CARBON DIOXIDE REMOVAL TECHNOLOGIES (CDR-T):

AFFORESTATION (AF)

CLIMATE-NEUTRAL SOCIETY BY 2050

In 2019, leaders of the European Union agreed on an ambitious goal: to make Europe climate-neutral by 2050. This means balancing the greenhouse gases we emit with actions that remove carbon dioxide from the atmosphere. This commitment builds on the promises made by EU countries when they signed the Paris Agreement in 2015, a global agreement to limit global warming to well below 2°C and ideally to 1.5°C above pre-industrial levels to reduce the worst impacts of climate change
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To turn this vision into law, the EU introduced the European Climate Law in 2020 as part of the European Green Deal. This law legally commits the EU to climate neutrality by 2050 and sets a clear milestone for 2030: cutting net greenhouse gas emissions by at least 55% compared with 1990 levels. Looking ahead, the EU has also proposed an even more ambitious target, a 90% reduction by 2040 ((EU) 2021/1119, 2025).

Reaching these goals will require more than just reducing emissions. Although switching to renewable energy and improving energy efficiency are essential, they are not enough on their own. Some sectors—such as aviation, cement, and chemicals and steel industry—are very difficult to fully decarbonize. That is why carbon dioxide removal (CDR) is becoming increasingly important. It involves actively removing carbon dioxide from the air and storing it safely and durably, helping to balance remaining emissions and reduce the overall amount of CO_2 in the atmosphere.

Carbon removal is also needed because natural carbon sinks, like forests and soils, are becoming less effective due to climate change and land-use pressures. When combined with strong emissions reductions, CDR can help the EU reach net-zero. Beyond its climate benefits, CDR also presents opportunities for innovation, new industries, and job creation.

The EU is developing policies to support both nature-based solutions, such as tree planting and climate-friendly farming, and industrial technologies, including direct air capture and bioenergy with carbon capture and storage. To ensure trust and environmental integrity, the EU is setting up clear rules and certification systems for carbon removal, including the Carbon Removals and Carbon Farming (CRCF) Regulation (EU 2024/3012).

Economic incentives also play a key role. The EU Emissions Trading System (ETS), the EU's main tool for reducing emissions cost-effectively—can help create demand for verified carbon removals and encourage investment in these solutions.

Within this context, the C-SINK project, funded by Horizon Europe, aims to help build the foundations for a transparent and reliable European carbon removal market. The project focuses on developing trustworthy methods to measure, report, and verify carbon removal, ensuring that CDR contributes responsibly and effectively to Europe's climate goals while complementing existing EU and international efforts.

CARBON DIOXIDE REMOVAL (CDR) TECHNOLOGIES

CDR is a general term for ways to take CO_2 out of the air and store it safely long-term. The captured CO_2 can be stored underground in rock formations, in soils and plants, in the ocean, or in products that keep the carbon locked away for decades, centuries, or even on geological timescales (Brunner et al., 2024, Intergovernmental Panel on Climate Change [IPCC], 2018).

Land-based CDR approaches fall into two main groups:

Nature-based solutions
These approaches use natural processes to absorb and store carbon.

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- Planting trees (afforestation and reforestation) helps capture CO_2 by absorbing it from the air and storing it in biomass and soils.
- Improving farming and land-management practices so soils can hold more carbon
- Soil carbon sequestration: natural process where plants convert CO_2 from the air into organic matter through photosynthesis, that gets stored in the soil as stable organic carbon when litter is incorporated into soil.
- Peatland restoration involves rewetting damaged peatlands so they can store large amounts of carbon in the soil.

Engineered solutions

These rely on technology and industrial processes to remove carbon from the air.

- Direct Air Carbon Capture and Storage (DACCS) uses turbines to pull CO_2 directly from the atmosphere and stores it underground in geological formations.
- Bioenergy with Carbon Capture and Storage (BECCS) uses plants to absorb CO_2 as they grow. When the plants are used to produce energy, the released CO_2 is captured and stored underground.
- Biochar is a charcoal-like material made by heating biomass and agricultural waste with little or no oxygen that stores carbon and can improve soil health when added to farmland.
- Enhanced rock weathering, where crushed alkaline rocks are spread on farmland to absorb CO_2 while also improving soil quality.

Nature-based solutions are currently the most affordable and ready-to-use options, making them especially important in the near term. More advanced technological solutions are still developing but could play an important role in near future. For this reason, the European Commission is placing strong emphasis on nature-based solutions (NbS). EC has preference for these NbS due to their higher level of development and their recognized environmental, social and economic co-benefits. Furthermore, they help to support the delivery of a range of ecosystem services. This focus is further reinforced by related EU policy frameworks, including the Green Infrastructure Strategy and the Biodiversity Strategy, with ecosystem restoration targets being especially significant. At the international level, similar principles were endorsed in March 2022, when the United Nations adopted a resolution on nature-based solutions at the fifth UN Environment Assembly (UNEA-5), closely aligning with the European Commission's definition.

Some carbon removal methods, such as BECCS and DACCS, use carbon capture and storage (CCS) technology to permanently store CO_2 (assuming well managed systems). Some studies indicated that these methods could lead to net negative emissions, meaning they reduce the overall amount of carbon dioxide in the atmosphere (Xie et al., 2025).

However, it is important to understand that CCS used on fossil fuel emissions only reduces emissions it does not remove carbon already in the atmosphere. For this reason, carbon capture and storage (CCS) and carbon dioxide removal (CDR) are related but not the same, and the terms should not be used interchangeably.

AFFORESTATION

Natural land ecosystems help remove CO_2 from the air mainly through photosynthesis. Plants take in CO_2 as they grow and store it in their leaves, wood, roots, and the soil. Forests are especially important because trees can store large amounts of carbon for long periods, both above ground in their trunks and branches and below ground in their roots and soils. Around the world, forests hold a major share of the carbon stored on land, making them a key part of how the planet regulates climate (figure 1).

Afforestation, or planting trees on land that has not been forested for a long time, removes carbon by allowing new forests to grow. Although forest soils can store carbon for many years, this storage is not permanent, fires, pests, storms, and natural decay can release carbon back into the atmosphere. For this reason, the long-term climate benefits of afforestation depend on how fast trees grow, which species are planted, where they are

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planted, and how the forests are managed. (Figure 2)

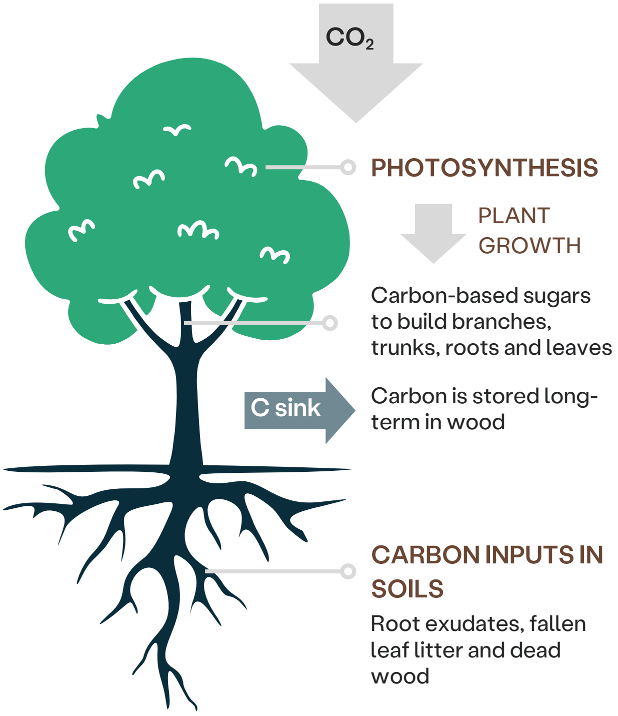

Figure 1. CO_2 fixation and carbon cycle in afforested ecosystems.

Figure 2. Steps procedure for afforestation.

Afforestation is often used on degraded, abandoned, or marginal land, where it can both remove carbon from the air and help restore ecosystems. The amount of carbon stored—and how long it stays stored—varies depending on local climate, soil conditions, tree species, and forest management practices. The long-term carbon storage also depends on the usage of wood: while it is possible to store a share of the carbon in timber products (e.g., buildings, furniture), some of the carbon from the leftover parts of the trees that remain in the woods (e.g., branches, stumps) will still be released to the atmosphere.

Designing successful afforestation projects requires thoughtful choices. Different tree species grow at different speeds, use water and nutrients differently, and vary in how well they cope with pests, diseases, and extreme weather. Planting a mix of native species is increasingly preferred because these forests are more resilient, support more wildlife, and are less vulnerable to large-scale damage than single-species plantations. Forest management practices, such as thinning or selective harvesting, also influence how much carbon remains stored in the forest over time.

Beyond climate benefits, afforestation can provide many additional advantages. It can help restore damaged land, protect soils from erosion, improve water regulation, support biodiversity, provide areas for education, learning and recreation as well as for physical and mental well-being, and contribute to local economies through sustainable timber production. When wood is used in long-lasting products, such as buildings or furniture, the carbon stored in the trees can remain locked away for many years, extending the climate benefits beyond the forest itself (Hasegawa et al. 2024).

Afforestation is considered a nature-based carbon removal solution. It works through natural biological processes, rather than industrial technologies, but its success still depends heavily on good planning, long-term management, and strong governance. Poorly designed projects such as planting the wrong species or relying on large monocultures can harm biodiversity, increase water stress, or make forests more vulnerable to fire and disease.

When carefully planned and combined with wider land-use and climate strategies, afforestation offers a practical and scalable way to remove

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carbon dioxide from the atmosphere. At the same time, it supports healthier ecosystems and more sustainable land management, making it a valuable tool in the response to climate change (Udawatta et al. 2022).

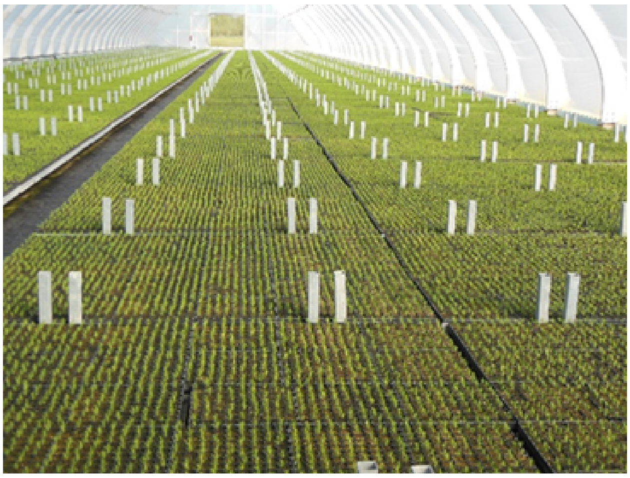

Figure 3. Plant preparation

Figure 4. Afforestation planting design

CURRENT STATE OF AFFORESTATION AS CDR TECHNOLOGY

Planting trees on previously non-forested land known as afforestation is a well-known practice, but it still needs ongoing research to work effectively to remove CO_2 from the atmosphere. Researchers are improving how trees are selected, where they are planted, how forests are managed, and how carbon stored in trees and soils is measured over time, especially as the climate changes (Li et al. 2025, Strauss et al. 2024).

Because forests take decades to grow, stable long-term funding and clear policies are essential. Even though tree planting is less expensive than high-tech carbon removal, it still carries risks such as drought, fire, pests, and uncertain growth. Public support helps manage these risks, especially for projects on degraded land or those testing new approaches like mixed-species forests.

Demonstration projects remain important to show that afforestation can store carbon reliably in real-world conditions. These projects also help improve how carbon storage is measured and build public trust by showing added benefits like healthier ecosystems, better water management, and rural jobs (Cook-Patton et al 2021).

Afforestation is now considered a mature and proven climate solution. The main challenge is scaling it up responsibly by securing enough land, funding, and long-term management. Over time, afforestation can become self-sustaining by fitting into normal land-use planning, forestry markets, and climate policies, reducing the need for ongoing public subsidies (Jovanelly et al. 2026).

CONCLUSIONS FROM C-SINK PROJECT

Afforestation has limits and risks. Large areas of land are needed, which can compete with farming or housing. Climate benefits take time to appear, and forests can lose stored carbon due to fires, pests, droughts, or poor management. Poorly planned projects such as large single-species plantations or planting trees in unsuitable places can harm biodiversity and water resources.

For these reasons, afforestation for maximising carbon capture works best as part of a wider climate strategy, not as a single solution. Combining it with other approaches such as improving soil carbon, using biochar, or pairing bioenergy with carbon capture can make carbon removal more reliable and reduce risks. This also helps use land more efficiently and supports wider goals related to energy, resource use, and the circular economy.

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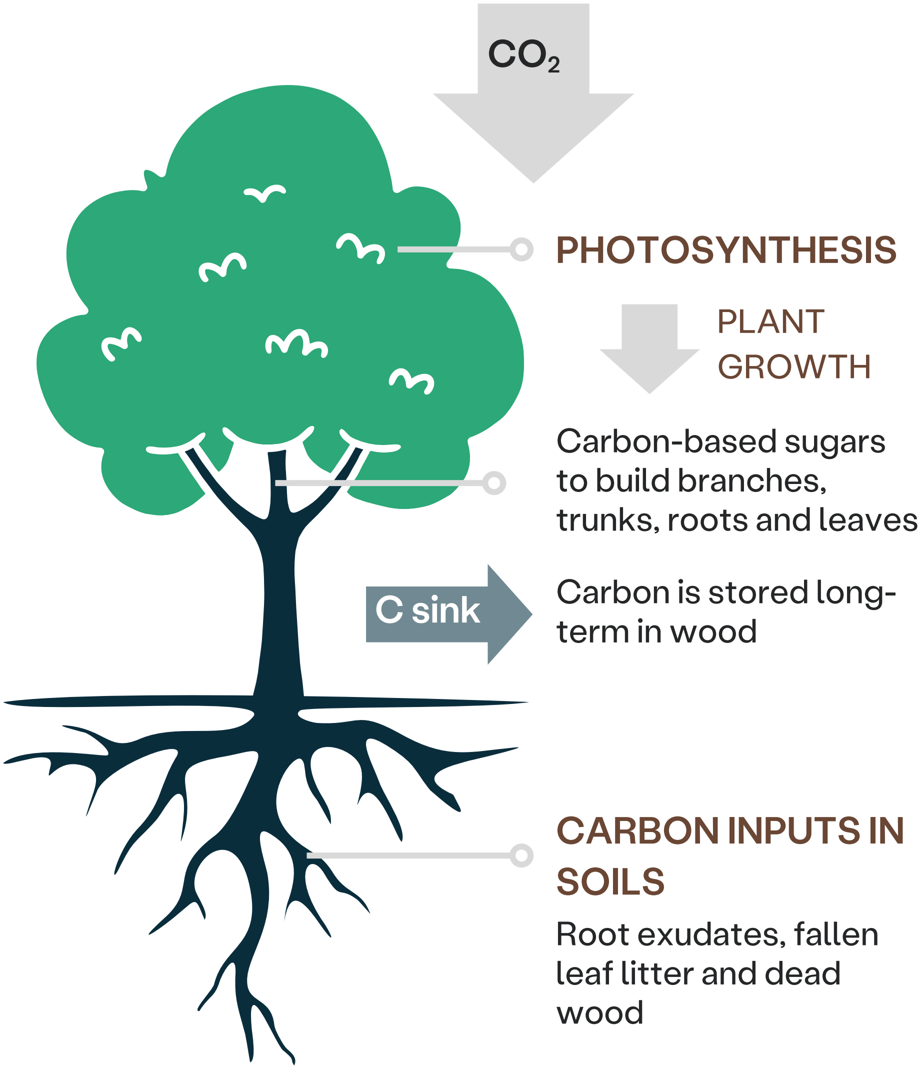
To ensure trust and effectiveness, strong systems are needed to measure and track carbon storage in forests and soils over time. New tools, such as satellite monitoring, forest surveys, and digital data systems, help provide transparency and accountability at large scales.

Overall, when supported by long-term policies, good land-use planning, and sustainable forest management, afforestation can play an important role in tackling climate change. It is a practical, affordable, and multi-purpose solution that can remove carbon from the air while also restoring ecosystems and benefiting society.



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