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Carbon Sequestration: A Key Strategy for Climate Change Mitigation

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Carbon sequestration has emerged as a critical approach to mitigate climate change by capturing and storing atmospheric carbon dioxide, one of the primary greenhouse gases responsible for global warming. With increasing industrialization, deforestation and fossil fuel use, atmospheric CO_2 levels have risen significantly, leading to severe environmental consequences. In response, global efforts are focusing on enhancing both natural and artificial carbon sinks to achieve climate targets such as net-zero emissions. Carbon sequestration not only reduces greenhouse gas concentrations but also improves soil health, ecosystem productivity and long-term sustainability, making it a vital component of climate change mitigation strategies.

Concept and Types of Carbon Sequestration

Carbon sequestration refers to the process of capturing and storing atmospheric CO_2 in various reservoirs such as forests, soils, oceans and geological formations. It can broadly be classified into geologic, oceanic and terrestrial sequestration. Geologic sequestration involves capturing CO_2 from industrial sources and storing it deep underground in geological formations such as depleted oil and gas reservoirs or saline aquifers. This method includes three main steps: capture, transport and storage. A notable example is the Sleipner project in Norway, which has successfully stored millions of tonnes of CO_2 underground since 1996 (Manuel et al. 2010).

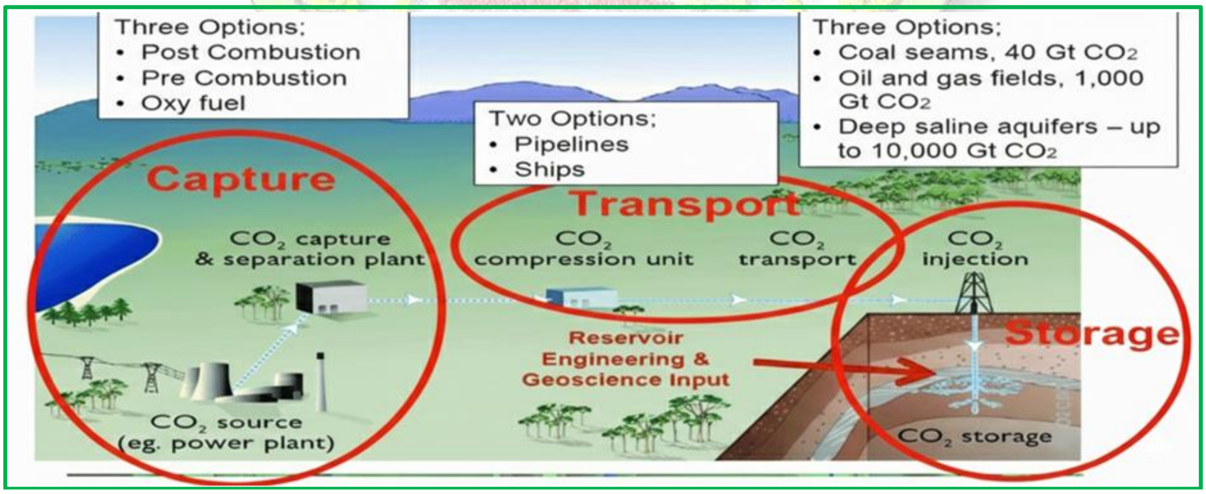

Fig 1 - Main steps involved in carbon capture and storage

Oceanic sequestration occurs when oceans absorb CO_2 through physical and biological processes. The solubility pump, biological pump and carbonate pump play key roles in transferring carbon from the atmosphere to deep ocean layers. Oceans are the largest natural carbon sink, storing a significant proportion of global carbon (Britannica, 2026).

Terrestrial sequestration involves storing carbon in vegetation and soils through natural processes such as photosynthesis. Forests, grasslands and agricultural lands act as important carbon sinks. Soil organic carbon is particularly significant as it can store carbon for decades to centuries, improving soil fertility and structure.

Carbon Sinks and Types of Carbon

Carbon sinks are systems that absorb more carbon than they release. Natural sinks include forests, soils, oceans, wetlands and phytoplankton, while artificial sinks include technologies like carbon capture and storage (CCS), bioenergy with CCS and direct air capture. Different forms of carbon also influence the environment differently. Black carbon, produced from incomplete combustion, strongly absorbs sunlight and accelerates warming. Brown carbon contributes to atmospheric heating and affects radiation balance. Green carbon is stored in terrestrial ecosystems such as forests and soils, while blue carbon is stored in coastal ecosystems like mangroves and seagrasses, which are highly efficient carbon sinks (IOC-UNESCO, 2022).

Carbon Credit, Offset and Carbon Tax

Carbon sequestration is closely linked to economic instruments such as carbon credits, offsets and taxes. A carbon credit represents the reduction or removal of one tonne of CO_2 equivalent and can be traded in carbon markets. Countries earn carbon credits through mechanisms like the Clean Development Mechanism, emission trading systems and voluntary carbon markets.

Carbon offsets allow entities to compensate for their emissions by investing in projects that reduce or remove greenhouse gases elsewhere. On the other hand, carbon tax is a policy tool that imposes a fee on carbon emissions, encouraging industries to adopt cleaner technologies and reduce their carbon footprint (Insights on India, 2022).

Research on Carbon Storage

Several studies highlight the effectiveness of carbon sequestration in different systems. Long-term nutrient management practices in acid *Alfisols* at Palampur showed that integrated use of fertilizers and farmyard manure significantly increased the carbon management index, indicating improved soil carbon storage (Aashin Sharma, 2023). Similarly, diversified cropping systems such as rice–wheat with legumes demonstrated higher carbon sequestration rates compared to monocropping systems (Shivakshi Sharma, 2023). Agroforestry systems in Himachal Pradesh also showed high carbon storage potential, particularly in Toona-based systems, which enhanced both biomass and soil carbon (Manshi Mehta, 2019). At a global level, biochar application in Brazil demonstrated the potential to sequester large amounts of carbon, contributing up to 50 Mt CO_2-equivalent annually (Lefebvre et al. 2020). Modeling studies using WRF-VPRM indicated that afforestation could nearly double carbon sequestration rates in the Indo-Gangetic plains, while deforestation significantly reduces carbon storage (Huggannavar et al. 2023).

Limitations of Carbon Sequestration

Despite its potential, carbon sequestration faces several limitations. One major challenge is the limited storage capacity of natural sinks, which can become saturated over time. Additionally, the permanence of stored carbon is uncertain, as disturbances such as forest fires, land-use changes and soil degradation can release stored carbon back into the atmosphere. Another limitation is the slow rate of natural sequestration compared to the rapid increase in emissions. Economic and policy barriers, including high costs of implementation, monitoring and lack of stable carbon markets, further restrict large-scale adoption of sequestration technologies.

Conclusion and Future Prospects

Carbon sequestration plays a crucial role in mitigating climate change by enhancing carbon storage in natural and artificial systems. Practices such as agroforestry, conservation agriculture and integrated nutrient management not only increase carbon sequestration but also improve soil health and agricultural productivity. Advanced tools like remote sensing and modeling have further improved the accuracy of carbon estimation and monitoring. In the future, integrating carbon sequestration into climate policies, promoting climate-smart agriculture and adopting innovative technologies such as biochar and microbial interventions can significantly enhance sequestration potential. With coordinated global efforts, carbon sequestration can serve as a powerful tool to achieve sustainable development and net-zero emission targets.

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