

Approaches and Challenges in Reducing Greenhouse Gas Emissions with Carbon Capture Chemistry

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Abstract:

It is essential to have carbon capture and storage (CCS) technology in order to lessen the effects of climate change and global warming, which are caused by emissions of carbon dioxide (CO₂). chemical elements involved in the process of removing CO₂ from air and industrial pollution, with an emphasis on the many methods specifically employed for this objective. The oxy-fuel combustion procedures, post-combustion, and pre-combustion methods all employ chemical solvents, adsorbents, and membranes to remove CO₂. possible new methods for the massive removal of CO₂, such biological technology and direct air capture (DAC). Energy demands, cost, scalability, and long-term storage stability are some of the main obstacles that have prevented CCS from being widely used, even though there have been scientific improvements in the field. Legislative and regulatory frameworks, social and environmental acceptability, and related themes are also treated. By analyzing these methods and obstacles, we may better grasp carbon capture's potential as a game-changing tactic in the fight against climate change and the mitigation of CO₂ emissions on a worldwide scale.

Keywords: carbon capture, greenhouse gas emissions, carbon dioxide (CO₂), carbon capture and storage (CCS), post-combustion

Introduction:

In particular, rising concentrations of carbon dioxide (CO₂) and other greenhouse gases are largely responsible for the alterations in the world's climate. Carbon dioxide emissions are increasing due to the ongoing use of fossil fuels to power industries and power homes. This is triggering climate change, shifting weather patterns, and rising sea levels. First and foremost, we must reduce emissions of carbon dioxide if we are serious about reducing the pace of climate change. Carbon capture and storage (CCS) systems offer the best hope among the many potential answers to the climate change problems. A process known as "carbon capture" is employed to remove carbon dioxide (CO₂) from the air and other large-scale point sources like power plants and factories. The collected carbon dioxide can be used in a variety of industrial operations or stored in subterranean geological formations. By lowering CO₂ levels in the air, these technical developments hope to lessen the impact of the greenhouse effect. The primary goal of chemical carbon capture processes is to isolate CO₂ from other gases and then concentrate it into a more transportable and storage-friendly state. Carbon collection methods have included post-combustion, oxy-fuel combustion, and pre-combustion experiments. Chemical solvents, adsorbents, and membranes are used in these methods to extract CO₂ from exhaust gases. A novel alternative for directly extracting CO₂ from the air is direct air capture

(DAC), which is a relatively young technology. This has the potential to lead to future emission restrictions as well as a decrease in current CO₂ levels. Plant and algae-based carbon capture is one of the emerging biological strategies under investigation for potential carbon capture solutions. There are still major obstacles that limit the broad use of CCS technologies, notwithstanding their improvements. Among these factors are reliable CO₂ storage over the long term, low cost, large-scale deployment, and high energy consumption. Subterranean CO₂ storage faces additional challenges from public support and regulatory concerns over the risks and implications to the environment. In order to extend and incorporate carbon capture technology into global efforts to mitigate climate change, it is important to resolve these obstacles. takes a look at the science underlying carbon capture and storage (CCS) systems, assesses the technical hurdles they must overcome, and finds out if CCS can cut down on CO₂ emissions worldwide. Our hope is that this research will shed light on carbon capture's function in the fight against climate change by analyzing existing and prospective methods. In addition, it highlights the significance of ongoing innovation, research, and policy creation in order to make these technologies more accessible, effective, and widely used.

Carbon Dioxide Adsorbents and Chemical Solvents

Isolating CO₂ from other gases is a crucial capability of carbon capture systems. Adsorbents and chemical solvents are a typical tool for this separation's execution. In order to transport, treat, and store CO₂, these materials are designed to selectively absorb it from exhaust streams. Here we will discuss the process, benefits, and drawbacks of CO₂ capture using chemical solvents and adsorbents.

Solvents Based on Amines

In post-combustion processes, amine-based solvents are commonly used as a CO₂ collection method. The fundamental idea behind how they work is that amines can be converted into carbamate molecules by adding carbon dioxide. After that, you can release the CO₂ using heat to revive them.

1. **Mechanism of Amine-Based CO₂ Capture:** During the absorption phase, a reversible carbamate is formed when CO₂ dissolves in an amine solution and interacts with the amine groups. The capture of carbon dioxide gas from flue gases emitted by power plants and other industrial processes is made possible by this reaction. Following CO₂ capture, a distinct regeneration unit is used to heat the amine solution, which breaks down carbamate and releases pure CO₂. This CO₂ can subsequently be compressed and used or stored.
2. **Advantages:**
 - **High Efficiency:** The high CO₂ absorption capacity of amine-based solvents makes them ideal for removing massive quantities of CO₂ from gas streams.
 - **Well-Developed Technology:** There is a wealth of information available for optimisation and scaling up related to the long history of studying and using amines in gas separation for industrial purposes.

- **Selective Absorption:** Amines are ideal for removing CO₂ from flue gas mixes because they selectively absorb CO₂ while retaining other gases, including nitrogen, oxygen, and water vapour.

3. **Challenges:**

- **Energy Intensity:** Regeneration is an energy-intensive process because the CO₂-amine bonds must be heated to be broken. The high operational cost that can result from this is a major obstacle to the widespread use of capture devices based on amines.
- **Degradation of Solvents:** Amines can undergo degradation with time when exposed to gas stream contaminants and high temperatures; this results in decreased efficiency and the necessity to regenerate or replace the solvent on a frequent basis.
- **Environmental Concerns:** The disposal of amine solvents necessitates meticulous supervision to prevent environmental pollution due to their potentially toxic breakdown products.

Solid Adsorbents

In addition to chemical solvents, solid adsorbents are another possible material for CO₂ capture. These materials are able to absorb carbon dioxide (CO₂) onto their surfaces through physical or chemical interactions. The porous ingredients that make them up commonly include activated carbon, zeolites, and metal-organic frameworks (MOFs). Adsorption is the process by which CO₂ molecules attach to an adsorbent surface; regeneration, on the other hand, entails reversing this connection by raising the temperature or lowering the pressure.

1. **Mechanism of Adsorption-Based CO₂ Capture:** Adsorbing CO₂ is the job of solid adsorbents, which have a big surface area. Chemical adsorption involves stronger connections formed by CO₂ with the adsorbent, such as ionic or covalent interactions, as opposed to physical adsorption, which uses van der Waals forces. Reducing pressure or applying heat to the adsorbents allows them to be regenerated by releasing the CO₂ that has been absorbed.
2. **Advantages:**
 - **Lower Energy Consumption:** In some cases, solid adsorbents are more cost-effective than amine-based solvents because they regenerate with less energy. This is particularly true when using pressure swing adsorption (PSA) or temperature swing adsorption (TSA) methods.
 - **Reusability and Stability:** Adsorbents like metal-organic frameworks (MOFs) and zeolites are often reusable and very stable, meaning they maintain their effectiveness over time with little degradation.
 - **High Surface Area:** Materials with a high CO₂ adsorption capacity per mass include activated carbon, metal-organic frameworks (MOFs), and zeolites.
3. **Challenges:**

- **Scalability:** Despite solid adsorbents' proven efficacy in the lab, bringing their use to industrial scale is still a major hurdle. Making adsorbents in big quantities while maintaining quality is a big challenge.
- **Selectivity:** The selective extraction of CO₂ from streams of mixed gases can be challenging for some adsorbents since they also adsorb other gases, which reduces the system's overall effectiveness.
- **Cost of Materials:** The high cost of synthesising some sophisticated adsorbents, such as MOFs, prevents their broad commercial use until methods to reduce this cost are found.

Membranes for CO₂ Separation

Membrane technologies are being investigated as an additional potential strategy for CO₂ extraction, alongside adsorbents and solvents. As a selective barrier, membranes let CO₂ through but prevent other gases from passing through. These materials can be engineered with pores or chemical capabilities that let CO₂ pass through more easily than other components like nitrogen or oxygen, while keeping those other elements intact.

1. Advantages of Membrane Technologies:

- **Compact and Efficient:** When compared to more conventional methods of chemical absorption or adsorption, membranes often take up less room and are more compact.
- **Energy Efficiency:** Combining membrane-based CO₂ capture with additional methods, such as pressure swing or vacuum swing, can significantly reduce energy consumption.
- **Scalability:** In comparison to other capture methods, membrane systems are more amenable to scalability and integration into preexisting industrial processes.

2. Challenges:

- **Selectivity and Permeability:** Membranes do provide selective CO₂ separation, but it is difficult to achieve high selectivity and permeability on a big scale.
- **Material Durability:** Membranes must be able to sustain good performance for extended periods of time, particularly when subjected to extreme temperatures and pressures typical in industrial settings.

Among the several materials studied and used for CO₂ collection, chemical solvents and solid adsorbents stand out. With their high capacity and selective absorption, amine-based solvents show a lot of promise. However, they suffer from solvent degradation and energy consumption. In contrast, an option that is more economical and energy-efficient is provided by solid adsorbents. Their long-term stability and reusability are also questions; nonetheless, scale is still an issue. Additional promising new technologies for improving CO₂ capture efficiency include membrane systems and improved adsorbent materials. Further research into improving these materials and finding solutions to the problems they cause is necessary if we are to see

widespread usage of carbon capture technology and a global reduction in greenhouse gas emissions.

conclusion

Chemical solvents and solid adsorbents play a major role in shaping the future of carbon capture technology; these materials present both possibilities and threats for reducing CO₂ emissions and reducing the impact of climate change. This is due to the fact that these chemicals have traits that are both beneficial and detrimental. Nevertheless, solvents derived from amines can be effective in post-combustion processes for removing carbon dioxide from flue gases. Problems with amine-based solvents include their high energy requirements, solvent degradation, and ecological problems. Some solid adsorbents, such as zeolites, activated carbon, and metal-organic frameworks (MOFs), provide a stable and energy-efficient alternative during regeneration. They still face obstacles that prevent them from being widely used, though. Scalability, selectivity, and material cost are three of these obstacles. In an effort to circumvent the drawbacks of using chemical solvents and solid adsorbents, R&D is continuously seeking out novel approaches. In the quest for an efficient method of capturing and storing carbon dioxide (CO₂), new technologies are demonstrating promise, including direct air capture and membrane-based CO₂ separation. Advancements in material design, regeneration procedures, and the integration of these technologies into existing industrial processes are crucial for achieving large-scale use. To sum up, these obstacles must be surmounted and materials and techniques optimized for CO₂ collection methods to achieve their full potential. To make carbon capture technologies more accessible and effective in the fight against climate change, research and innovation must be sustained to bring their prices down and their effectiveness up. Reduced emissions of greenhouse gases and enhanced sustainability and resilience in the future are both possible thanks to these technological advancements. To achieve this goal, we must overcome technological, economic, and environmental obstacles while simultaneously improving the chemistry of carbon capture.

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