INTERGOVERNMENTAL PANEL ON climate change
Working Group III-Mitigation of Climate Change

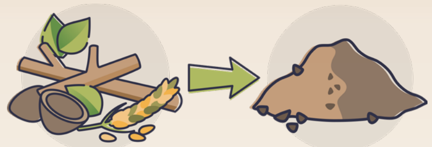
Carbon Dioxide Removal

CARBON DIOXIDE REMOVAL (CDR) refers to technologies, practices, and approaches that remove and durably store carbon dioxide (CO_2) from the atmosphere. CDR is required to achieve global and national targets of net zero CO_2 and greenhouse gas (GHG) emissions. CDR cannot substitute for immediate and deep emissions reductions, but it is part of all modelled scenarios that limit global warming to 2°or lower by 2100. Implementation will require decisions regarding CDR methods, scale and timing of deployment, and how sustainability and feasibility constraints are managed.

What is Carbon Dioxide Removal?

CDR refers to deliberate technologies, practices, and approaches that remove carbon dioxide (CO_2) from the atmosphere.

CDR also involves durably storing carbon after it has been extracted from the atmosphere, either in reservoirs such as vegetation, soils, geological formations, or the ocean, or in manufactured products.



CDR only refers to human activities that intentionally remove CO_2 from the atmosphere. It does not include natural CO_2 removal (such as through growth of natural forests).

There are many different CDR methods and associated implementation options, with different timescales and risk factors. Depending on scale and deployment scenario, CDR methods could have co-benefits or adverse side effects, which should be managed through appropriate CDR governance and policies.

How is CDR done and what are the different CDR options?

CDR methods differ in terms of removal process, timescale of carbon storage, technological maturity, mitigation potential, cost, co-benefits, adverse side-effects, and governance requirements. Implementation strategies need to take into account these differences and potential trade-offs.

Earth system: Land

CDR METHOD	Afforestation, Reforestation, Improved Forest Management		Soil carbon sequestration	Biochar	Bioenergy with Carbon Capture and Storage (BECCS)	Direct Air Carbon Capture and Storage (DACCS)	Enhanced rock weathering	Peatland and wetland restoration
IMPLEMENTATION OPTIONS	Agroforestry; tree planting, silviculture; timber in construction; bio-based products		Agricultural practices; pasture management	Cropping and forestry residues; urban and industrial organic waste; purpose-grown biomass crops		Solid sorbent; liquid solvent	Spreading crushed silicate rock	Rewetting; revegetation
STORAGE TIMESCALE	Decades to centuries *(in vegetation, buildings, soils)*		Decades to centuries *(in soils, sediments)*	Centuries to millennia *(in soils and sediments)*	10,000+ years *(in geological formations)*	10,000+ years *(in geological formations)*	10,000+ years *(in minerals)*	Decades to centuries *(in vegetation, soils, sediments)*
FINANCIAL COST ($ per tonne of CO_2)	Afforestation/ reforestation: $0-$240	Agroforestry and forest management: *not enough data*	–$45-$100	$10-$345	$50-$200	$100-$300	$50-$200	*Not enough data*
TRADE-OFFS and RISKS	Afforestation/ reforestation: Inappropriate deployment at large scales can increase competition for land (limiting land for biodiversity conservation and food)	• Agroforestry: limited impacts on agricultural crop production • Forest management: if fertiliser use and introduced species are involved, risks include: reduced biodiversity, increased eutrophication, and upstream GHG emissions	• Increasing carbon sequestration can occur at the expense of production • Sequestration contribution per hectare is small and hard to monitor	• Negative impacts from dust • Competition for biomass	Growing energy crops increases competition for land (limiting land for biodiversity conservation and food)	High energy requirement could lead to growing competition for low-carbon energy or increased GHG emissions. Some DACCS processes require water.	• Dust emissions • Potential for increased GHG emissions from energy generation	Some peatlands are used for food production, so could result in competition for land

This document has not been subject to the procedural IPCC review processes and has not been endorsed by the IPCC.

Earth system: Ocean

CDR METHOD	Blue carbon management	Ocean alkalinity enhancement	Ocean fertilisation
IMPLEMENTATION OPTIONS	Rewetting; coastal revegetation (e.g. mangroves, seagrass, saltmarsh)	Adding alkaline materials such as carbonate or silicate rock	Iron fertilisation; nitrogen and phosphorus fertilisation; enhanced upwelling
STORAGE TIMESCALE	Decades to centuries *(in vegetation, soils, sediments)*	10,000+ years *(in minerals)*	Centuries to millennia *(in marine sediment)*
FINANCIAL COST ($ per tonne of CO_2)	*Not enough data*	$40-$260	$50-$500
TRADE-OFFS and RISKS	• If subsequently degraded or destroyed, these ecosystems are likely to release carbon back to the atmosphere. • Maximum benefits will require many years to be achieved	Potential for increased GHG emissions from mining, transport and deployment	• Ocean acidification and deoxygenation • Altered supply of ocean macronutrients • Fundamental changes to food webs and biodiversity

CDR considerations for policymakers

Depending on the scale and deployment scenario, CDR methods could bring about various co-benefits and adverse side effects, further emphasising the need for appropriate CDR governance and policies. For instance, afforestation and reforestation, soil carbon sequestration, and biochar have co-benefits for food security and/or biodiversity.

When governments design mitigation policies to achieve net-zero or net-negative emissions, these policies will need to include some kind of CDR.

In determining how to include CDR in mitigation portfolios, policymakers should consider costs, storage times, risks, and trade-offs of various CDR methods.

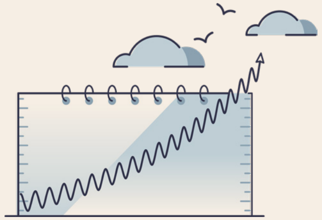
The choice of CDR methods and the scale and timing of their implementation depends on a variety of factors. These include emissions reduction ambition, sustainability, feasibility, political preferences, and social acceptability.

Most CDR options based on storage in vegetation, soils, or sediments are easier and less expensive to implement, and have biodiversity or food security co-benefits, but these methods store carbon for less time and can be more vulnerable. In contrast, CDR based on storage in geological formations is less understood and more expensive, but the carbon is stored for much longer periods.

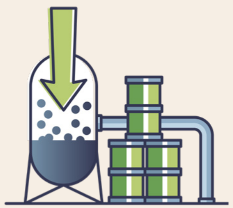
Effectively integrating CDR into mitigation portfolios can build on already existing rules, procedures and instruments for emissions abatement. To accelerate research and development and incentivise CDR deployment, a political commitment to formal integration into existing climate policy frameworks is required, including reliable measurement, reporting, and verification (MRV) of carbon flows

CDR is required to limit global warming to 1.5°C

CDR is required to limit warming to ˚1.5C. Particularly, CDR is needed to counter-balance emissions from difficult-to-decarbonise sectors, such as industry, long-distance transportation, and agriculture.



Mitigation scenarios assume large volumes of future global CDR deployment compared to current volumes of deployment.



Future deployment of CDR will require rapid and sustained upscaling.

Role of CDR in mitigation

CDR is not a substitute for deep emissions reductions, but it is an important tool that should be deployed in tandem with other mitigation methods.

CDR can complement other mitigation strategies by further reducing net greenhouse gas emissions, especially in the near-term.

CDR can help achieve and sustain net negative greenhouse gas emissions (where more greenhouse gasses are removed from the atmosphere than added to the atmosphere), especially in the long-term.