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Carbon Dioxide Removal
An introduction

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Contents

What is carbon dioxide removal?

The Intergovernmental Panel on Climate Change (IPCC)[1] defines carbon dioxide removals (CDR) as *"anthropogenic activities that remove CO_2 from the atmosphere and store it durably in geological, terrestrial, or ocean reservoirs, or in products."*

What does not count as carbon dioxide removal?

The IPCC's definition shows that, to count as CDR, CO_2 must be removed:

a) from the **atmosphere** and

b) by **humans**.

Any capturing of carbon dioxide that is not from the atmosphere, but from a point source (such as from a smokestack, or a flue gas stack, connected to a coal power plant or cement factory) doesn't count as a carbon removal.[2] This is instead describing Carbon Capture, Utilisation, and Storage (CCUS). It *reduces* carbon emissions, instead of *removing* carbon emissions that have already been emitted.

Similarly, the utilisation of removed carbon in activities and products that would allow for it to be re-emitted, such as within carbonated drinks, would also not count.

In reference to point b, as the removal method must be anthropogenic, any carbon removed by natural sinks, such as rainforests or seagrass meadows, would not count as CDR. However, any *human* efforts to restore or expand these ecosystems would.

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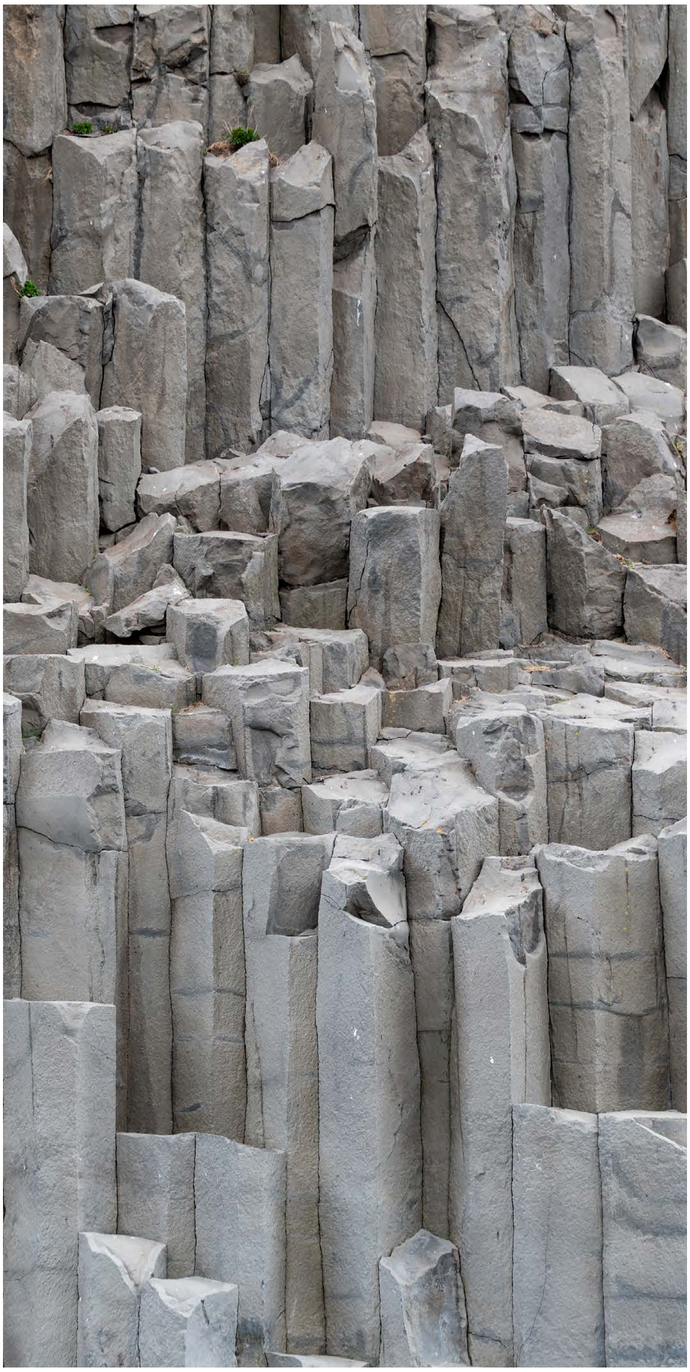


How do we store the carbon dioxide removed from the atmosphere?

There are four main storage options for carbon removed from the atmosphere:[3]

Biosphere
Vegetation, soils, biomass, etc.

Geosphere
Rocks and minerals above or below the Earth's surface

Oceans
Blue carbon ecosystems, deep sea and sediments

Products
Long-lived products (e.g., structural timber)

Biosphere

Carbon that's stored in the biosphere is mostly achieved by restoring or managing our natural systems. The amount of carbon removed by the biosphere can also be increased by working with nature in the following ways:

- **Restore:** Restoring ecosystems such as forests, peatlands and mangroves will increase their capacity to capture carbon through photosynthesis and store it within their soils or biomass
- **Manage:** Managing our natural systems involves increasing the effectiveness of carbon storage without changing the current use of land. This method is useful where land is required for food production or other essential purposes. Examples of this include **regenerative agriculture** (e.g., no tillage, use of cover crops), **silvopastoralism** (including trees in pasture lands), **agroforestry** (including trees in agricultural land) and **climate smart forestry** (including reduced impact logging, shifting plantations to be more species-rich and age-diverse, or simply extending the average age of trees before harvesting)
- **Work with nature:** Working with nature and enhancing natural processes to remove CO_2 whilst nurturing ecosystems. One example of this is the use of **biochar** (a form of charcoal created by burning biomass without oxygen) on soils. Biochar locks away carbon while boosting the health and water retention of soils, which can make crops more resilient to drought. Other solutions include **woody biomass burial**, where carbon captured by plants can be buried in conditions that inhibit biomass decomposition (such as saline soils).

Geosphere

The geosphere (i.e., rocks above and below the Earth's surface) offers some of the greatest capacity for storage of CO_2. The two main forms of geological storage are Direct Air Carbon Capture and Storage (DACCS) and Bioenergy with Carbon Capture and Storage (BECCS).

DACCS uses chemical solvents or sorbents to directly capture CO_2 from the air. This is then stored in geological formations for up to 10,000 years. BECCS utilises the natural carbon removal capability of plants (usually woody biomass), which is converted into bioenergy (through combustion, fermentation or pyrolysis). Carbon emissions from this process are captured and stored, avoiding the re-release of removed CO_2.

These methods require significant energy input and are currently more expensive than biosphere storage options. However, the cost involved is already decreasing. With continued research and development, it's set to reduce even further as the technology improves and becomes more widespread alongside the increasing availability of renewable energy.

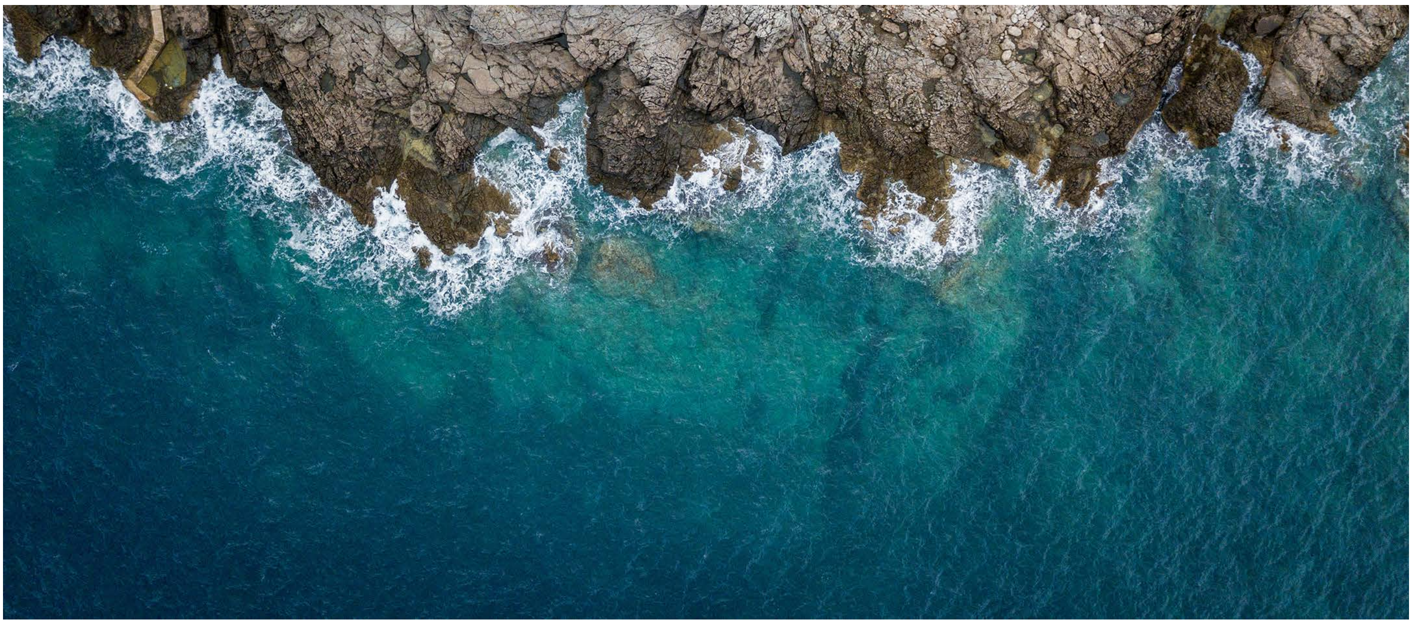
Another method of carbon removal under the geosphere involves the spreading of finely-ground silicate rock on soils – usually agricultural land. This is known as **enhanced weathering**. It enables greater up-take of carbon in soil and can also boost soil nutrient levels, improve crop yields and restore agricultural soils.

Oceans

The ocean holds a substantial opportunity for CO_2 storage in the deep sea and within its natural waters and ecosystems. There are a range of options to explore, including the restoration of oceanic ecosystems, such as mangroves and seagrass meadows.

These plants capture CO_2 through photosynthesis and can store it in their roots and sediments within the marine environment for thousands of years. Restoring these ecosystems can also avoid large-scale release of carbon that was previously stored and provide additional carbon capture capacity. It's also worth considering the cultivation of **microalgae** (phytoplankton) as it similarly removes CO_2 through photosynthesis and holds significant potential for high-durability storage in the deep ocean.

Another option is adding **calcium** to the ocean to enhance its natural ability to remove CO_2 and reverse acidification. This would also help resolve other ecosystem concerns related to ocean acidification, such as the bleaching of coral reefs. However, if carried out without conducting necessary checks and consultations with local communities beforehand, this method carries a risk of inflicting unintended and adverse impacts on ecosystems and communities.

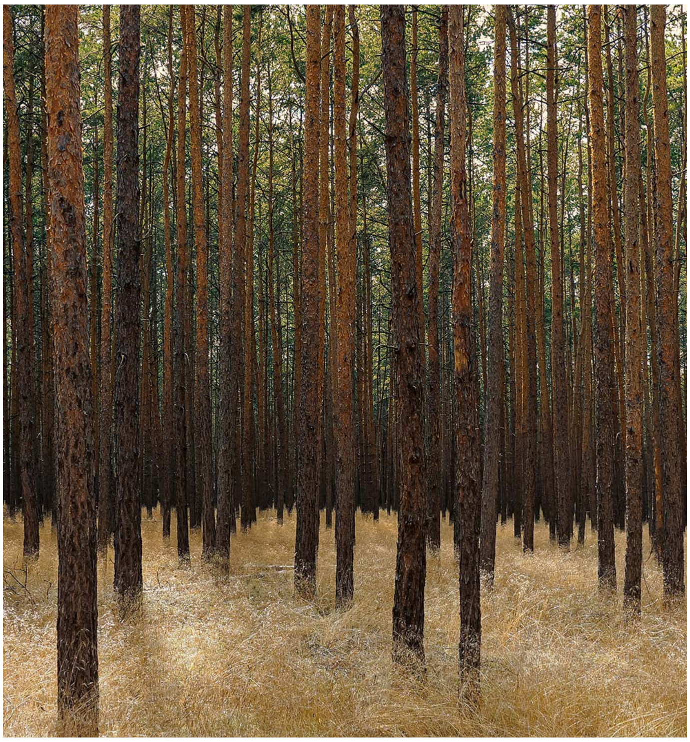


Products

CO_2 can be stored in products such as structural timber and concrete as well as inks, alcohols, and plastics.

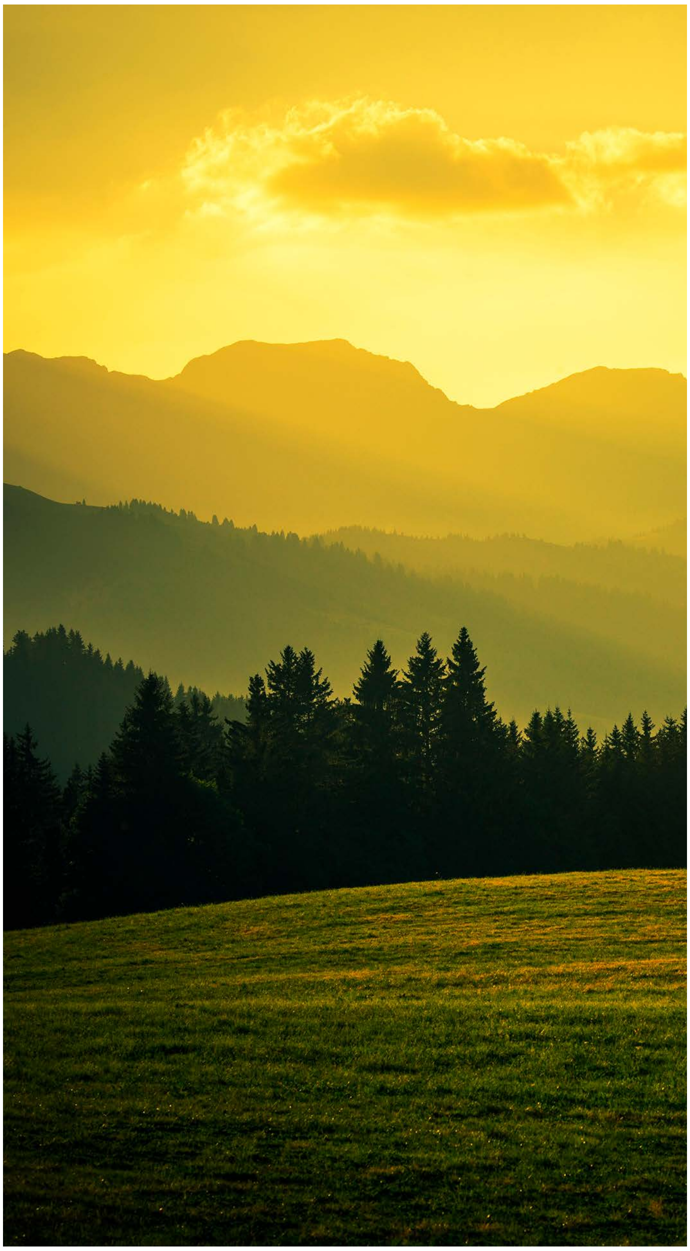
Products that store CO_2 are made in a variety of ways, usually by replacing a carbon intensive constituent with one that captures CO_2. For example, plant-based components could be used to make polymers for plastic instead of petrochemicals. Additionally, instead of using limestone-based cement to make concrete, calcareous microalgae could be used. The use of carbon-negative products has the added benefit of further reducing emissions. Further, structural timber could be used as an alternative to cement and steel, and reduce our need for materials known for the significant volumes of carbon involved in their manufacture.

This method of storage can carry a higher reversal risk, whereby the product is destroyed and releases the stored carbon, than some of the other storage options.



Why do we need carbon dioxide removal?

We cannot ensure a safe climate unless we cut CO_2 emissions by 50 per cent or more by 2030, reach net-zero emissions by 2050 and stay at net-negative emissions throughout the second half of the century.



All pathways[1] that keep warming below the Paris Agreement threshold of 2°C, or preferably 1.5°C, require year-on-year emission reductions, as well as the safe removal and storage of CO_2 from the atmosphere. The IPCC estimates that we will need to remove up to 6 billion tonnes of CO_2 per year through net removal on managed land (including afforestation and reforestation) and approximately another 3 billion tonnes per year through solutions such as DACCS and BECCS by 2050.

Simply put, the 'net' of net-zero comes from carbon dioxide removals. Removals complement rapid emissions reductions and, if we are to 'keep 1.5 alive', cannot be used as a substitute for decarbonisation. 2020 saw us emitting approximately 37 billion tonnes of CO_2, while we only remove a few million tonnes of CO_2 per year.

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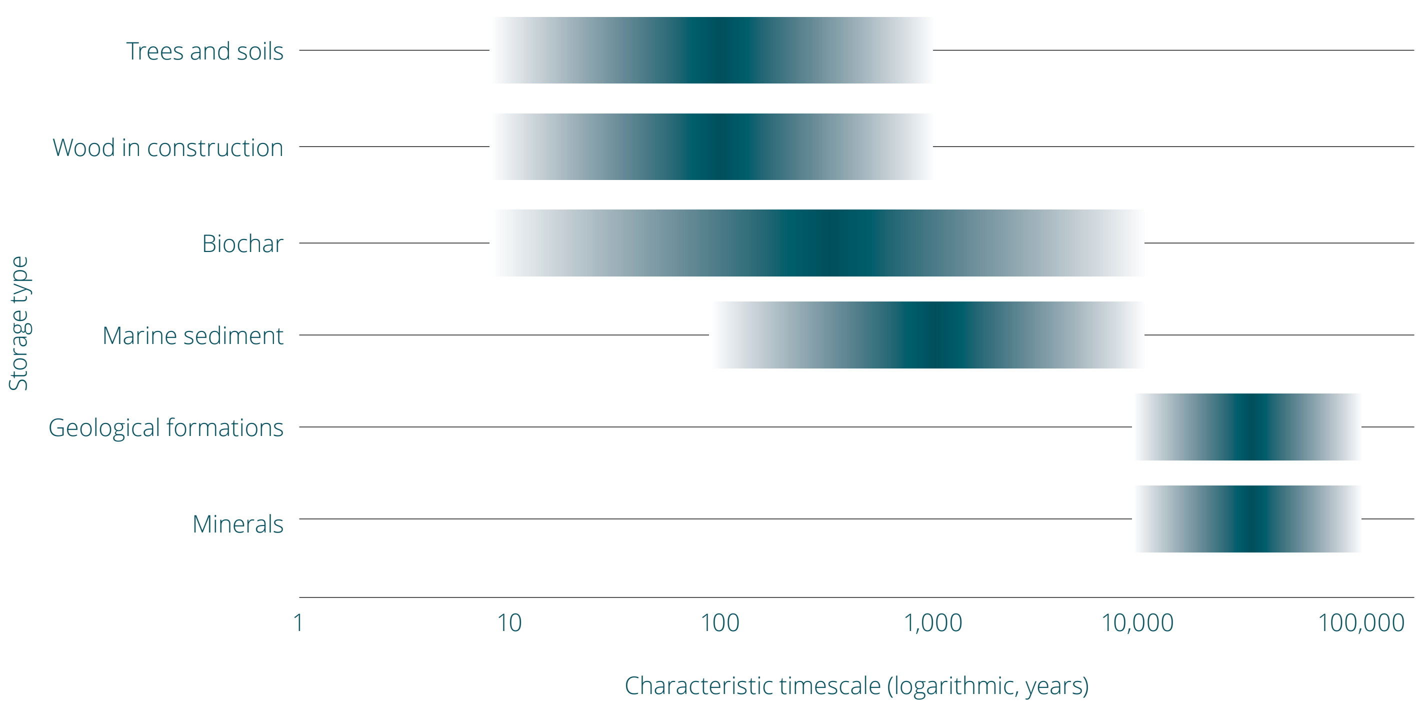
Why is durability important for carbon dioxide removal?

The durability of CDR refers to the length of time that carbon is stored and the risk of reversal (i.e., the risk that it is re-emitted).

The temperature-raising effect of CO_2 emissions lasts for thousands of years. This means that any CDR efforts that store CO_2 for less than this timescale are only able to partially counterbalance CO_2 emissions. Storing carbon dioxide in well-chosen geological formations offers the longest durability – up to 10,000 years – and the lowest risk of reversal. Land-based options, such as ecosystem restoration or regenerative agriculture, can store carbon for a duration of decades to centuries. However, they are also at risk of reversal due to human interventions such as logging, wildfires and a change in land-use. While geological formations are the most reliable and longest-lasting form of carbon storage, other forms such as biomass and land-based storage are also important in providing short-term solutions that can still have an impact on reducing global emissions. Figure 1 shows the durability of different methods for storing carbon.[3]

Figure 1. The durability of different carbon storage pools ranges from decades to tens of millennia.



Source: IPCC WG3 AR6 Chapters 7 & 12, as cited in Smith et al., 2023.

What can we do to get it right?

We must ensure that CDR capacity development is more than just selecting technologies through a science-informed lens. It's about how we develop carbon dioxide removals and minimise the negative impacts of the approaches on communities and biodiversity. It's of paramount importance for us to consider the goals of communities, as well as to build and scale the carbon dioxide removals ecosystem in a way that is just and equitable.

This means that carbon removal must be done in a way that doesn't compromise the health of communities, provides economic vitality, regenerates ecosystems, promotes social and environmental justice, and increases our resilience to the effects of climate change.

It's essential that CDR strategies are created, developed and implemented with the principles of ecological, social and economic sustainability at their core. This must be done in a manner that minimises negative impacts on the environment and on disadvantaged and marginalised communities, who are already disproportionately impacted by the climate crisis. The benefits of these approaches must also be equitably shared among all stakeholders.

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Busting myths

Myth 1: "Carbon dioxide removals are an excuse to carry on as normal."
This is indeed a risk involved with carbon dioxide removals. It's known as the 'moral hazard'. The idea that, if the world relies too heavily on CDR and doesn't sufficiently reduce emissions in the first place, we risk overshooting targets to limit warming. This means that more work will be required to limit the emissions from non-human emission sources, or feedback loops.[4]

The deployment of large-scale carbon removal systems and programmes shouldn't replace the drastic reduction of carbon emissions needed to reach net-zero; it must be done in addition to this. Carbon dioxide removals aren't a means to justify a business-as-usual attitude. CDR is an additional tool to help us reach net-zero and should only be used to neutralise residual emissions (i.e., the emissions that remain after we've done everything available to decarbonise/reduce emissions in the first place).[5]

Myth 2: "Carbon dioxide removals will just damage the environment they're based in."
All forms of CDR come with benefits and risks. A crucial element of their widespread adoption will be to ensure that benefits are maximised while avoiding risks.

For example, forest restoration provides additional carbon removal capacity and can increase biodiversity. However, there is a history of land acquisition for conservation and offset purposes associated with this, which displaces local communities and indigenous peoples.

Geological storage solutions (such as BECCS) can provide fossil fuel-free energy generation and skilled employment, raising the living standards of many. DACCS offers similar employment opportunities. However, storing CO_2 near or on geological fault lines can increase the risk of earthquakes.

Therefore, it is key that CDR solutions are designed and deployed responsibly.

Myth 3: "The emissions involved in setting up CDR solutions are greater than the emissions that the solution will actually remove."
An additional challenge to carbon removal solutions is ensuring that it actually results in negative emissions. Past initiatives aimed at carbon removal and storage in the biosphere through reforestation, afforestation and the strictly controlled management of forests have sometimes resulted in more deforestation taking place in another part of the forest or region. This is referred to as 'leakage' and is a common issue with carbon emission reduction initiatives too.

It's important to ensure that all carbon removals solutions are in fact net-negative. To do this, a full life cycle analysis is often required. For example, when planning and deploying BECCS, we must make sure that the energy in setting it up – including construction, transport, land use change, harvest of biomass, etc. – doesn't cause more emissions than are captured by the system. As such, projects must understand all risks and associated shortcomings, and take those into account when designing and implementing CDR projects to ensure a net removal of emissions.

Myth 4: "We can just plant more trees."
Tree planting is a relevant form of carbon removal and it's one that comes with a host of co-benefits. However, tree planting is inherently limited by:

- **Availability and competing needs:** Land is needed for natural ecosystems, food security and to support people's livelihoods. To take this into account, it is recommended that afforestation and reforestation projects take place on marginal and degraded land (to avoid displacing local communities and livelihoods). Assuming we only deploy afforestation and reforestation projects on this type of land and at a cost-effective price of no more than US$100 per tonne, an analysis by the Energy Transitions Commission[6] (ETC) found that globally we have approximately 300 million hectares of land available, mostly in the tropics for these types of projects. This would be equivalent to sequestering 1.9 billion tonnes of CO_2 per year by 2050. Given that we should be removing at least 5 billion tonnes per year by 2050, carbon removal by tree-planting alone will not be enough to keep us within 1.5°C warming

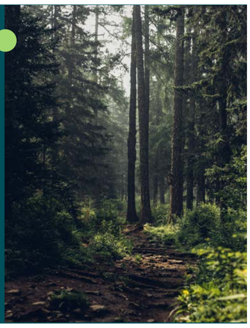
- **Risk of reversal:** CO_2 that's been sequestered within trees faces the risk of being re-emitted due to wildfires, changes in government policy or economic incentives, and potentially climate change itself

- **Quality of management and monitoring:** It's not enough to just plant trees. We need to plant the *right trees in the right places* and manage them appropriately so that they survive and stay healthy. We also need resources and methodologies to monitor, report and verify the amount of CO_2 that's being removed by the plants.

... tree planting is inherently limited by the amount of land available and competing needs, the risk of reversal, the quality of management, and the ability to monitor the amount of carbon sequestered.

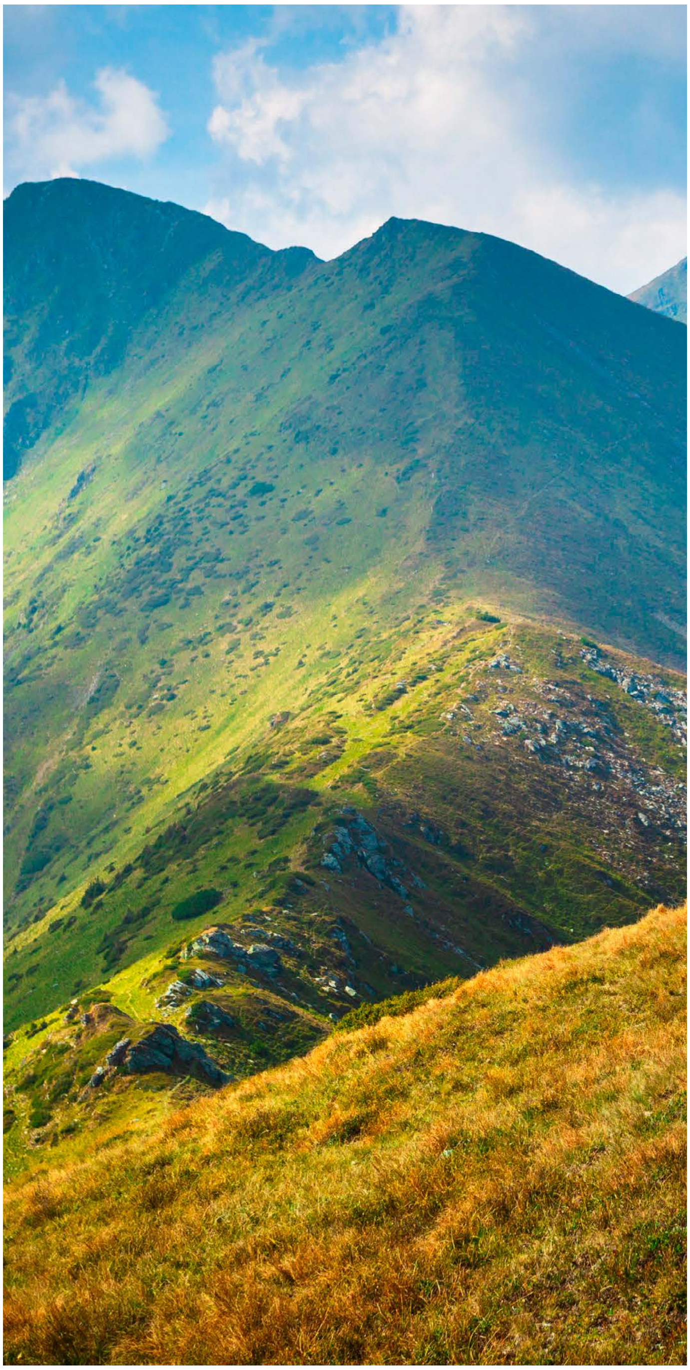
Myth 5: "We do not need technology to do carbon removal."
CDR is not a case of nature *vs* technology. Every method of removing carbon from the atmosphere involves a combination of natural resources and human ingenuity. Carbon removal relies on humans working with nature to reverse the imbalance we've created in our atmosphere and Earth system. We see this as a team effort in many existing carbon removal approaches today:

High-quality reforestation and forest management projects are complemented by tracking and monitoring via drones, lidar and satellite technology



DACCS projects require renewable energy such as solar or geothermal energy, as well as the right type of rocks or underground aquifers to store carbon dioxide

Enhanced weathering speeds up the slow, natural process of rock erosion (which sequesters carbon). This involves pulverising rocks and spreading it on agricultural land where plant roots and microbes in the soil speed up the chemical reactions.



Looking forward

The removal of carbon dioxide is scaling now. We'll need to have a diverse portfolio of removal types and solutions – big and small – across all regions to bolster our removal efforts. Each region has something to offer and every solution used depends on local contexts, potential co-benefits and what communities want and need.

For example, agricultural areas can benefit from the use of enhanced weathering to improve the health of their soil and increase yield. Coastal areas can focus on restoring mangroves, which can improve the biodiversity of marine ecosystems, and positively impacting fisheries harvests. For areas with the correct geology and high potential for renewable energy, DACCS may be an option.

Furthermore, increasing our carbon removal capacity makes us more resilient to climate change, in the short and long-term, locally and globally. From a local and short-term perspective, applying biochar to agricultural land can help farms become more resilient to droughts, as biochar increases the water retention and health of soils.

From a longer-term and global perspective, carbon removals are a means to counterbalance any additional emissions from feedback loops in the Earth system that result from warming itself.

An example of such emissions are those produced by thawing permafrost (perennially frozen ground) containing carbon which has been locked in place over thousands of years. If permafrost begins to melt (due to rising temperatures) the emissions will continue to be produced long after we have reached net-zero. Such feedback loops threaten to take the biosphere and the natural storage solutions from net sink to net source.

Increasing our removals capacity scales our toolbox and resilience in the face of earth system feedbacks and, if designed responsibly, can have wide and positive impacts on global ecosystems and communities.

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Endnotes

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