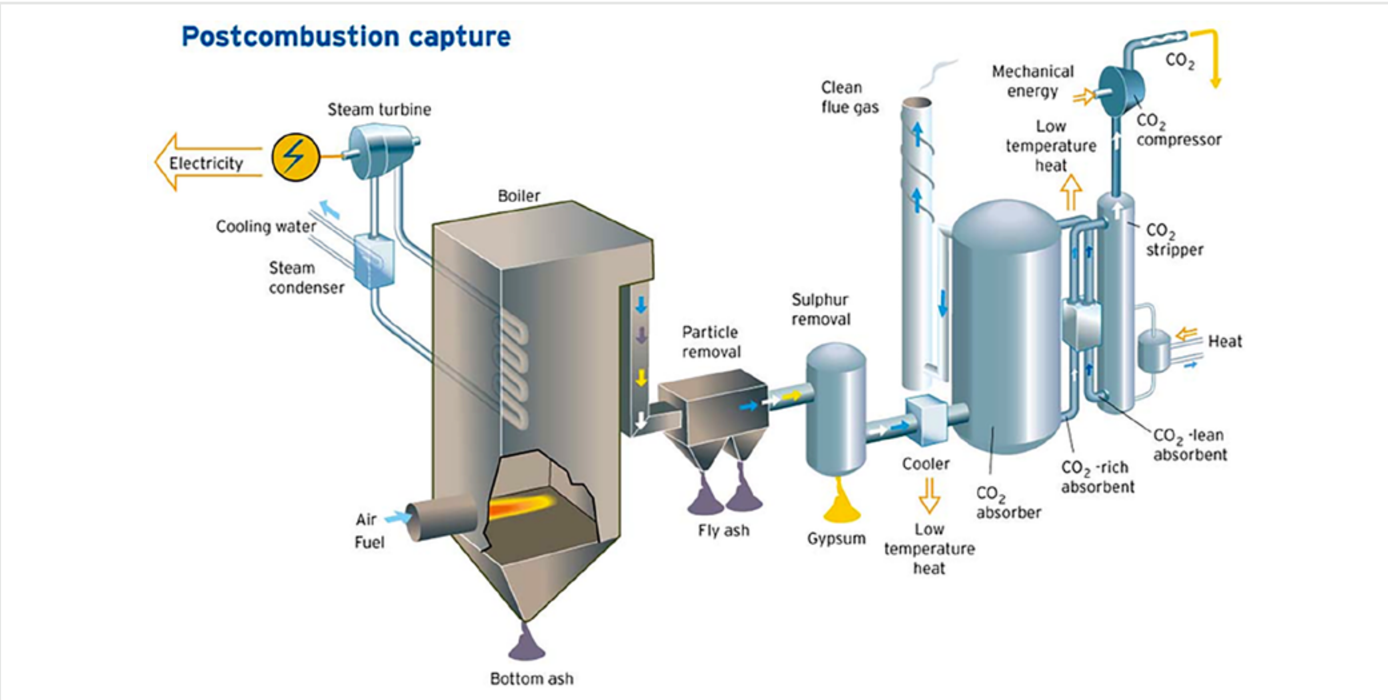


Figure 2: Post-combustion capture system

Source: https://www.researchgate.net/figure/Post-combustion-capture-system-Photo-Courtesy-of-wwwkjell-designcom-Vattenfall_fig22_303785003

Key benefits of technology

- **Flexibility:** Can be retrofitted to existing power plants and industrial facilities, reducing CO_2 emissions.
- **Proven Technology:** Well-established with a history of successful implementation in various industries.
- **High Capture Rates:** Achieves high CO_2 capture rates (85%-95%), effectively reducing greenhouse gas emissions.
- **Environmental Compliance:** Helps facilities comply with strict emissions regulations and carbon pricing mechanisms.

Challenges:

- Energy-intensive process, leading to reduced overall efficiency.
- Handling and disposal of used solvents can be environmentally challenging.

Example Project:

Boundary Dam Carbon Capture and Storage Project: This project upgraded a unit of the Boundary Dam Power Station using PCC. Amine-based solvents let it collect up to 90% of the CO_2 from the flue gas, or around 1 million tonnes of CO_2 yearly. The captured CO_2 is deposited in deep geological formations and utilized for enhanced oil recovery, thereby demonstrating the feasibility of large-scale post-combustion collection.

3. Oxy-Fuel Combustion

Fuel is burnt using pure oxygen or a mixture of oxygen and recirculated flue gas, rather than air, in oxy-fuel combustion. The combustion efficiency is considerably improved by this method, which also reduces the production of pollutants such as nitrogen oxides (NOx).

Process Steps:

- **Oxygen Production:** Oxygen is separated from air using an oxygen concentrator or an air separation unit (ASU), resulting in a stream that is approximately 95% oxygen.
- **Combustion:** The fuel (e.g., coal, natural gas) is burned in a combustion chamber with the oxygen-enriched gas mixture. Since nitrogen is not present, the flame temperature is higher, and the combustion process is more efficient.
- **Flue Gas Production:** CO_2 and water vapor comprise most of the flue gas generated by the combustion process, with nitrogen and other pollutants present at exceptionally low levels.
- **CO_2 Capture:** The CO_2 in the flue gas can be easily separated and captured using conventional methods like chemical absorption or membrane separation.
- **CO_2 Compression and Storage:** CO_2 is compressed and conveyed for storage in geological formations or use in industrial applications after its capture.

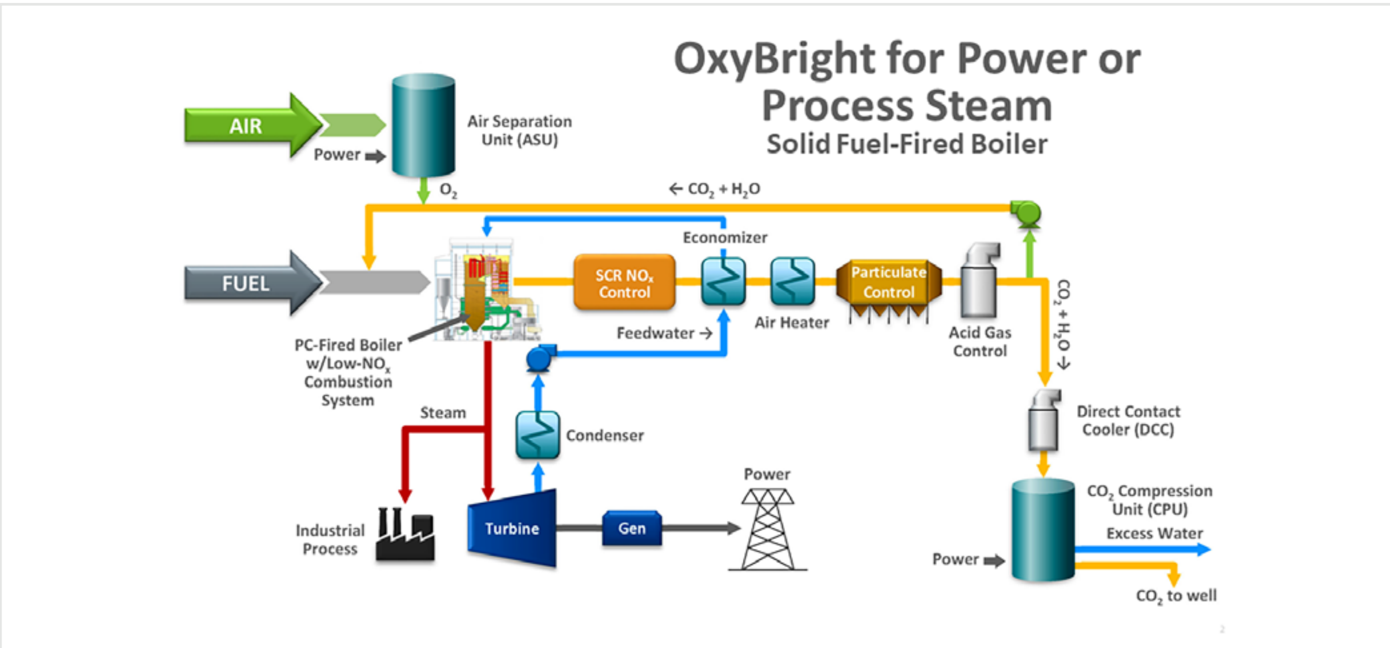


Figure 3: OxyBright™ Oxy-Fuel Combustion

Source: https://www.babcock.com/home/environmental/decarbonization/oxy-fuel-combustion/

Key benefits of technology

- **High Combustion Efficiency:** Oxy-fuel combustion achieves higher flame temperatures and more complete combustion, leading to improved fuel efficiency.
- **Reduced Pollutant Emissions:** By eliminating nitrogen from the combustion process, oxy-fuel combustion significantly reduces the formation of nitrogen oxides (NOx)2.
- **Simplified CO_2 Capture:** Oxy-fuel burning generates flue gas with concentrated CO_2 and water vapor, which facilitates the separation and collection of CO_2.
- **Versatility:** This method can be applied to various types of fossil fuels, making it a versatile solution for different industries.
- **Environmental Benefits:** Oxy-fuel combustion contributes to reducing greenhouse gas emissions and helps in achieving climate goals.

Challenges:

- Requires an oxygen production plant, which is energy intensive.
- High operational costs due to the need for pure oxygen.

Example Project:

Callide Oxyfuel Project: The viability of oxy-fuel combustion in a modified coal-fired power plant was demonstrated in this initiative in Queensland, Australia. The project made use of CO_2 it successfully gathered from the combustion process for EOR. Valuable information on the performance and economics of oxy-fuel combustion technology was offered by the Callide Oxyfuel Project.

4. Direct Air Capture (DAC)

Using chemical or physical techniques, Direct Air Capture (DAC) removes CO_2 from the air. Unlike conventional techniques that gather CO_2 from certain sites, DAC can be applied anywhere to eliminate CO_2 now in the atmosphere.

Process Steps:

- **Air Intake:** The DAC system draws ambient air in.
- **CO_2 Absorption:** The air is subjected to a filter or chemical solution that selectively absorbs CO_2. Chemical solvents, such as sodium hydroxide or amine solutions, are frequently employed.
- **CO_2 Separation:** The CO_2 is then separated from the absorbent, resulting in a concentrated stream of CO_2.
- **Regeneration:** The absorbent is regenerated by heating or other processes to release the captured CO_2, which can then be reused in the system.
- **CO_2 Compression and Storage:** Compressed CO_2 is then moved to geological formations for storage or utilized in numerous other applications.

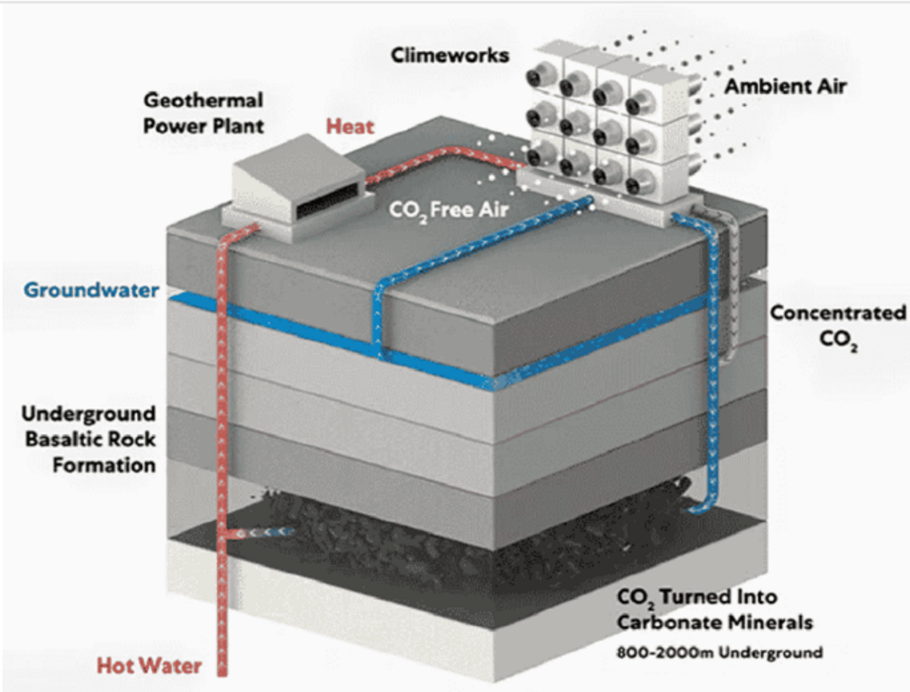


Figure 4: Direct Air Capture [DAC]
Source: https://carboncredits.com/how-direct-air-capture-works-and-4-important-things-about-it/

Key benefits of technology

- **Carbon-Negative Technology:** DAC is considered a carbon-negative technology because it removes CO_2 from the atmosphere, helping to reduce the overall concentration of greenhouse gases.
- **Versatility:** DAC systems can be deployed in various locations, making them suitable for regions where point-source capture is not feasible.
- **Environmental Impact:** By capturing CO_2 directly from the air, DAC contributes to mitigating climate change and achieving climate goals.
- **Potential for Utilization:** Synthetic fuels, carbonated beverages, and enhanced hydrocarbon recovery are among the numerous applications for the captured CO_2.
- **Scalability:** DAC technology can be scaled up to capture large amounts of CO_2, potentially contributing significantly to global carbon reduction efforts.

Challenges:

- High energy requirements and costs per tonne of CO_2 captured.
- Requires significant advancements to become economically viable at scale.

Example Project:

Climeworks Orca Plant: The world's largest DAC facility is the Orca refinery, situated in Iceland. CO_2 is extracted from the air through the utilization of a modular system of filters and blowers. Water is combined with the captured CO_2 and injected into basalt rock formations, where it mineralizes and is permanently stored. Showcasing the scalability of DAC technology, the Orca facility can capture 4,000 tonnes of CO_2 annually.

5. Carbon Utilization

One effective way to use carbon is by converting it into fuels, chemicals, and construction materials. This reduces CO_2 emissions and generates revenue from waste. Technologies like chemical conversion, biological processes, and mineralization facilitate this. Combining these methods with CO_2 capture systems provides a comprehensive carbon management strategy.

Key Benefits of Technology:

- Creates economic value by converting CO_2 into marketable products.
- Reduces the carbon footprint of industries like construction.

Challenges:

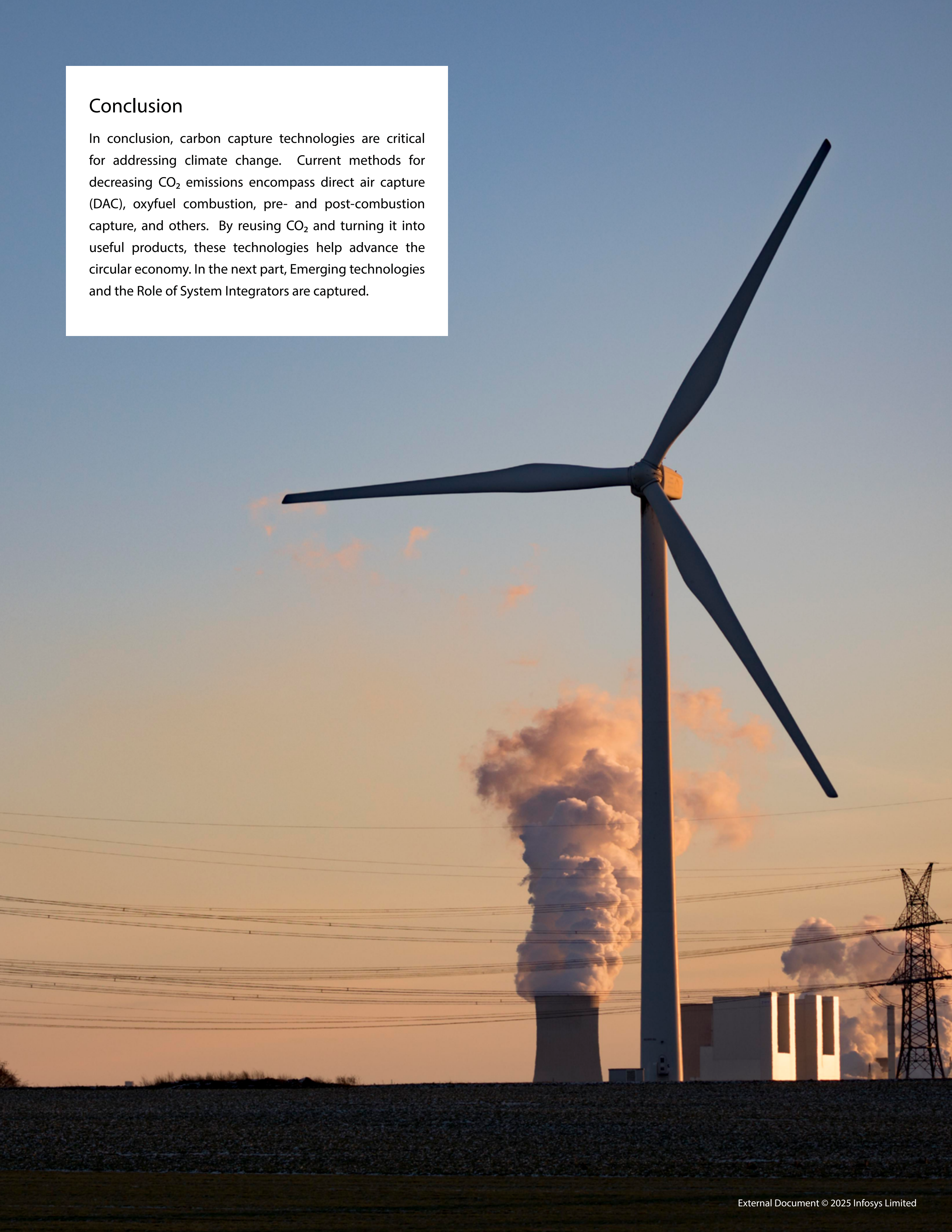
- Market demand for CO_2-derived products needs to be developed.
- Technological and economic barriers to scaling up utilization processes.

Example Project:

CarbonCure Technologies: Concrete is injected with captured CO_2 by this Canadian firm during the blending process. The strength of the concrete is improved, and its carbon footprint is reduced as the CO_2 reacts with calcium ions in the cement to generate calcium carbonate. CarbonCure's technology is currently being implemented in numerous concrete facilities throughout North America, which serves as an illustration of the commercial feasibility of carbon utilization in the construction sector.

Conclusion

In conclusion, carbon capture technologies are critical for addressing climate change. Current methods for decreasing CO_2 emissions encompass direct air capture (DAC), oxyfuel combustion, pre- and post-combustion capture, and others. By reusing CO_2 and turning it into useful products, these technologies help advance the circular economy. In the next part, Emerging technologies and the Role of System Integrators are captured.



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About the Author

Syman Biswas is a Senior Associate Consultant working at iCETS. His main objective revolves around researching various industries for trends and emerging technologies like AI, Blockchain, etc., and their impact on several industries. He is a technology enthusiast who enjoys exploring and learning about new & emerging technologies.