CLIMATOLOGY

A woody biomass burial

Ancient, buried wood points to a possible low-cost method to store carbon

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Limiting climate change requires achieving net zero carbon dioxide emissions. Although substantial reductions in fossil fuel emissions are essential, they are insufficient for achieving the international goal of limiting global warming to 1.5 or 2°C above preindustrial levels. These targets, established by the Paris Agreement, aim to avoid severe impacts of climate change by keeping the global average temperature increase within these limits. (*1*). Achieving net-zero necessitates approaches that remove carbon dioxide from the atmosphere, known as carbon dioxide removal (CDR) (*2*). Engineering CDR methods, such as direct air capture, are expensive and energy-intensive. Nature-based CDR, such as reforestation and afforestation, are cheaper but face land use competition, scalability issues, and carbon leakage risks (*3*). On page XXX of this issue, Zeng et al.(*4*) describe a hybrid nature-engineering CDR method that is inspired by a 3775-year-old wood log buried belowground, which could contribute to meeting the 1.5 °C warming threshold.

Forests are central to climate change discussions because of their critical role as a dominant land carbon sink in natural carbon cycles (*5*). They sequester carbon from the atmosphere through photosynthesis. This carbon is stored in wood with ~ 50% carbon content that varies by species (*6*). The carbon is released back to the atmosphere through burning (forest fires or prescribed burning for fire risk management) or decomposition of woody biomass. Globally, 10.9 ± 3.2 Gt (billion tonnes) of carbon could be emitted from deadwood per year, higher than anthropogenic carbon emissions from fossil fuels (*7*). If an approach can extend the duration of carbon storage in wood to hundreds of years or longer and prevent the release of carbon back into the atmosphere, it would naturally be an effective CDR approach.

Zeng et al. describe a pathway to make deadwood carbon storage a reality. The authors present a CDR approach involving the burial of sustainably sourced wood in an underground engineered structure called as "wood vault" to prevent wood decomposition. This method is based on their discovery of an ancient Eastern red cedar wood log in Saint-Pie, Quebec, Canada, 50 km east of Montreal. The log was found two meters underground and surrounded by clay soil. Carbon-14 analysis indicates that it is 3775±35 years old. Scanning electron microscopy revealed that the latewood portion (the wood produced late in the growing season) is well preserved.

How much carbon was lost from this wood log over time has direct implications for the viability of wood burial for durable carbon storage. It is difficult to estimate carbon loss by comparing ancient wood with a perfectly preserved wood sample from the original tree that lived thousands of years ago. To address this, Zeng et al. cut one end of the ancient wood log and a modern wood sample from the same species and compared their physical properties and chemical compositions. They found that although the density of the ancient wood is lower than that of the modern sample, the tensile strength and main chemical compositions were similar. Holocellulose, which includes cellulose and hemicellulose, and lignin are the main chemical components of wood carbon (*8*). Holocellulose loss is a common indicator for analyzing minor wood decay (*9*). Based on the loss of holocellulose, the authors estimated the carbon loss in the ancient sample to be up to 5%. This provides evidence for preserving carbon in wood through burial with low carbon reemission risk.

The preservation conditions of the ancient wood log are crucial to replicate for achieving long-term carbon storage. Zeng et al. attributed the well-preserved ancient wood mainly to the clay soil characteristics that created an environment lacking oxygen. Oxygen, moisture, and temperature are the main factors contributing to wood decomposition. The latter two factors are not limited at the Montreal site where the ancient wood log was discovered. The site has low-permeability clay soil, as well as waterlogged and stagnant soil conditions, creating an oxygen-depleting environment. Fungi and insects, the main decomposers, cannot survive in this environment. Anaerobic bacteria can, but they cannot break down lignin, the most stable biomass component that protects cellulose structure (*10*). Thus, coarse woody biomass, such as a whole log with its original structure maintained, will be better for wood preservation than fine woody biomass. Based on these findings, the Zeng et al. suggest that burying clean, coarse woody biomass in a chamber capped by low-permeability clay soil—a "wood vault"—would replicate oxygen-depleting conditions.

An exciting aspect of the Zeng et al. study is the potential for wood burial as a low-cost, highly scalable CDR. Zeng et al. estimated a CDR cost of $100-200 per tonne. Scaling up and optimizing the process over the next one to two decades would potentially lower the cost to $30-100/tonne. The cost of future individual wood burial projects can vary substantially, depending on wood sourcing and transportation distances. Considering these variations, wood burial can be cost-competitive compared to engineering approaches such as direct air capture ($125-335 per tonne of carbon dioxide) (*11*) or other hybrid nature-engineering methods such as bioenergy combined with carbon capture and storage ($15-400 per tonne)(*12*). The latter involves using biomass (organic matter such as plants) to generate energy, while capturing and storing the resulting carbon dioxide underground. Wood burial has an advantage in using underutilized wood residues, such as urban tree wastes and forest residues from commercial thinning. It can be integrated into sustainable forest management, especially in areas with overstocked forest residue and increasing fire risks due to climate change. Zeng et al. estimated the global potential of wood burial to be as large as 10 $GtCO_2$ per year, on the basis of potentially available coarse woody biomass. This CDR potential per year is the largest in South America (3.3 $GtCO_2$) and Africa (2.1 $GtCO_2$), followed by the Maritime Continent (1.0 $GtCO_2$), United States (0.51 $GtCO_2$), and China (0.51 $GtCO_2$), which would compensate for 9-300% of fossil fuel emissions from these countries.

To accelerate wood burial as a CDR pathway, more knowledge is needed to guide projects in locations with environmental conditions different from the Montreal site and for various wood sources or other biomass types, such as agricultural biomass (*10*). Effective monitoring, reporting, and verification of CDR impacts is essential. Many such protocols have been developed for carbon markets and policies, but only 1 protocol is available for biomass burial (*12*). Some protocols use life cycle assessment to assess the net carbon negativity of a CDR project. The initial estimates from Zeng et

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al. pinpoint several greenhouse gas emission sources, such as biomass transportation and vault construction. However, a full life cycle assessment is needed to quantify the net emissions and environmental impacts across ecosystems, supply chains, and engineered wood vaults, as well as to understand how these impacts vary by location and wood sources. Specifically, these assessments should include the potential environmental impacts of all energy and materials used in a wood vault project and consider the competition with alternative wood uses, such as bioenergy, pulp and paper, and durable wood products. These understandings will be critical to develop biomass burial projects on a global scale.

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