



Carbon Sequestration: Mechanisms Ecosystem Services and Climate Mitigation

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Abstract

Carbon sequestration refers to the long term storage of carbon dioxide (CO₂) and other forms of carbon in natural reservoirs such as forests, soils, and oceans, as well as in engineered systems like geological formations. It is a critical process for mitigating atmospheric CO₂ concentrations and combating climate change. Terrestrial ecosystems capture carbon through photosynthesis, storing it in biomass and soils, while oceans absorb carbon through physical and biological processes. Enhanced understanding of sequestration mechanisms, quantification methods, and management strategies is essential for effective climate policy and sustainable ecosystem management. This article reviews the major pathways of carbon sequestration, its role in climate mitigation, and key environmental implications.

Keywords: Carbon Sequestration, Climate Mitigation, Terrestrial Ecosystems, Soil Organic Carbon, Ocean Carbon Uptake, Carbon Cycle

Introduction

Carbon sequestration encompasses the processes by which carbon is removed from the atmosphere and stored in other components of the Earth system for extended periods. Atmospheric CO₂ has risen sharply since the Industrial Revolution due to fossil fuel combustion, deforestation, and land-use change, driving global warming and climate disruption. Mitigating these impacts requires both reducing emissions and enhancing carbon sequestration in natural and managed systems.

The global carbon cycle involves exchanges of carbon among the atmosphere, biosphere, oceans, and geosphere. Natural sequestration processes — such as photosynthesis in plants and phytoplankton, soil organic matter formation, and dissolution of CO₂ in seawater — transfer carbon from the fast-cycling atmosphere into slower reservoirs. Anthropogenic strategies, such as afforestation, soil management, and geological CO₂ storage, seek to augment these natural processes [1]. Understanding the mechanisms and capacities

of different sequestration pathways is essential for climate mitigation strategies and ecosystem management.

Carbon Sequestration Pathways and Processes

Terrestrial ecosystems — forests, grasslands, and soils — are major carbon sinks. Carbon is sequestered as biomass carbon in plant tissues and as soil organic carbon (SOC) through litter deposition and decomposition. Plants absorb CO₂ during photosynthesis, converting it into organic carbon stored in leaves, stems, roots, and woody biomass. Forest ecosystems are among the largest terrestrial carbon pools. Mature forests store significant amounts of carbon in biomass and soils, while young, rapidly growing forests can act as strong carbon sinks due to high rates of carbon uptake. Soils contain more carbon than vegetation and the atmosphere combined, largely in the form of soil organic matter (SOM). Carbon enters soils through plant litter, root exudates, and microbial residues, where it can persist for decades to millennia depending on soil conditions and management practices. Practices such as reduced tillage, cover cropping, and organic amendments enhance SOC sequestration by increasing carbon inputs and reducing decomposition rates [2].

The world's oceans are the largest active carbon sink, absorbing CO₂ through physical and biological processes. CO₂ dissolves in surface waters where it reacts with water to form bicarbonate and carbonate ions. Circulation transports carbon-rich deep waters to the ocean interior, where it can remain isolated for centuries [3]. Phytoplankton in surface waters convert dissolved carbon into organic matter via photosynthesis. When these organisms die or are consumed, a fraction of their biomass sinks to deeper layers, transferring carbon from the surface — a process termed the biological carbon pump. This mechanism is crucial for long-term sequestration in deep ocean sediments. Beyond natural systems, carbon can be sequestered through engineered approaches. Captured CO₂ from industrial sources can be injected into deep geological formations — such as depleted oil and gas reservoirs or deep saline aquifers — where it is trapped under impermeable rock layers. This approach, known as carbon capture and storage (CCS), has the potential to reduce point-source emissions significantly [4].

BECCS combines biomass energy production with CO₂ capture and storage, generating energy while removing carbon from the atmosphere. This strategy is considered a potential negative emissions technology in climate mitigation portfolios.

Enhancing carbon sequestration offers co-benefits including improved soil health, biodiversity support, and water quality. However, there are challenges — saturation of sinks, land-use trade-offs (e.g., food vs. bioenergy production), and permanence. Policies like REDD+ (Reducing Emissions from Deforestation and Forest Degradation) incentivize conservation and sustainable management of forests to maintain and enhance carbon stocks. Climate models regularly include sequestration scenarios to estimate future atmospheric CO₂ trajectories under different mitigation strategies [5].

Conclusion

Carbon sequestration is a fundamental process in the global carbon cycle and a key strategy for mitigating anthropogenic climate

change. Terrestrial ecosystems store carbon in vegetation and soils, while oceans absorb CO₂ through physical and biological processes. Engineered approaches like geological storage and BECCS provide additional pathways to reduce atmospheric carbon. Understanding the capacities, rates, and controls of different sequestration mechanisms informs effective climate policy and ecosystem management. While sequestration cannot replace emissions reduction, it complements mitigation strategies and contributes to climate stabilization goals. Ongoing research and targeted policy incentives are essential to enhance natural and engineered carbon sinks in a changing climate.

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