

Review Article

Pioneering Carbon Recapture for a Greener Planet

Anil Kumar

Associate, Professor, Department of Mechanical Engineering, Indo Global College of Engineering, Punjab, India.

INFO

E-mail Id:

anil.me77@gmail.com

Orcid Id:

<https://orcid.org/0000-0002-0100-9790>

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ABSTRACT

This research paper explores a diverse portfolio of constructive ideas and strategies aimed at mitigating atmospheric CO₂ concentrations to safer levels. Focused on the utilization of both live and dead trees, the proposed techniques involve harvesting through collection and selective cutting strategies to recapture and lock up carbon. Mature trees, which exhibit reduced growth and biomass formation compared to their infancy, provide an opportunity to preserve heavy wood logs either by depositing them in trenches or utilizing them as construction materials.

The preservation of these logs in a largely anaerobic environment, created by a sufficiently thick layer of soil, prevents the decomposition of buried wood. By interrupting the return pathway of assimilated CO₂ to the atmosphere, this approach establishes an effective carbon sink. This not only aids in reversing dangerous atmospheric CO₂ levels but also offers additional advantages, such as minimizing CO₂ emissions from deforestation, extending the lifetime of reforestation carbon sinks, and reducing the risk of wildfires.

While burying wood as a carbon sequestration method holds promise, there are potential environmental impacts, such as nutrient lock-up. Despite appearing manageable, it is essential to acknowledge that certain concerns and factors may limit the realization of the full potential of this approach. Further research and consideration of these limitations will be crucial in developing sustainable and effective carbon sequestration strategies.

Keywords: Carbon Sequestration, Tree Biomass, Selective Cutting, Carbon Recapture, Anaerobic Preservation, Carbon Sink, Reforestation, Photosynthesis, Biomass formation, CO₂ Assimilation

Introduction

Climate change is the most significant threat facing the planet due to the increasing percentage of CO₂ in the atmosphere. The carbon locked in fossil fuels for millions of years is being rapidly released into the atmosphere. While the Earth naturally stores carbon in forests, oceans, and soil, these carbon sinks are insufficient to accommodate the excessive and increasing amounts of carbon dioxide.

Current Scenario

Keeping atmospheric CO₂ concentration below 450–600 ppmv poses an unprecedented challenge. Two main approaches are reducing emissions and capturing CO₂ at the source for storage, i.e., sequestration. Drastic changes in technology and lifestyle are needed to reduce carbon emissions, but alternative energy sources are

not yet economically competitive. Even with advanced technologies, such as hydrogen power and nuclear fusion, the infrastructure switch will take decades. Carbon sequestration is likely necessary in the near future to prevent dangerous CO₂ levels.¹

Even if advanced technologies such as hydrogen power and nuclear fusion become economical, the infrastructure switch will take many decades. It is thus very likely that at least some carbon sequestration will be needed in the near future to keep CO₂ below a dangerous level.¹

What is Carbon Recapturing?

Carbon recapturing technology captures CO₂ before release, preserving it underground in geological formations. This process, known as "carbon capture and sequestration" (CCS), involves compressing CO₂ into a dense liquid and depositing it underground for safe and permanent storage.

Carbon Sink and Carbon Recapturing

Forests serve as a carbon sink through photosynthesis, enabling trees to capture substantial amounts of CO₂ and sequester it as wood. Approximately 0.9 tons of CO₂ are trapped in each cubic meter of wood. The total carbon stored in Europe's forests, excluding the Russian Federation, is estimated at 9,552 million t C, with an annual increase of 115.83 million t C. Additionally, the vast forests of the Russian Federation store an annual increment of 37,000 million t C, increasing by 440 million t C each year. Managed forests prove to be more efficient carbon sinks compared to their natural counterparts.

Younger trees, experiencing vigorous growth, absorb more CO₂ than mature trees, which eventually decompose, releasing their stored CO₂ into the atmosphere. Conversely, in managed forests, most of the CO₂ from harvested trees continues to be stored throughout the life of the resulting wood product. Consequently, researchers are exploring methods to enhance the absorption capacity of natural carbon sinks and investigate artificial carbon dioxide storage underground.

The innate ability of trees to naturally sequester carbon contributes significantly to mitigating the effects of climate change. Wood, being a sustainable and renewable construction material, aids in maintaining carbon sequestration within buildings. It also plays a crucial role in assisting the construction industry in reducing carbon emissions.²

Importance of Carbon Recapturing and Sequestration

Carbon recapturing and sequestration are indispensable strategies in the battle against climate change, specifically aimed at curbing the rise in atmospheric carbon dioxide (CO₂) levels. Given the heavy reliance on fossil fuels for energy, carbon emissions have become a significant driver of

global warming. The process of carbon recapturing involves capturing CO₂ before it is released into the atmosphere, effectively preventing its contribution to the greenhouse effect. Subsequently, sequestration entails securely storing the captured CO₂ in geological formations, preventing its release back into the air.

These techniques play a pivotal role in reducing atmospheric CO₂ concentrations, which is crucial for mitigating the adverse impacts of climate change, including extreme weather events, rising sea levels, and disruptions to ecosystems. Implementing carbon recapturing and sequestration aligns with sustainable practices, contributing to the creation of a cleaner and healthier environment for both current and future generations. The integration of these strategies is imperative for achieving global emission reduction goals and fostering a more sustainable and resilient planet.

Currently, 85% of our societal energy needs are met by fossil fuels, a dependency projected to persist for the next half-century. Without an 80% reduction in carbon dioxide (CO₂) emissions from current levels by mid-century, a bleak future awaits. The potential consequences include the disappearance of summer sea ice in the Arctic, endangering polar bears, the loss of sugar maples, and a significant impact on New England's ski industry. Moreover, the inevitable transformation of most CO₂ into oceanic carbonic acid could lead to the demise of coral reefs and essential zooplankton, disrupting marine food chains supporting species like salmon and whales. The looming threat also extends to the potential submergence of southern Florida and the Gulf Coast due to rising sea levels.

This alarming scenario underscores the urgent need for effective measures to combat climate change. Fortunately, the growing momentum of carbon recapturing technology offers hope, demonstrating widespread applications and promising outcomes, particularly in regions with the highest CO₂ emissions.³

The Kyoto Protocol

The Kyoto Protocol, established in 1997, marked a significant milestone in addressing climate change by introducing legally binding targets for the first time. The accord required industrialized nations to reduce their greenhouse gas emissions to an average of 5% below their 1990 levels as an initial step. However, the efficacy of the protocol relied on the ratification of industrialized countries, constituting a minimum of 55% of global CO₂ emissions.

Despite the promising objectives, the United States, contributing 36% of emissions, declined to sign the agreement and subsequently withdrew from it. The Protocol faced an impasse until Russia, responsible for 17%, became the 141st party to ratify it. This development, surpassing the

crucial 55% threshold, led to the protocol coming into force on February 16, 2005. The Kyoto Protocol laid the groundwork for international cooperation in addressing climate change, emphasizing the need for collective efforts to combat the global environmental challenge.

Techniques used for Carbon Recapturing

Carbon capture and storage directly involves three steps: CO₂ capture, transport to the injection site, and injection deep underground to achieve "sequestration." In the first step, CO₂ is captured from large point sources using any of a number of different processes. It is then dried, compressed, and cooled, converting gaseous CO₂ to a supercritical fluid. Supercritical CO₂ is moved from the site of capture to the site of injection, typically by pipeline, although oceangoing tankers (similar to LNG tankers) could also be used where appropriate. Once at the site of injection, CO₂ is injected into a geologic formation deep enough below the surface that the CO₂ remains as a supercritical fluid. The minimum depth that meets this criterion is typically 800 m or 2,600 ft, although the precise depth varies from one location to another.

Currently there are three main forms of carbon capturing techniques are being used, these are post-combustion, pre-combustion, and oxy-fuel combustion.

Pre-combustion Capture

Pre-combustion capture is less energy intensive than post-combustion, but it is not a retrofit for older power plant generators. In pre-combustion capture, coal is burned in pure oxygen, producing a flue gas mixture composed of mostly CO₂ and H₂. This mixture is then treated with steam in a catalytic converter. Catalytic converters function to reduce pollutants to less harmful chemical species before leaving the system. In a coal-fired power plant, catalytic converters work to reduce CO₂, volatile organic compounds, and nitrous oxides. Inside a catalytic converter, there are two types of catalysts or substances that cause a chemical reaction to accelerate without being changed by that reaction. Good converters expose a large amount

of surface area to flue gases, while minimizing the amount of catalyst required. Inside the converter, the reduction catalyst reduces nitrous oxides to pure nitrogen and oxygen gases while the oxidation catalyst causes leftover hydrocarbons and carbon monoxide to be oxidized to CO₂. After leaving the converter, the mixture is mostly H₂ and CO₂, and after being passed through a CO₂ absorbing solvent, the mixture is heated and a concentrated stream of CO₂ is released (figure 1).

Post-Combustion Capture

The main advantage of post-combustion capture is its implementation through retrofitting existing coal-fired power plants. Inside the power plant, coal is burned to generate heat, which turns into steam. This steam turns a turbine, producing electricity. The steps involved to convert the energy from heat to mechanical motion of the turbine encompass the process of combustion. When the coal is burned, CO₂ gas is produced, along with other flue gases, like H₂O, SO₂, NO₂, and, depending on the grade of the coal used, other trace gases. Post-combustion refers to separating the CO₂ gas from these flue gases after the combustion process. This process has been used in the past as a way to capture CO₂ for enhanced oil recovery, and is usually accomplished by passing the flue gases through an appropriate CO₂-absorbing solvent. The solvent is later heated, releasing steam and leaving behind concentration CO₂. These plants release flue gases through chimneys or smokestacks, and a solvent filter can be installed to capture the CO₂ as it leaves through these openings.

Oxy-Fuel Combustion

Oxy-fuel combustion is a highly energy-intensive process. This process eliminated the separation step by fired coal in pure oxygen, producing pure CO₂ as a byproduct of combustion. Since air is only 19% oxygen by volume, the other gases must first be separated. If this process were to be implemented, power plants would have to be redesigned to use pure oxygen, as the combustion from pure O₂ produces a 3500°C flame, which is too hot for most power plant materials.⁴

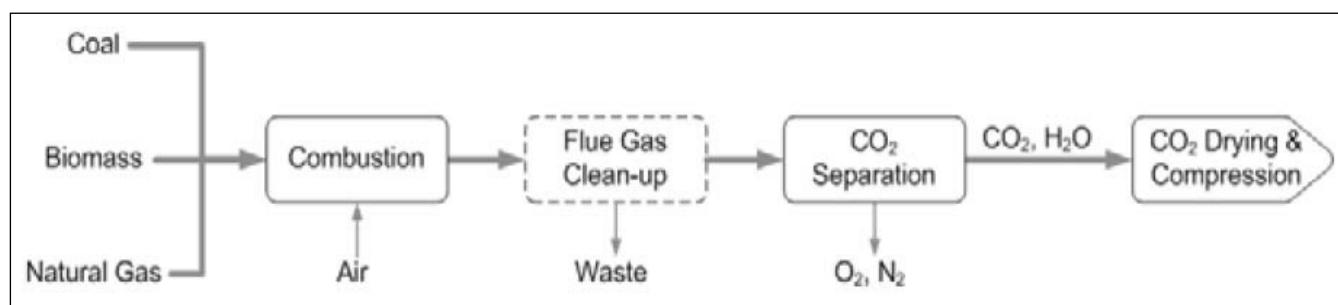


Figure 1. Flow diagram of a carbon capture process, illustrating the combustion of coal, biomass, or natural gas with subsequent CO₂ separation and drying for capture

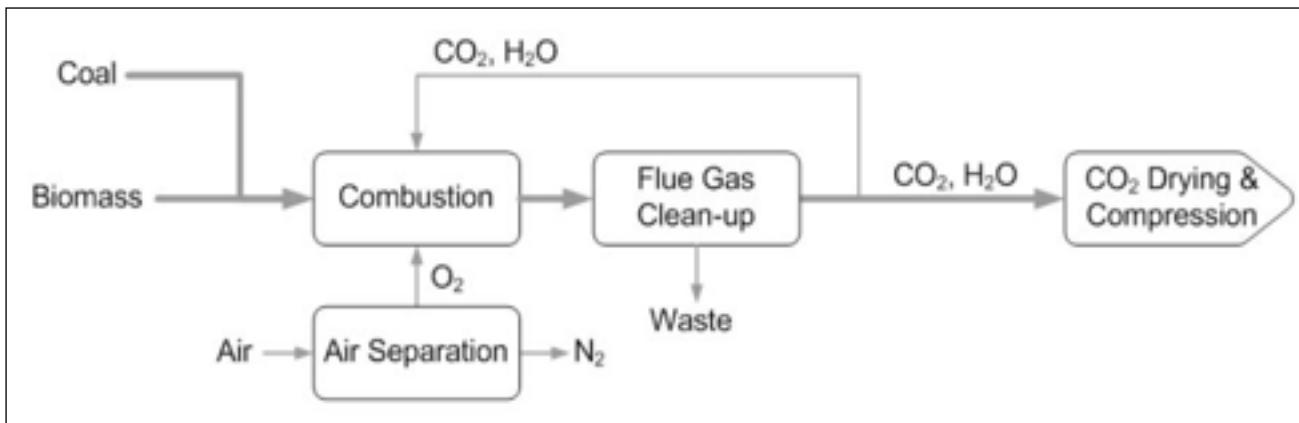


Figure 2. Flow diagram of an oxy-fuel combustion carbon capture process with air separation, flue gas clean-up, and CO₂ drying and compression

Scope and Application Areas of Carbon Capturing

Carbon capturing holds immense potential across various sectors, playing a pivotal role in mitigating climate change and reducing greenhouse gas emissions. The scope of carbon capturing extends to industrial processes, particularly power generation from fossil fuels, where large point sources emit substantial CO₂. Additionally, carbon capturing technologies find application in other industrial settings, such as cement and steel production, where carbon emissions are inherent. These techniques are essential for achieving emission reduction targets, particularly in sectors where alternative, low-carbon technologies are not readily available or economically viable.

Furthermore, the application of carbon capturing is not confined to large-scale industries.

Figure 2 shows flow diagram showing the flow of carbon in oxy-fuel combustion.

Emerging technologies aim to capture CO₂ directly from the air, offering a versatile solution applicable to various contexts. Research and development in this area explore innovative approaches to enhance the efficiency and cost-effectiveness of carbon capturing methods, making them scalable and accessible.

The potential impact of carbon capturing spans geographical boundaries, addressing global challenges associated with climate change. Its multifaceted scope and diverse applications underscore its significance in the broader context of sustainable development and environmental stewardship.

Typical features of various large point sources of CO₂ are shown in Table 1

Table 1. This table represents CO₂ emissions in million tons annually, with Electric Power Generation being the highest contributor among the categories

Industrial Process/ classification	CO ₂ Emissions (Million Tons per year)
Electric Power Generation	6.60
Chemical & Petrochemical	3.61
Other Industrial	4.44

Process of Sequestration

Sequestration, a critical component of carbon capture and storage (CCS), involves the long-term storage of captured carbon dioxide (CO₂) to prevent its release into the atmosphere. Various methods of sequestration have been explored, each with its own advantages and challenges:

- **Geological Storage:** Depleted oil and gas reservoirs, saline aquifers, and deep coal seams serve as promising geological formations for storing CO₂ underground. These formations have held oil and gas for millions of years, providing stability for the stored CO₂.⁵
- **Ocean Storage:** Carbon dioxide can be injected into the deep ocean, where natural processes would allow it to be stored for extended periods. The ocean's mixing cycles and gravity contribute to moving CO₂ to lower depths. However, concerns about ocean acidification and potential ecological impacts make this method subject to careful consideration.
- **Mineralization:** CO₂ can react with certain minerals, forming stable carbonates. This mineralization process

results in the transformation of CO₂ into a solid state, making it less prone to leakage. However, this method often involves slow reaction rates, limiting its immediate effectiveness.

- **Enhanced Oil Recovery (EOR):** In certain oil fields, CO₂ can be injected to enhance the recovery of remaining oil reserves. While this is not a permanent storage solution, it provides an additional economic incentive for carbon capture projects.
- **Biological Sequestration:** Forests and other vegetation naturally absorb CO₂ through photosynthesis. Afforestation, reforestation, and sustainable land management practices contribute to biological sequestration, enhancing the capacity of ecosystems to store carbon.

The choice of sequestration method depends on geological characteristics, environmental considerations, and project-specific factors. Ongoing research and technological advancements continue to refine these methods, making carbon sequestration a key strategy in addressing climate change and achieving global emission reduction goals.

Transportation Technology

The transportation of carbon dioxide (CO₂) after the separation step in carbon capture and storage (CCS) presents unique challenges and requires specific technologies. It is neither efficient nor economical to transport CO₂ as an uncompressed gas. Therefore, after the separation process in CCS, CO₂ is converted into its supercritical liquid form for transportation through pipelines.

Supercritical CO₂ exists at a temperature and pressure at or beyond the critical point, displaying properties that lie between those of a gas and a liquid. The critical pressure of CO₂ is 72.9 atm, and the critical temperature is 31.3°C. To achieve this supercritical state, energy is required for the phase conversion. However, once in its supercritical form, CO₂ can be efficiently transported through pipelines using an air compressor.

This technology ensures that CO₂ is transported in a state that optimizes both efficiency and cost-effectiveness. By utilizing the unique properties of supercritical CO₂, the transportation phase of CCS becomes a crucial component in the overall process of capturing and storing carbon emissions from industrial processes and power generation.⁶

Risk Factors

Carbon capture and storage (CCS) is a promising technology to mitigate climate change by reducing carbon dioxide (CO₂) emissions from industrial processes and power generation. However, like any complex technological solution, CCS comes with certain risks that need careful consideration:

- **Health and Safety Risks:** During the capture, transportation, and storage of CO₂, there is a potential for leaks or accidental releases. In high concentrations, CO₂ can pose health risks to humans, leading to asphyxiation.
- **Underground Storage Risks:** Injecting CO₂ underground for storage in geological formations, such as depleted oil and gas reservoirs or saline aquifers, raises concerns about the potential for leaks. If not properly contained, CO₂ could migrate and jeopardize surrounding ecosystems or contaminate drinking water sources.
- **Seismic Activity:** The injection of CO₂ into geological formations may induce seismic activity, leading to small earthquakes. While these events are typically of low magnitude, they need to be carefully monitored to avoid any potential harm.⁷
- **Long-Term Storage Integrity:** Ensuring the long-term integrity of storage sites is crucial. Over time, there is a risk of leaks or structural failures in the seals or cap rocks that contain the stored CO₂.
- **Public Perception and Acceptance:** The public's perception and acceptance of CCS play a vital role in its successful implementation. Concerns about safety, environmental impact, and the permanence of storage may affect public support and regulatory approval.
- **Economic Viability:** The costs associated with implementing and maintaining CCS technologies could impact their widespread adoption. Economic viability and government incentives are crucial factors in determining the feasibility of large-scale CCS projects.
- **Regulatory and Legal Challenges:** The absence of clear and comprehensive regulations for CCS poses challenges. Legal issues related to liability, property rights, and responsibility for any adverse impacts need to be addressed.⁸

Addressing these risks requires rigorous monitoring, effective regulations, transparent communication, and ongoing research and development. While CCS holds promise for significantly reducing CO₂ emissions, its deployment must be carefully managed to mitigate potential adverse effects and ensure its overall effectiveness as a climate change mitigation strategy.²

Economic Viability

Overall, the technological options assessed above are capable of removing the majority of carbon dioxide from the exhaust gases emitted by coal-fired power plants and other major polluters. While these options are technologically viable, their use in industry depends on whether or not the process of carbon capture can be cost effective.

Conclusion

Amidst the challenges and risks associated with Carbon capture and sequestration (CCS), the prospect of tempering

global warming, safeguarding ecosystems, and securing future generations from the perils of climate change takes center stage. The strides in carbon recapturing technology amplify its relevance, especially in sectors with substantial emissions.

As we stand at this juncture of innovation and environmental responsibility, the collaborative endeavors of scientists, policymakers, and industries will shape the global success of CCS. Drawing insights from past agreements like the Kyoto Protocol and harnessing emerging technologies, we embark on a transformative journey toward a sustainable future. The quest for effective carbon capture and sequestration transcends academic discourse; it is a collective pursuit holding the key to reshaping our trajectory for a habitable planet..

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