Carbon Capture by Carbonaceous Materials and Nanomaterials

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Abstract

Carbon dioxide (CO_2) is one of the most urgent anthropogenic emissions because it accumulates excessively in the environment. Hence, it is imperative to use advanced and efficient CO_2 capture technologies to reduce CO_2 levels. The development of carbon dioxide capture and storage (CCS) technologies could play a significant role in this direction. Carbonaceous materials and nanomaterials are currently used in CO_2 capture for various industrial processes. This process category depends heavily on non-materials' characteristics to improve their CO_2 absorption capacity. This chapter aims to examine the role of carbonaceous materials and nanomaterials in the absorption of CO_2 from combustion processes. Carbon nanotubes, graphene oxides, and carbon aerogels are examined as representative carbonaceous materials for CO_2 adsorption, as well as coal-derived carbon, polymer-derived carbon, metal-organic framework-derived carbon, and coal-derived carbon. The present study has studied nanomaterials and carbonaceous materials for their functions. Furthermore, various carbon absorption techniques and challenges associated with nanomaterials have been discussed. Finally, conclusive remarks and future work are Further proposed.

Key Points

- Carbon Capture Process Overview: Discusses the primary steps in carbon capture and storage (CCS), emphasizing the significance of developing efficient and economically feasible capture methods.
- Chemical Adsorption: Carbonaceous materials facilitate stronger CO_2 interaction via chemical bonding on their surfaces, enhancing capture efficiency.
- Nano adsorbents Review: Comprehensive review of solid carbon-based nano adsorbents covering sources, chemistries, and mechanisms for CO_2 capture.
- Carbon Dioxide Conversion: Explores converting CO_2 into nanomaterials, contributing to fundamental CO_2 capture and conversion knowledge.
- Nanomaterials for Capture: Discusses nanomaterials and hybrid nanocomposites' role in CO_2 capture, addressing concerns about long-term liability, limited storage, and cost-effectiveness.

Introduction

Carbon dioxide emissions contribute to global warming, ocean acidification, and other environmental problems (Anwar *et al.*, 2019), volcanic eruptions, fossil fuel consumption, the destruction of forest resources, and industrialization (Harrould-Kolieb, 2020). These factors intensify greenhouse effects (D'Alessandro *et al.*, 2010). As a result of fossil fuel combustion, climate change is regarded as the primary cause of global warming. Between 1960 and 2019, atmospheric CO_2 concentrations increased from 310 parts per million (ppm) to 411 parts per million and are expected to reach 500 ppm by 2050 (**Fig. 1**). The primary anthropogenic source of CO_2 emissions is the burning of fossil fuels. These fuels include coal, oil, and natural gas (Rackley, 2017).

As carbon dioxide emissions increase globally, their adverse effects on the environment have created several urgent challenges for humans worldwide. To become developed countries throughout the world, different nations compete with one another. Therefore, the establishment of large-scale industries, factories, and companies continues to negatively impact the environment, with no regard for its effects. The entire population is currently heavily dependent on oil-based commodities, including coal,

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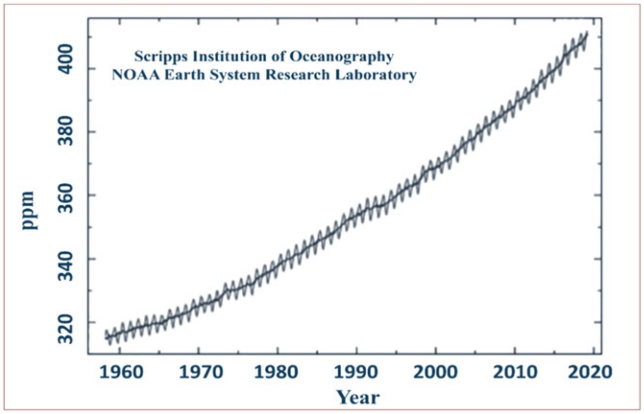

Fig. 1 Atmospheric CO_2 concentration from 1958 to 2019 (Rackley, 2017).

combustible gases, and crude oil, which each contribute about 41, 21, and 5%, respectively. The use of these commodities increases the risk of climate destabilization due to increased carbon dioxide (CO_2) emissions.

To minimize the impact of climate change, it is essential to reduce CO_2 emissions from various industrial processes (Worrell *et al.*, 2018). Consequently, CO_2 emissions need to be reduced by developing carbon capture and storage (CCS) technologies, such as capturing CO_2 from emissions sources such as power plants, improving energy efficiency, and switching to renewable energy sources (Davis *et al.*, 2010; Yoro and Daramola, 2020). Three CO_2 separation and capture methods are present in fossil fuel combustion based on their fundamental chemical processes: post-combustion, pre-combustion, and oxyfuel combustion (Worrell *et al.*, 2018).

Carbonaceous materials and nanomaterials can capture carbon from post-combustion flue gas (Gao *et al.*, 2022). Moreover, in this process, it is difficult to regenerate the sorbent (The amine solution) from the formation of C-N chemical bonds between the amine functionalities and CO_2. Therefore, the development of a chemical sorbent with a low regeneration cost is highly demanded. This chapter provides an overview of the advances in materials research for carbon capture beyond carbonaceous materials and nanomaterial technologies, some of the published reviews of CO_2 capture methods and adsorbent criteria were included in section "Understanding Carbon Capture", Carbonaceous materials as adsorbents for Carbon capture were reviewed during section "Carbonaceous Materials as Adsorbents for Carbon Capture", techniques for capturing and storing carbon were mentioned in section "Carbon Capture Techniques", moreover, innovative and prospects of Nanomaterials in Carbon Capture were discussed in sections "Innovative Techniques in Carbon Capture" and "Prospects of Nanomaterials in Carbon Capture" respectively.

Understanding Carbon Capture

Simultaneously, carbon capture and utilization projects are fueling the energy industry's need to manage both greenhouse gas emissions and decarbonization (Cabral *et al.*, 2019). In response to the urgent need to reduce greenhouse gas emissions and the transition to a low-carbon economy, carbon capture and use projects are being developed. Carbon capture and utilization technologies are crucial in mitigating climate change by capturing CO_2 from industrial processes and utilizing it for various purposes, such as enhancing oil recovery, producing renewable fuels, and manufacturing building materials. In addition, carbon capture and utilization technologies can not only reduce greenhouse gas emissions but moreover, create economic opportunities. Carbon capture and utilization technologies are being adopted to reduce greenhouse gas emissions and promote the transition toward a low-carbon economy to achieve global climate goals (Mikulčić *et al.*, 2019). Carbon capture and use technologies can reduce greenhouse gas emissions, create economic opportunities, and support the transition to a low-carbon economy. Carbon capture and utilization technologies are essential for managing greenhouse gas emissions and achieving decarbonization in the energy industry, creating economic opportunities, and promoting a low-carbon economy (Lau *et al.*, 2021).

The most common fossil fuel used to generate electricity is coal, which produces approximately 15% of the flue gas from power plants. Biomass, solar, and wind energy have been explored as alternatives to fossil fuels (Kabir *et al.*, 2018; Wang *et al.*, 2020). The erratic nature of the electricity supply and low usage ratios of these energy sources are limiting further industrial (Schlögl, 2010; Gür, 2018; Krishan and Suhag, 2019). In addition to combustion products being pollution-free, hydrogen is another renewable and clean energy source. Zhao and Chen (2018) report that most of the hydrogen generated by steam methane conversion and subsequent water-gas shift reactions is generated by these two processes, which reduces the efficiency of energy conversion and intensifies environmental pollution (Zhao and Chen, 2018).

A recent study indicates that global carbon dioxide emissions will decrease by 5% between 2020 and 2021, mainly because COVID-19-forced confinement reduced natural gas, oil, and coal usage by 2.3, 4.5, and 8%, respectively (Aktar *et al.*, 2021; Smith *et al.*, 2021; Gollakota and Shu, 2023). With the Paris Agreement, approximately 200 countries agreed to stop emitting net greenhouse gases by the end of this century to combat climate change (Meinshausen *et al.*, 2022; Santos *et al.*, 2022).

Table 1 Published reviews of CO_2 capture methods

Year	*Review*	*Topic*	*Refs.*
2012	Performance Enhancement of Calcium Oxide Sorbents for Cyclic CO_2 Capture: A Review	Assess potential solutions for loss-of-capacity issues. By calcining dry minerals followed by hydrating them, natural minerals can recover some of their capacity, while mixing creates highly effective synthetic sorbents. To overcome the technical issues associated with loss-of-capacity and to meet the physical requirements of sorbents in many applications, periodic hydration of synthetic sorbents might be a good idea.	(Liu *et al*., 2012)
2014	Recent Advances in Solid Sorbents for CO_2 Capture and New Development Trends	Based on their working temperatures, CO_2 sorbents are divided into three categories: low temperature (200°C), intermediate temperature (200–400°C), and high temperature (over 400°C).	(Wang *et al*., 2014)
2015	CO_2 Capture Using Solid Sorbents	The typical solid sorption family includes active carbonate materials, polymers, zeolites, silicon, metal organic frameworks (MOFs), and alkaline metal carbonates, which may contain functionalities for the adsorption of CO_2.	(Samanta *et al*., 2012)
2016	Carbon-Based Adsorbents for Post-combustion CO_2 Capture: A Critical Review	Activated carbon (AC), metal carbon composites, and pyrogen carbon are among the low-cost materials used in this study to capture CO_2. Additionally, it discusses their overall CO_2 absorption potential as well as recent developments in metal organic frameworks (MOFs).	(Creamer and Gao, 2016)
2019	Rational Design of Tailored Porous Carbon-Based Materials for CO_2 Capture	Using sound, high-performance carbon-compaction materials for CO_2 capture, this review will assist scientists and engineers in designing this emerging, potentially world-changing field.	(Zhang *et al*., 2019)
2020	The Role of Nanotechnology on Post combustion CO_2 Absorption in Process Industries	This study concluded that nanomaterials have improved their thermal stability and excellent properties, thereby popularizing their use in CO_2 capture processes.	(Kumar *et al*., 2020)
2021	The Progress of Nanomaterials for Carbon Dioxide Capture via the Adsorption Process	It reviews the most widely used technologies for CO_2 capture, discusses the state of nanomaterials studies in CO_2 capture, and examines surface microstructures and modifications to materials that affect CO_2 capture ability.	(X. Wang *et al*., 2021)
2022	Synthetic Solid Oxide Sorbents for CO_2 Capture: State-of-the-Art and Future Perspectives	Solid metal oxide CO_2 sorbents are critically evaluated for their ability to capture CO_2 at moderate to high temperatures in this review. Specifically, it discusses oxides of groups 1 and 2 (Li, Na, and K). Current challenges and opportunities in metal oxide sorbent research.	(Chang *et al*., 2022)
2023	Graphene-based nanomaterials for CO_2 capture and conversion	This chapter reviews recent advances and developments in graphene-derived nanomaterials, particularly in the capture and conversion of CO_2.	(Chin *et al*., 2023)

Several alternative actions have been taken in response to the decrease in CO_2 emissions from industries, such as the use of low-carbon energy (i.e., nuclear energy, ammonia energy, and natural gas), energy efficiency improvements, and the development of renewable energy sources, such as biomass, wind, and solar energy. The use of renewable energy sources has not yet significantly reduced CO_2 emissions (Mikulčić *et al*., 2013; Mi *et al*., 2015). An emission source is captured, and CO_2 is transported to a storage site via CO_2 capture and storage technology. As a final alternative, it is also possible to store it geologically or in the ocean (Anwar *et al*., 2018). Gibbins *et al*. (2011) suggest that CCS technology be applied to existing and retrofitted power plants to reduce CO_2 emissions into the atmosphere (Gibbins *et al*., 2011). Some excellent reviews on CO_2 capture have already been published, as listed in **Table 1**.

Alonso *et al*. (2017), illustrated comprehensive and significant progress in the development of nanomaterials capable of absorbing CH_4 and CO_2 (Alonso *et al*., 2017). A review of the state of the art by Yaghi *et al*. (2019), was published on the latest developments in the synthesis and design of metal-organic frameworks (MOFs) and MOF-based materials for CO_2 capture and conversion (Yaghi *et al*., 2019). According to Zhang *et al*., their systematic review presented the main strategies for designing and synthesizing porous carbons for CO_2 capture in the same year (Zhang and Shen, 2019). A literature review and CO_2 capture technology are not provided. Additionally, they neglected other carbon-based nanomaterials that are more valuable to researchers and concentrated only on porous carbon. This chapter contains some of the more than 3000 articles published after 2016 regarding CO_2 capture. According to Sai *et al*., their study was conducted in 2021. Reddy *et al*. (2021), examined different porous materials for CO_2 adsorption, including metal oxides, organic polymers, porous carbons, clays, mesoporous silicon, and zeolites, as well as MOFs (Reddy *et al*., 2021). Hence, this chapter summarises significant work on various carbonaceous materials and nanomaterials and their CO_2 capture ability.

The ideal CO_2 adsorbent's properties are shown in **Fig. 2**. According to Abuelnoor *et al*. (2021), adsorbent materials must possess high specific adsorption capacities, high selectivity, and long-term stability (Abuelnoor *et al*., 2021). In addition, large-scale industrial applications must require as little energy and chemical consumption as possible.

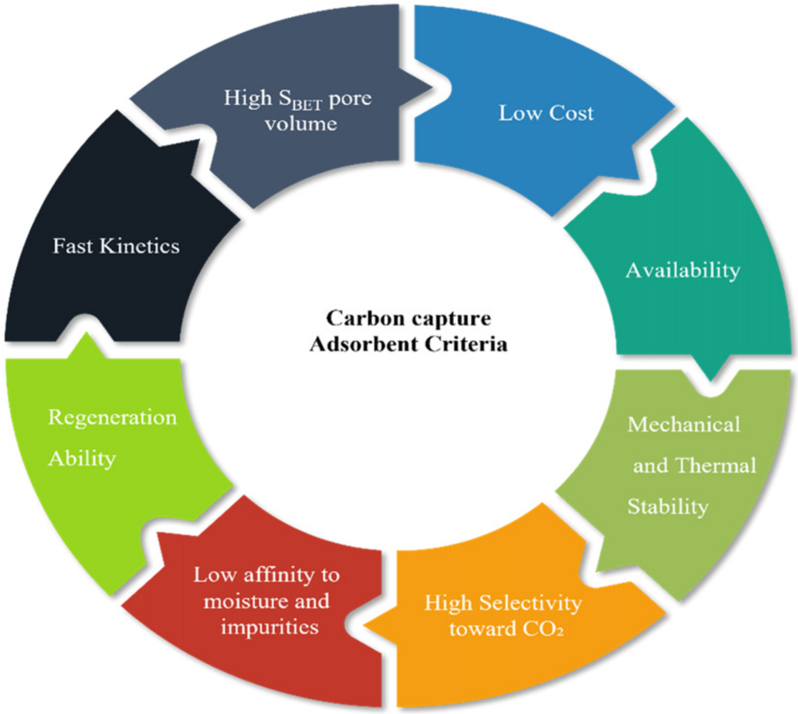

Fig. 2 Carbon Capture Adsorbent Criteria (Abuelnoor *et al.*, 2021).

Recent research has led to the development of various adsorbents, including zeolites (Chen *et al.*, 2020; Kumar *et al.*, 2020; Lai *et al.*, 2021), metal oxides (Chen *et al.*, 2021; Zhang *et al.*, 2021; Zhao *et al.*, 2022), porous polymers (Xie *et al.*, 2019), metal-organic frameworks (MOFs) (Parmar *et al.*, 2021), porous silica (Yan *et al.*, 2022) and carbon materials.

Carbonaceous Materials as Adsorbents for Carbon Capture

Carbonaceous adsorbents offer more environmental benefits than hydrophobic adsorbents, and they are also easily modified and offer high adsorption capacities. Carbon adsorbents are available, such as activated carbon (AC), carbon nanotubes (CNTs), graphene-based adsorbents, carbon aerogels, and carbons derived from precursors (Abd *et al.*, 2020; Yan *et al.*, 2022). Recent reviews have examined biomass-derived carbons (Abuelnoor *et al.*, 2021), carbon composites (Wang *et al.*, 2021), and activated carbons (Abd *et al.*, 2021). In addition to carbonization and activation, Saha and Kienbaum (2019) also examine surface modification and carbonization and activation (Saha and Kienbaum, 2019). However, a comprehensive summary of synthesis processes, modification strategies, and carbon types has rarely been reported in recent years.

As highly efficient CO_2 adsorbents, carbon-based materials (**Fig. 3**) exhibit a tunable morphology, high surface area, functionality, abundant pores, superior gas storage capabilities, good reproducibility, and electronic properties (Zhang *et al.*, 2021). There is a strong correlation between the CO_2 uptake ability of carbonaceous materials and their intrinsic properties. Additionally, the conditions under which carbons are synthesized (e.g., carbonization or activation) have an extensive effect on their structure and morphology.

Saha and Kienbaum (2019) further explain how atomic doping and heterostructure help improve adsorption and energy efficiency in carbon matrixes (Saha and Kienbaum, 2019). Carbonaceous materials have shown promise in carbon capture technologies, but they Furthermore, present specific challenges. One major challenge is their low selectivity to capture carbon dioxide (CO_2) due to their tendency to adsorb other gasses (Jewell *et al.*, 2023). In addition, regeneration of carbonaceous materials can be energy-intensive and time-consuming. In order to address these challenges, researchers are exploring different solutions. These include developing novel carbonaceous materials with improved selectivity for CO_2 capture, integrating carbon capture technologies with renewable energy sources to reduce energy consumption during regeneration, and optimizing regeneration processes to enhance efficiency (Gür, 2022). To overcome these challenges, carbon capture systems based on carbon materials can reduce CO_2 emissions and combat climate change.

Nanomaterials in Carbon Capture

Nanotechnology has attracted the attention of researchers because of its use in many energy systems (Mikulčić *et al.*, 2019; Firdaus *et al.*, 2021). In addition to controlling pollution with CO_2 -nanofluid systems may also be important for other applications

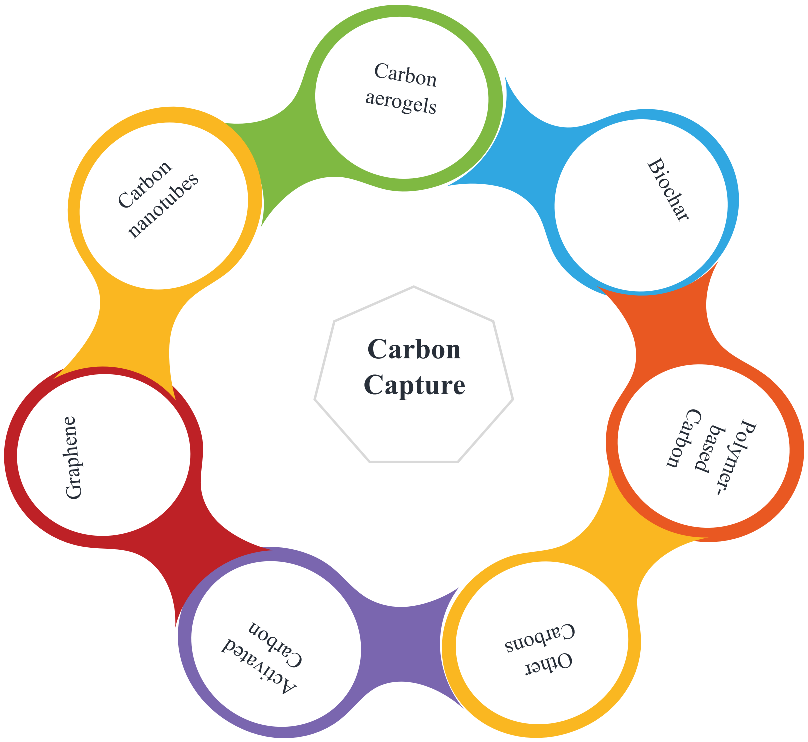

Fig. 3 Carbonaceous materials used as CO_2 adsorbents (Kamran and Park, 2021).

(Firdaus *et al.*, 2021; Mikulčić *et al.*, 2019). Global CO_2 emissions have created numerous challenges for the atmosphere due to their impact on the environment. Nevertheless, researchers have suggested prevention measures and techniques for overcoming this problem. In this suffocatingly polluting environment, it is critical to increase technological and process advancements. The study by Osman *et al.* outlines several techniques for capturing CO_2 through absorption and adsorption, including several cost-effective regeneration methods for CO_2 -loaded adsorbents (Osman *et al.*, 2021).

For co-adsorbed H_2O, a study on CO_2 adsorption employing nanocrystalline and other nanomaterials was suggested. According to the comparison, MgO nanoparticles are more important than ZnO and Al_2O_3 nanomaterials (Hu *et al.*, 2020; Saleem *et al.*, 2022). Lin and Park (2011) created organic hybrid materials (NOHMs) from nanoparticles to increase their thermal stability and assess their capacity to absorb CO_2 (Lin and Park, 2011). This study describes how the ether and amine groups affect CO_2 collection using nanoparticles' organic hybrid materials (NOHMs). The effects of pressure and temperature are Furthermore noted. The exceptional qualities and large surface area of nanomaterials have demonstrated their potential for a significant role in CO_2 capture. Lee *et al.* (2012) discussed the potential and development of nanomaterials as CO_2 removal sorbents. Montmorillonite (MMT) nanoclays were used to create an amine-containing solid sorbent designed to absorb CO_2. With a 7.5-wt% CO_2 capture rate using amine, the primary benefit is its high specific surface area and convenient availability (Roth *et al.*, 2013; Gupta *et al.*, 2023). **Table 2**. illustrates the CO_2 capture process using a sorbent based on nanomaterials.

The utilization of boron nitride (BN) nanotubes for CO_2 adsorption at varying charges was described by Sun et al. (2013). According to the findings, BN materials are superior adsorbents (Sun *et al.*, 2013). With a charge control switch, CO_2 may be captured and released from the BN nano sorbents. To trap CO_2, mesoporous silica nanotubes have been produced as a nano-composite (Sun *et al.*, 2013). Ngoy (2016) analysis of the Cu nanoparticle-assisted CO_2 capture technique was done (Ngoy, 2016). The use of carbon nanotubes and appropriate surfactants for CO_2 collection has been suggested (Ngoy, 2016). After observing how well SiO_2 particles captured CO_2, Choi *et al.* (2015). concluded that performance could be improved by up to 13.1% Choi *et al.* (2015). Analysis was done on the application of surface functionalized SiO_2 nanoparticles for CO_2 separation.

Prospective possibilities for enhancing carbon capture methods are nanomaterials. These materials' adsorption capacities and surface area can be enhanced due to their distinct nanoscale characteristics (Wang *et al.*, 2021). This study aims to provide more economical and effective ways to capture and store carbon dioxide emissions from industrial processes by introducing nanomaterials into carbon capture systems. To further enhance the development of highly effective carbon capture devices, nanomaterials can selectively capture CO_2 above other gases (Alonso *et al.*, 2017). Current studies in this area investigate various nanomaterials, including graphene-based materials and metal-organic frameworks, to maximize their efficacy in carbon capture applications.

The carbon material is classified under multiple names according to its geometrical structural properties, synthetic process, and surface functionalities. Some of these materials (Wang, 2005; Wang and Dai, 2015) are carbon nanofibers, carbon aerogels, carbon molecular sieves, carbon derived from biomass, pyogenic carbon, template-based carbon, amorphous carbon, porous carbon,

Table 2 CO_2 absorption capacity of the nanomaterial-based sorbent

	Properties				
Nanomaterials	*Surface area (m^2/g)*	*Temperature (°C)*	*Pressure (kPa)*	*CO_2-adsorption capacity (Mol/kg)*	*References*
Activated carbon	1284	25	100	2.23	(Lu *et al.*, 2008)
Zeolites (CNTs)	788	20	100	1.44	(Su *et al.*, 2009)
Si/Ca	78	10	150	–	(Lu *et al.*, 2009)
TiO_2	43	30	20	–	(Tahir and Amin, 2013)
CaO-$CaCO_3$	10.40	20	–	–	(Huang *et al.*, 2021)

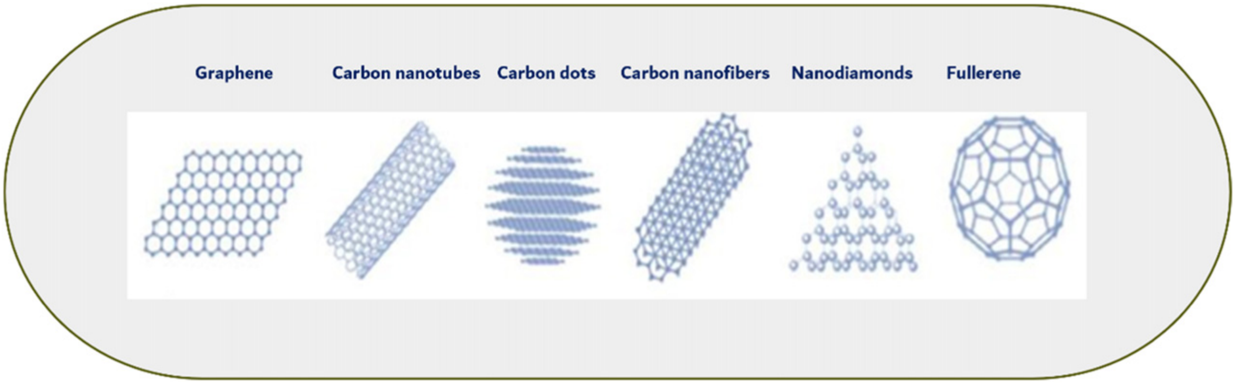

Fig. 4 Carbon nanomaterials allotropes schematic (Wang and Dai, 2015).

activated carbon, fullerene, graphene oxide, graphene quantum dots, reduced graphene oxide, carbon nanotubes, carbon nanodiamonds, and carbon dots. **Fig. 4** shows the schematic representation of carbon allotropes.

The character of these molecules can differ depending on their atomic arrangement. The covalent bonding between the layers of graphite, for example, is crucial in the carbon plane because it is soft and stable (Wang and Dai, 2015). In contrast, diamonds are transparent, complex forms of carbon, made from carbon atoms aligned in regular hexagonal lattices.

Carbon Capture Techniques

Through Carbon Capture and Storage, CO_2 is separated from diverse industries operating at high temperatures, injected deep under the ground, and then dissolved in a variety of solvents. As a result, greenhouse gas emissions are reduced after it is transported to storage. As shown in **Fig. 5**, CO_2 can be captured using three basic processes: pre-combustion, post-combustion, and oxy-fuel combustion. A review of CO_2 capture and storage technologies has already been provided by researchers (Sifat and Haseli, 2019; Kumar *et al.*, 2020; Alalwan and Alminshid, 2021; Madejski *et al.*, 2022). Furthermore, the thermophysical properties of carbon capture systems during operation have been reviewed and discussed critically (Sifat and Haseli, 2019).

After fuel combustion, CO_2 is separated from the atmosphere by post-combustion decarbonization. Despite this, this approach is still in the early stages of development. This technology can be installed in existing power plants without excessive disruptions. The primary purpose of oxy-fuel combustion is to remove inert gases from the combustion of flue gases (Tan *et al.*, 2016). In this method, fuel can only be burned with oxygen to achieve complete combustion. As a result, a considerable amount of CO_2 is produced, and a small amount of water vapor is produced during combustion (Martínez *et al.*, 2019).

In addition to these methods, more effective ones are being developed, such as chemical looping combustion (CLC), in which metal ions oxidize when they come into contact with oxygen in the air (Adánez *et al.*, 2018). Following that, the combustion chamber is filled with metal ions that have been oxidized. The pre-combustion process reduces the CO_2 content of fuel before it enters the combustion stage to create more unburned gases. Carbon monoxide (CO) and hydrogen (H_2) are both primary gases in this mixture (Fan *et al.*, 2019). The gas produced is also purified to eliminate harmful particles that might damage system components, such as steam turbines.

An in-depth review of membrane-based CO_2 capture Furthermore discusses the role of nanofillers containing nanocomposite membranes (Khalilpour *et al.*, 2015). An experiment was conducted using water-based nanofluids to eliminate CO_2 through a hollow fiber membrane. Aluminum oxide was the most suitable material for the experiments, followed by silicon oxide and TiO_2 nanoparticles (Mohammaddoost *et al.*, 2018). $CaCO_3$ nanoparticles have been used as catalysts for removing CO_2 from natural gas using a new membrane structure (Fosi-Kofal *et al.*, 2016; Zaliman *et al.*, 2022).

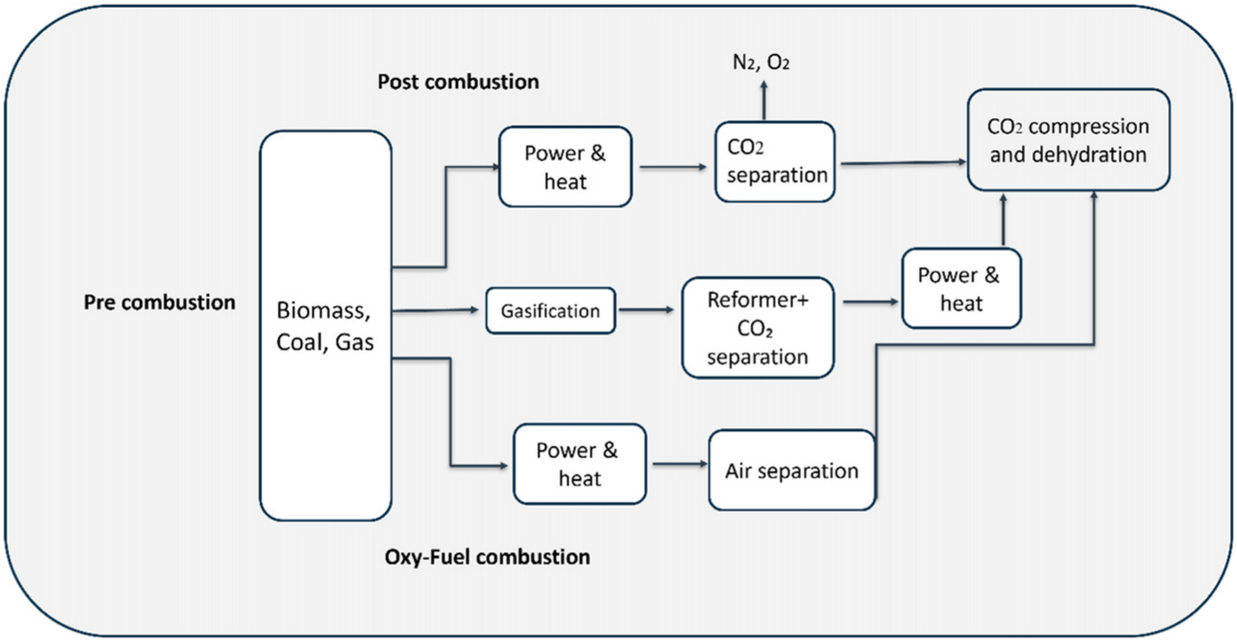

Fig. 5 Techniques for capturing and storing carbon (Chouliaras *et al.*, 2013).

Innovative Techniques in Carbon Capture

One of the most important technologies in the fight against climate change is carbon capture and storage, or CCS. It entails storing carbon dioxide (CO_2) emissions underground once they are captured from factories and power plants. Even if conventional CCS technologies have proven successful, new approaches are required to improve the process's performance and cost-effectiveness.

One innovative technique in carbon capture is the use of solid sorbents. These materials have a high affinity for CO_2 and can capture it from flue gas streams (Caram *et al.*, 2020). Unlike traditional liquid solvents, solid sorbents are more stable and easily regenerated, making them more sustainable and cost-effective (Caram *et al.*, 2020; Ji *et al.*, 2020). Additionally, solid sorbents can be tailored to capture specific gases, allowing for the selective removal of CO_2 from flue gas.

Carbon capture can Furthermore be achieved using membranes. Compared to traditional absorption processes, membrane-based separation is more energy-efficient and cost-effective (Shen and Salmon, 2023). CO_2 can pass through these membranes while preventing other gases, thereby allowing pure CO_2 to be captured (Siagian *et al.*, 2019; Prasetya *et al.*, 2020). In addition, membrane-based carbon capture systems can be easily integrated into existing industrial processes, which reduces infrastructure requirements.

In addition, direct air capture (DAC) systems have been developed due to advancements in carbon capture technology (McQueen *et al.*, 2021). CO_2 emissions are reduced directly from the atmosphere with DAC systems. These systems can be used in sectors that are difficult to control, like aviation and shipping. In these systems, CO_2 is captured using chemical sorbents or solid adsorbents. In addition to enhancing oil recovery and generating synthetic fuels, this CO_2 can Furthermore be stored or utilized for other purposes (Breyer *et al.*, 2019).

Prospects of Nanomaterials in Carbon Capture

A nanomaterial's unique properties and adaptability make it ideal for improving carbon capture systems (Firdaus *et al.*, 2021). Researchers have shown encouraging advancements in using nanoparticles in CO_2 capture, as shown in **Fig. 6**, and a bright future is predicted for their use in greenhouse gas reduction.

i. Increased adsorption capacity for CO_2: Nanoparticles have an extremely high surface area-to-volume ratio, resulting in enhanced adsorption capacity (Firdaus *et al.*, 2021). By tailoring their surface chemistry, they are more likely to interact with CO_2 molecules, resulting in efficient CO_2 capture.
ii. Selective Capture: Functionalized nanoparticles allow the capture of CO_2 selectively, unlike other gases. It contributes to cost-effective capture by minimizing energy-intensive separation processes (Anwar *et al.*, 2018).
iii. Nanomaterials can be regenerated and reused, reducing carbon capture systems' operational costs and resource consumption (Lee *et al.*, 2012).
iv. It is important to realize that nanoparticles can be integrated with existing technologies, such as adsorption or absorption so that they can increase the efficiency and scalability of these technologies (Talapaneni *et al.*, 2020).

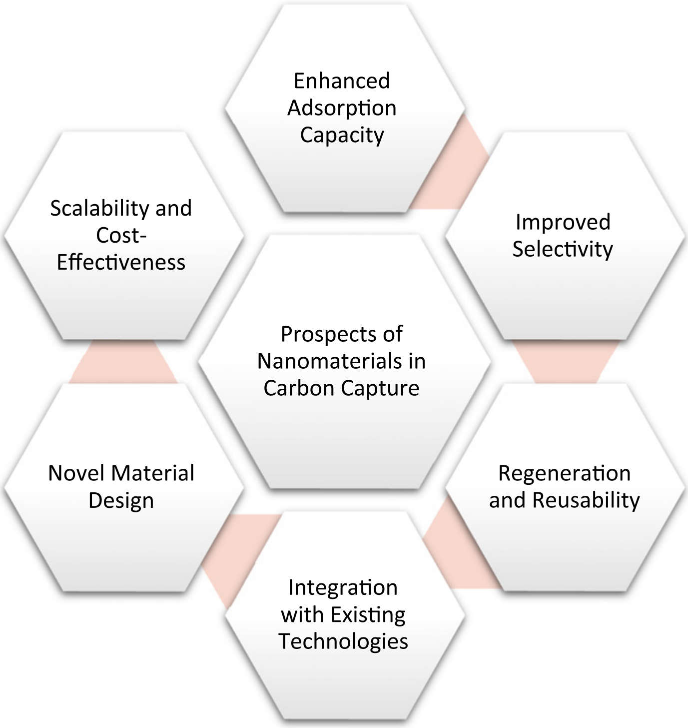

Fig. 6 Carbon capture applications of nanoparticles.

v. Novel Nanomaterial Design: Current research focuses on graphene-based designs, metal-organic frameworks, and graphene-based structures aimed at enhancing CO_2 capture efficiency (Najafabadi, 2015).
vi. Cost-Effectiveness and Scalability: Large-scale nanomaterial production methods may address scalability issues, making carbon capture more economical for industrial applications (Ashley *et al.*, 2012).

So, the prospects of nanomaterials in carbon capture are promising. Continued research and innovation in material science and engineering will drive the development of more efficient, cost-effective, and scalable nanomaterial-based solutions for mitigating CO_2 emissions from various sources.

Conclusion

This chapter discusses carbonaceous materials as well as nanomaterials concerning CO_2 absorption. Post-combustion CO_2 can be captured more effectively through chemical absorption than physical absorption. Upon reviewing a large amount of literature, this study concluded that nanoparticles and nanomaterials can capture CO_2 in a variety of CO_2 capture processes with significant potential. There are seven types of carbon adsorbents based on their capacity to adsorb CO_2, including activated carbon, coal and pitch-derived carbon, polymer-derived carbon, MOF-based carbon, carbon nanotubes, graphene oxide, and aerogels. A major advantage of nanomaterials over conventional materials is their exceptional properties, which make them highly effective at capturing CO_2. In conclusion, nanofluid concentration improves CO_2 absorption.

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