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CARBON CAPTURE AND STORAGE

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Abstract:

This review paper provides a comprehensive analysis of the latest developments in carbon capture and storage (CCS) technologies, with a particular focus on two prominent carbon capture methods: Direct Air Capture (DAC) and Post Combustion Capture (PCC). The paper explores the underlying principles, technological advancements, and current challenges associated with these methods. Furthermore, it delves into the various techniques employed for storing captured carbon, emphasizing the significance of carbon sequestration. The first section of the paper elucidates the principles behind DAC, highlighting its potential as a direct and scalable solution for reducing atmospheric carbon dioxide levels. The second part of the paper focuses on carbon storage techniques, emphasizing the critical role of carbon sequestration in mitigating climate change.

Key Words: Carbon, Carbon Capture And Storage (CCS), Direct Air Capture (DAC), Post Combustion Capture (PCC), Carbon Sequestration, Mitigating Climate Change

1. Introduction:

Global climate change stands as a pressing environmental and energy challenge, primarily fueled by the accumulation of greenhouse gases, especially Carbon dioxide (CO2), released through fossil fuel combustion and industrial processes. The conventional approach involved energy efficiency improvements and transitioning to less carbon-intensive energy sources. However, a more recent and pragmatic solution gaining recognition is "end-of-pipe" technologies collectively known as "Carbon Capture and Storage (CCS)." These technologies capture CO2 emissions from large stationary sources like power plants, preventing their release into the atmosphere. Following capture, the compressed CO2 is transported and securely stored in locations such as deep aquifers, the deep ocean, or depleted oil reservoirs. Unlike indirect sequestration methods, such as forestation, CCS focuses on averting atmospheric emissions entirely. This paper synthesizes existing literature to assess CCS feasibility, timing, environmental impacts, and its potential contribution to comprehensive climate policies.

2. Basics of Carbon Capture:

Carbon capture is a process designed to reduce the amount of carbon dioxide (CO2) emissions released into the atmosphere, particularly from industrial processes and power generation (1). The primary goal of carbon capture is to mitigate the impact of greenhouse gas emissions on climate change. Carbon capture and storage (CCS) facilitates the extraction of CO2 from energy-intensive sectors such as power plants, cement, iron and steel, chemicals, and refining-industries responsible for substantial carbon emissions (2). These sectors serve as ideal candidates for capturing CO2 emissions due to their status as significant stationary emission sources. Capture costs are predominantly influenced by flue gas stream characteristics, with observations indicating cost reductions at higher CO2 concentrations and lower temperatures. In addition to the aforementioned sources, concentrated CO2 by-products are generated in natural gas operations. Similarly, the decarbonization process for fossil fuels, aimed at producing hydrogen for applications like ammonia manufacture and oil refining, also results in CO2 by-products. CO2 capture employs three methods: pre-combustion, post-combustion, and oxyfuel. Pre-combustion and post-combustion involve capturing CO2 before and after combustion, respectively (5). The oxyfuel method entails storing all gases produced after burning the fuel in an oxygen-rich environment (3, 4).

3. Methods of Carbon Capture:

Two larger-scale methods are being developed: post-combustion capture and direct air capture.

Post-Combustion Capture: Post-combustion is a carbon capture method that involves capturing carbon dioxide (CO2) emissions after the combustion process in power plants or industrial facilities. In this approach, the flue gas, which contains a mixture of gases including CO2, is subjected to a separation process to isolate the CO2. One of the most established and commercially viable techniques for post-combustion capture utilizes chemicals called amines. These amines react with CO2 in the flue gas, binding to it and separating it from other components. The amine-CO2 compound is then processed to release nearly pure CO2, which can either be stored underground or used for various industrial applications. Post-combustion technology offers flexibility by allowing retrofitting into existing facilities, making it a key focus for carbon capture initiatives, especially in regions like the United States, where it is actively pursued to reduce emissions from a variety of industrial sources (2, 4). In the post combustion method, the gas is collected and the CO2 is isolated. To isolate the CO2, the captured gas is put into a chamber with amine solution. The amine binds with CO2, separating it. Then from the chamber the other gases are removed from the top and the carbon and amine are passed to the second chamber where a very high temperature is set which helps in separating amine and carbon dioxide. At a high temperature the amine releases the CO2. The separated CO2 is then released and ready for transport or use.

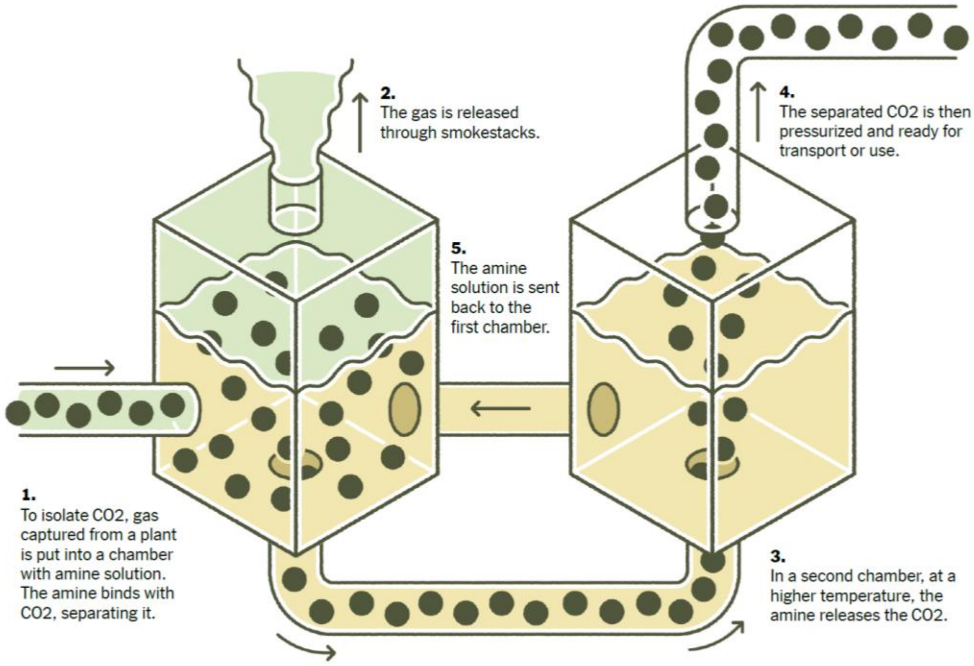

Figure 1: Post Combustion Capture (2)

Direct Air Capture: Direct Air Capture (DAC) is a technology designed to extract carbon dioxide (CO2) directly from the ambient air (8). This process involves the use of sorbents, either through absorption or adsorption. In absorption, CO2 is dissolved into the sorbent, while adsorption binds CO2 to the sorbent's surface (13). A notable and mature DAC method utilizes strong liquid bases like potassium or sodium hydroxides, initiating a chemical reaction that forms a carbonate product (12). Air is increasingly recognized as a source of CO2, with concentrations reaching 407.4 ppm in 2018 and projected to surge to 600-1550 ppm by 2030 without mitigation efforts (14). Direct Air Capture (DAC) is a technology for extracting CO2 from the atmosphere. This process employs sorbents for either absorption, where CO2 is dissolved into the sorbent, or adsorption, involving binding CO2 to the sorbent's surface. The maturest DAC method utilizes strong liquid bases like potassium or sodium hydroxides, leading to a chemical reaction forming a carbonate product. Subsequent separation of CO2 is achieved through a reaction with calcium hydroxide, generating a precipitate (calcium carbonate). An alternative uses solid amines for CO2 adsorption. DAC offers flexibility as it can be implemented anywhere due to the rapid mixing of CO2 in the air. However, challenges persist, primarily concerning the energy-intensive separation process. DAC incurs higher costs (~27-1000 $/tCO2) compared to carbon capture from large exhaust sources (~20-100 $/tCO2) or high-purity sources like ethanol processes (~6-12 $/tCO2). The sustainability of DAC hinges on sourcing energy from low-carbon options, such as renewables or recycled high-quality energy streams (16, 17).

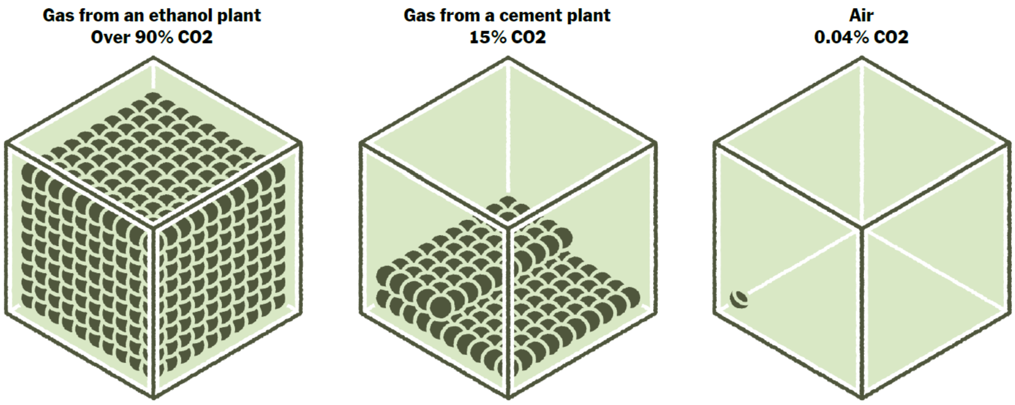

Figure 2: Direct Air Capture (2)

4. Next Step After Carbon Has Been Captured:

Once captured and isolated, the CO_2 is pressurized into a liquid state so that it can be transported by a pipeline to a place where it can be used or stored. Two pipeline projects currently in the works would carry carbon dioxide from Midwestern ethanol plants to sites in North Dakota and Illinois. This carbon that is captured and stored can be put to use, there are commercial uses for carbon dioxide, but many of them result in the gas eventually being released back into the atmosphere. The CO_2 used to carbonate beverages, for example, begins to escape the moment a soda can is cracked open, and dry ice returns to the air as it melts. The other primary use of CO_2 is in the energy industry. The gas is injected into dwindling older oil wells to try to force more crude out of the ground. Many environmentalists are skeptical of a process that uses captured carbon to obtain more fossil fuels that will release more carbon.

5. Carbon Sequestration:

Carbon sequestration is the process of capturing, securing and storing carbon dioxide from the atmosphere. The idea is to stabilize carbon in solid and dissolved forms so that it doesn't cause the atmosphere to warm. The process shows tremendous promise for reducing the human "carbon footprint." There are two main types of carbon sequestration: biological and geological (9).

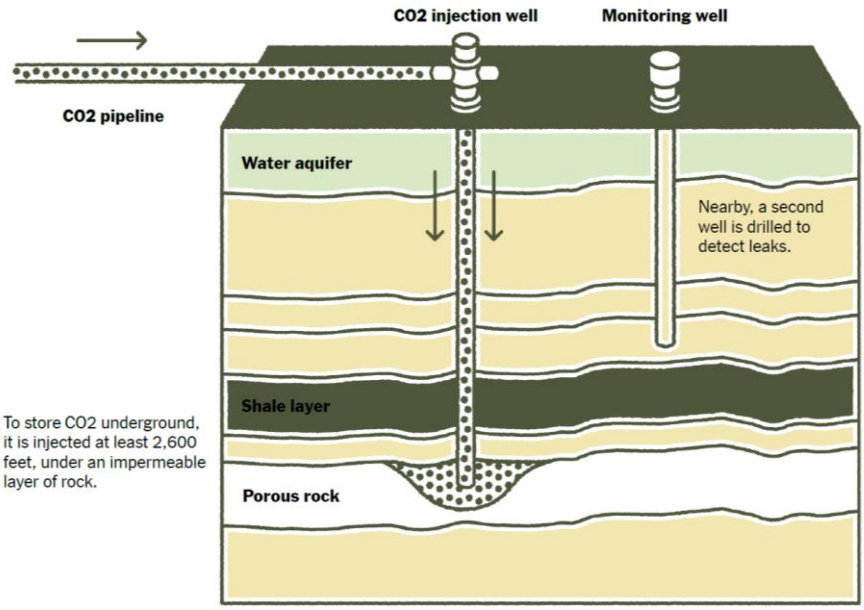

Figure 3: How Carbon Sequestration Works

Carbon sequestration involves the capture, extraction, and storage of carbon dioxide (CO_2) from the Earth's atmosphere, emerging as a crucial strategy for mitigating the impacts of global warming. Approximately 45% of human-emitted CO_2 persists in the atmosphere, contributing significantly to climate change. By preventing additional emissions, carbon sequestration plays a pivotal role in averting further planetary warming (11).

The sequestration of carbon can occur through two primary mechanisms: biological and geological. Artificial encouragement of carbon sequestration employs various biological and geological methods, but it also occurs naturally on a grand scale in the environment.

Biological carbon sequestration involves natural processes such as photosynthesis in plants and the subsequent storage of carbon in vegetation and soils. Additionally, afforestation and reforestation initiatives contribute to the biological sequestration of carbon by enhancing the capacity of ecosystems to absorb and store CO_2 (10).

Geological carbon sequestration entails capturing CO_2 emissions and securely storing them underground, often in geological formations like depleted oil and gas reservoirs or deep saline aquifers. This method prevents the released CO_2 from re-entering the atmosphere and adds a layer of permanence to the sequestration process (10).

Overall, carbon sequestration represents a critical tool in the global effort to address climate change by actively removing CO_2 from the atmosphere and mitigating its detrimental effects on the planet.

Conclusion:

This review paper has provided a comprehensive examination of Carbon Capture and Storage (CCS) technologies, emphasizing key methods such as Post Combustion Capture (PCC) and Direct Air Capture (DAC). The analysis underscores the significance of these techniques in mitigating carbon dioxide (CO_2) emissions from diverse sources, including power plants and industrial facilities. Additionally, the focus on storage has elucidated the critical role of carbon sequestration, exploring various methods such as geological storage, ocean storage, and mineralization. The versatility of carbon sequestration strategies offers a range of options for effectively removing and securely storing captured CO2, addressing the urgent need for climate change mitigation. As the world grapples with the imperative to reduce atmospheric carbon levels, the synthesis of literature presented in this review highlights the feasibility, challenges, and potential contributions of CCS in shaping a sustainable and low-carbon future. Despite the hurdles, continued research and development in these technologies are crucial for advancing our collective efforts in combating climate change and fostering a resilient global environment.

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