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Sequestering Success: Integrating Carbon Capture into a Sustainable Future

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This article is about storing carbon so that it is not in the atmosphere. For removing carbon dioxide from industrial point sources before it enters the atmosphere, see Carbon capture and storage. For removing carbon dioxide from the atmosphere (and negative emissions), see Carbon dioxide removal.

Carbon sequestration is the process of storing carbon in a carbon pool. It plays a crucial role in mitigating climate change by reducing the amount of carbon dioxide in the atmosphere.

There are two main types of carbon sequestration:

1. Biologic (also called bio sequestration)
2. Geologic

Biologic carbon sequestration is a naturally occurring process as part of the carbon cycle. Humans can enhance it through deliberate actions and use of technology. Carbon dioxide (CO_2) is naturally captured from the atmosphere through biological, chemical, and physical processes. These processes can be accelerated for example through changes in land use and agricultural practices, called carbon farming. Artificial processes have also been devised to produce similar effects. This approach is called carbon capture and storage. It involves using technology to capture and sequester (store) CO_2 that is produced from human activities underground or under the sea bed. Forests, kelp beds and other forms of plant life absorb carbon dioxide from the air as they grow, and bind it into biomass. However, these biological stores are considered impermanent carbon sinks as the long-term sequestration cannot be guaranteed.

History of the term (etymology)

The term *sequestration* is based on the Latin *sequestrare*, which means set aside or surrender. It is derived from sequester, a depositary or trustee, one in whose hands a thing in dispute was placed until the dispute was settled. In English "sequestered" means secluded or withdrawn.

In law, sequestration is the act of removing, separating, or seizing anything from the possession of its owner under process of law for the benefit of creditors or the state.

Roles

In nature: Carbon sequestration is part of the natural carbon cycle by which carbon is exchanged among
the biosphere, pedosphere, geosphere, hydrosphere, and atmosphere of Earth. Carbon dioxide is naturally captured from the atmosphere through biological, chemical or physical processes, and stored in long-term reservoirs. Forests, kelp beds, and other forms of plant life absorb carbon dioxide from the air as they grow, and bind it into biomass. However, these biological stores are considered *volatile carbon sinks* as the long-term sequestration cannot be guaranteed. Events such as wildfires or disease, economic pressures and changing political priorities can result in the sequestered carbon being released back into the atmosphere.

In climate change mitigation: Carbon sequestration - when acting as a carbon sink - helps to mitigate climate change and thus reduce harmful effects of climate change. It helps to slow the atmospheric and marine accumulation of greenhouse gases, which are released by burning fossil fuels and industrial livestock production. Carbon sequestration, when applied for climate change mitigation, can either build on enhancing naturally occurring carbon sequestration or use technology for carbon sequestration processes. Within the carbon capture and storage approaches, *carbon sequestration* refers to the storage component. Artificial carbon storage technologies can be applied, such as gaseous storage in deep geological formations (including saline formations and exhausted gas fields), and solid storage by reaction of CO_2 with metal oxides to produce stable carbonates.

Biological carbon sequestration on land

Reforestation and reducing deforestation can increase carbon sequestration in several ways. Pandani (Richea pandanifolia) near Lake Dobson, Mount Field National Park, Tasmania, Australia.

Biological carbon sequestration (also called *biosequestration*) is the capture and storage of the atmospheric greenhouse gas carbon dioxide by continual or enhanced biological processes. This form of carbon sequestration occurs through increased rates of photosynthesis via land-use practices such as reforestation and sustainable forest management. Land-use changes that enhance natural carbon capture have the potential to capture and store large amounts of carbon dioxide each year.

Forestry: Transferring land rights to indigenous inhabitants is argued to efficiently conserve forests. Trees absorb carbon dioxide (CO_2) from the atmosphere through the process of photosynthesis. Throughout this biochemical process, chlorophyll in the tree's leaves harnesses sunlight to convert CO_2 and water into glucose and oxygen. While glucose serves as a source of energy for the tree, oxygen is released into the atmosphere as a byproduct. Trees store carbon in the form of biomass, encompassing roots, stems, branches, and leaves. Throughout their lifespan, trees continue to sequester carbon, acting as long-term storage units for atmospheric CO_2.

Wetlands: An example of a healthy wetland ecosystem Global distribution of blue carbon (rooted vegetation in the coastal zone): tidal marshes, mangroves and sea grasses. Wetland restoration involves restoring a wetland's natural biological, geological, and chemical functions through re-establishment or rehabilitation. It has also been proposed as a potential climate change mitigation strategy. Wetland soil, particularly in coastal wetlands such as mangroves, sea grasses, and salt marshes, is an important carbon reservoir; 20–30% of the world's soil carbon is found in wetlands, while only 5–8% of the world's land is composed of wetlands.

Peat lands, mires and peat bogs: Peat lands hold approximately 30% of the carbon in our ecosystem. When they are drained for agricultural land and urbanization, because peatlands are so vast, large quantities of carbon decompose and emit CO_2 into the atmosphere. The loss of one peat land could potentially produce more carbon than 175–500 years of methane emissions.

Agriculture: *Panicum virgatum* switch grass, valuable in bio fuel production, soil conservation, and carbon sequestration in soils. Compared to natural vegetation, cropland soils are depleted in soil organic carbon (SOC). When soil is converted from natural land or semi-natural land, such as forests, woodlands, grasslands, steppes, and savannas, the SOC content in the soil reduces by about 30–40%. This loss is due to the removal of plant material containing carbon, in terms of harvests. When land use changes, the carbon in the soil will either increase or decrease and this change will continue until the soil reaches a new equilibrium. Deviations from this equilibrium can also be affected by variated climate.

Carbon farming: Carbon farming is a set of agricultural methods that aim to store carbon in the soil, crop roots, wood and leaves. The technical term for this is *carbon sequestration*. The overall goal of carbon farming is to create a net loss of carbon from the atmosphere. This is done by increasing the rate at which carbon is sequestered into soil and plant material. One option is to increase the soil's organic matter content. This can also aid plant growth, improve soil water retention capacity and reduce fertilizer use. Sustainable forest management is another tool that is used in carbon farming. Carbon farming is one component of climate-smart agriculture. It is also one of the methods for carbon dioxide removal (CDR).

Prairies: Prairie restoration is a conservation effort to restore prairie lands that were destroyed due to industrial, agricultural, commercial, or residential development. The primary aim is to return areas and ecosystems to their previous state before their depletion. The mass of SOC able to be stored in these restored plots is typically greater than the previous crop, acting as a more effective carbon sink.

Biochar: Biochar is charcoal created by Pyrolysis of biomass waste. The resulting material is added to a landfill or used as a soil improver to create terra preta. Addition of pyrogenic organic carbon (biochar) is a novel strategy to increase the soil-C stock for the long term and to mitigate global warming by offsetting the atmospheric C (up to 9.5 Gigatons C annually). In the soil, the biochar carbon is unavailable for oxidation to CO_2 and consequential atmospheric release. However, concerns have been raised about biochar potentially accelerating release of the carbon already present in the soil.

Burial of biomass: Biochar can be landfilled, used as a soil improver or burned using carbon capture and storage. Burying biomass (such as trees) directly mimics the natural processes that created fossil fuels. The global potential for carbon sequestration using wood burial is estimated to be 10 ± 5 GtC/yr and largest rates in tropical forests (4.2 GtC/yr), followed by temperate (3.7 GtC/yr) and boreal forests (2.1 GtC/yr). In 2008, Ning Zeng of the University of Maryland estimated 65 GtC lying on the floor of the world's forests as coarse woody material which could be buried and costs for wood burial carbon sequestration run at 50 USD/tC which is much lower than carbon capture from e.g. power plant emissions. CO_2 fixation into woody biomass is a natural process carried out through photosynthesis. This is a nature-based solution and suggested methods include the use of "wood vaults" to store the wood-containing carbon under oxygen-free conditions.

Geological carbon sequestration

Underground storage in suitable geologic formations

Geological sequestration refers to the storage of CO_2 underground in depleted oil and gas reservoirs, saline formations, or deep, coal beds unsuitable for mining. Once CO_2 is captured from a point source, such as a cement factory, it can be compressed to ≈100 bar into a supercritical fluid. In this form, the CO_2 could be transported via pipeline to the place of storage. The CO_2 could then be injected deep underground, typically around 1 km, where it would be stable for hundreds to millions of years. Under these storage conditions, the density of supercritical CO_2 is 600 to 800 kg/m^3.

Sequestration in oceans

Marine carbon pumps: The pelagic food web, showing the central involvement of marine microorganisms in how the ocean imports carbon and then exports it back to the atmosphere and ocean floor The ocean naturally sequesters carbon through different processes. The solubility pump moves carbon dioxide from the atmosphere into the surface ocean where it reacts with water molecules to form carbonic acid. The solubility of carbon dioxide increases with decreasing water temperatures. Thermohaline circulation moves dissolved carbon dioxide to cooler waters where it is more soluble, increasing carbon concentrations in the ocean interior. The biological pump moves dissolved carbon dioxide from the surface ocean to the ocean's interior through the conversion of inorganic carbon to organic carbon by photosynthesis. Organic matter that survives respiration and remineralization can be transported through sinking particles and organism migration to the deep ocean. The low temperatures, high pressure, and reduced oxygen levels in the deep sea slow down decomposition processes, preventing the rapid release of carbon back into the atmosphere and acting as a long-term storage reservoir.

Conclusion

Carbon sequestration is a vital process in mitigating the impacts of climate change by capturing and storing atmospheric carbon dioxide (CO_2). This process can occur naturally through biological mechanisms such as photosynthesis in forests, soils, and oceans, or artificially through technological interventions like carbon capture and storage (CCS). Enhancing carbon sequestration capabilities, both natural and artificial, is essential for achieving global climate goals and reducing greenhouse gas concentrations in the atmosphere. Effective carbon sequestration strategies, supported by policies and technological advancements, have the potential to significantly contribute to a sustainable and climate-resilient future.

References

Lal, R. (2004). Soil Carbon Sequestration Impacts on Global Climate Change and Food Security. *Science*, 304(5677), 1623-1627. doi:10.1126/science.1097396.

IPCC. (2018). Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways. Retrieved from https://www.ipcc.ch/sr15/

Pacala, S., and Socolow, R. (2004). Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies. *Science*, 305(5686), 968-972. doi:10.1126/science.1100103.

Smith, P. et al. (2016). Biophysical and economic limits to negative CO_2 emissions. *Nature Climate Change*, 6, 42-50. doi:10.1038/nclimate2870.

Peters, G. P., et al. (2017). Key indicators to track current progress and future ambition of the Paris Agreement. *Nature Climate Change*, 7, 118-122. doi:10.1038/nclimate3202.

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