IMPERIAL
Grantham Institute

Background briefing

Carbon Dioxide Removal (CDR)

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Contents

Key points

- Carbon Dioxide Removal (CDR) is an umbrella term for techniques that capture carbon dioxide from the air and store it durably, as a result of human activity. CDR and Carbon Capture and Storage (CCS) are not the same thing, although the terms are sometimes incorrectly used interchangeably.
- CDR has three potential uses in reaching climate goals: in the near term, to reduce net emissions; in the medium term, to counterbalance residual emissions to achieve 'net zero'; and in the longer term, to achieve net-negative emissions in order to lower global temperatures if they exceed acceptable levels.
- Given the uncertainties, costs and resource constraints associated with CDR, pursuing rapid emissions reductions must be a priority to mitigate the risks of relying on large-scale CDR.
- Globally, almost all current removals come from CDR on land, primarily via afforestation, reforestation and improved management of existing forests. In future, CDR from 'novel' technologies will need to scale up rapidly – even for a lower-CDR pathways - requiring investment to stimulate innovation and drive down technology costs.
- Aligning climate and socio-ecological objectives in the development, deployment and regulation of CDR, while putting in place the appropriate regulatory frameworks, will help to ensure that co-benefits are realised and environmental harms are minimised.

What is Carbon Dioxide Removal (CDR)?

CDR is an umbrella term for techniques that can be used to deliver negative emissions. That is, they capture carbon dioxide (CO2) from the air and store durably.

Carbon dioxide capture from air can happen through biological processes, industrial chemical processes, or rock weathering processes. Depending on the technique, the carbon can be stored in trees, plant matter, in the soil, deep underground, in the oceans, or in long-lived products.

Examples include (but are not limited to):

- Afforestation/reforestation - trees can be planted to capture and store CO2.
- Peatland restoration – rewetting and revegetation of degraded peatlands can capture CO2, with CO2 stored in soils.
- Biochar – a charcoal-like substance created from plant matter which is able to store carbon; it can be used on agricultural land (with benefits for the soil and crop yields), or in products.
- Enhanced rock weathering – crushed silicate rock such as basalt can be spread on agricultural land (with benefits for the soil and crop yields) in order to capture and store CO2.
- Bioenergy with Carbon Capture and Storage (BECCS) – biomass (purpose-grown crops or agricultural/forestry residues) captures CO2 from the atmosphere as it grows; when the biomass is burned to generate electricity or heat, CO2 is captured and stored.

- Direct Air Carbon Capture and Storage (DACCS) – captures CO2 from the atmosphere using industrial chemical processes and stores it durably in geological storage or products.
- Marine-based techniques such as ocean alkalisation and coastal wetland management – there are a variety of methods that use geochemical or biological capture, and various forms of storage.

A subset of CDR methods—BECCS and DACCS— make use of Carbon Capture and Storage (CCS) technologies to deliver net negative emissions (that is, to reduce overall levels of carbon dioxide in the atmosphere) but it is important to note that applying CCS technologies to emissions from fossil fuels can never result in carbon dioxide removal from the atmosphere. Therefore, the terms CDR and CCS are not interchangeable.

The term Greenhouse Gas Removal (GGR) is broader, covering techniques that capture and store or convert other greenhouse gases such as methane, in addition to carbon dioxide.

Why is CDR needed?

CDR features in all the IPCC's scenarios for meeting the Paris temperature goal and plays a key role alongside rapid emissions reductions in reaching climate goals.

Specifically, the IPCC has highlighted that CDR can fulfil three major functions over the coming century:

- First, CDR can reduce net emissions in the near term.
- Second, CDR can offset unavoidable emissions from hard-to-abate sectors to achieve net-zero emissions in the medium term.
- Third, if removals exceed emissions, CDR can achieve net-negative emissions in the longer term. At the global level, this could be used to bring temperatures down in a scenario where global temperature increase exceeds acceptable levels (known as 'overshoot' scenarios).

Across the range of IPCC pathways, 420-1100 billion tonnes of CDR will be required by 2100 to limit global warming to 1.5°C with no or limited overshoot. For context, the world currently emits around 40 billion tonnes of carbon dioxide every year.

For every year that emissions do not fall substantially, dependence on CDR increases if we are to meet our climate goals. Given the uncertainties and costs inherent in scaling up CDR, and resource constraints (such as energy, land and water), it is far less risky to pursue rapid emissions reductions to minimise the requirement for CDR that is, follow a 'lower-CDR' pathway. This also necessitates low levels of residual emissions and hence rapid emissions reductions.

How advanced are the different CDR methods? When might we reasonably expect to deploy them, and at what scale?

There is a large diversity of CDR methods; some are much more advanced than others. Globally, almost all current removals come from CDR on land, primarily via afforestation, reforestation and improved management of existing forests. Other techniques are less advanced and are currently responsible for only a tiny fraction of CDR globally. Marine-based techniques tend to be at the lowest levels of advancement.

A portfolio of methods will be required to provide sufficient removal options. Given that many important technologies are at early stages of development, investment will be needed over the coming decade for driving innovation, 'learning by doing' and bringing the cost of technologies down. These 'novel' technologies will need to scale globally by a factor of 30 by 2030, and by 1300 times by 2050.

In the UK, techniques such as afforestation, peatland restoration, biochar, BECCS, DACCS and enhanced rock weathering are part of government-funded innovation and demonstration programmes. Globally, public and private sector funding is flowing into early-stage deployment: industrial-scale DACCS plants are already operating in Iceland (Orca) and in the US, while the largest BECCS plant to date is also located in Illinois in the US.

The suitability of deploying the various CDR methods in different parts of the world vary according to geography and resource availability. Choices of CDR methods will depend on regional and national capabilities, and the preferences of policymakers and publics.

The need to think about wider environmental and social factors

Frameworks for decision-making are emerging that can guide decision-making to reduce or avoid negative impacts, while supporting the delivery of co-benefits from GGR deployment. GGR-specific regulatory frameworks are still in development; for now, GGR is being deployed in the context of an existing, fragmented regulatory context and primarily private-sector voluntary standards.

Beyond climate change mitigation, CDR environmental impacts may be positive: some land-based CDR approaches deployed in appropriate locations have the potential to assist in biodiversity recovery, ecosystem restoration, and climate adaptation, alongside their climate benefits. Ideally CDR should be deployed in such a way that carbon removal and socio-ecological objectives are aligned. However, CDR approaches can require land, water, energy, and other inputs, which may be associated with resource competition or depletion, and raise pollution or ecological concerns.

CDR methods will interact with communities in both rural and urban areas, while beliefs and values about technologies and their implementation will reflect prevailing public attitudes to innovation and climate change and in turn affect social acceptance. Understanding perceptions and public engagement are key aspects of responsible innovation. More broadly, CDR innovation should be progressed with 'just transition' principles in mind.

The need to avoid CDR detracting from emissions reduction efforts

There are concerns about 'moral hazard' or 'mitigation deterrence' risks arising from an over-reliance on carbon removal strategies, which could deter or delay rapid emissions reduction. The specific risks are varied, including an overreliance on CDR as a result of a lack of information and lock-in to fossil-fuel-powered technologies as a result of delay.

Removing barriers to emissions reduction will help reduce mitigation deterrence risks. In addition, risks could be reduced by setting separate targets for emissions reduction and removal in the short term, and establishing principles for when it is appropriate to use carbon removals to counter hard-to-abate emissions in the longer term, for example.

Furthermore, CDR approaches can have multiple benefits for adaptation and mitigation, in addition to social and environmental goals. In some cases, these benefits may be a core motivator for adoption. Enhancing these synergies will be key.

Currently, many organisations are not transparent about the role of carbon offsets in their net zero strategies, and the environmental and social integrity of some offsets is questionable.

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Further reading

- What is GGR? CO2RE – The Greenhouse Gas Removal Hub.
- GGR Evaluation, CO2RE – The Greenhouse Gas Removal Hub.
- Smith, S. M., Geden, O., Gidden, M. J., Lamb, W. F., Nemet, G. F., Minx, J. C., Buck, H., Burke, J., Cox, E., Edwards, M. R., Fuss, S., Johnstone, I., Müller-Hansen, F., Pongratz, J., Probst, B. S., Roe, S., Schenuit, F., Schulte, I., Vaughan, N. E. (eds.) The State of Carbon Dioxide Removal 2024 - 2nd Edition. DOI 10.17605/OSF.IO/F85QJ (2024).
- Fankhauser, S., Smith, S.M., Allen, M. et al. (2022), The meaning of net zero and how to get it right. Nat. Clim. Chang. 12, 15–21.

- Höglund, R., Mitchell-Larson, E. and Delerce, S. (2023), How to avoid carbon removals delaying emissions reductions, Carbon Gap – discussion paper.
- Royal Society and Royal Academy of Engineering (2018), Greenhouse Gas Removal.
- National Academies of Science, Engineering and Medicine (2021), A research strategy for ocean carbon dioxide removal and sequestration.
- UN Environment Programme (2023), Emissions Gap Report 2023: Broken Record, Chapter 7 - The role of carbon dioxide removal in achieving the Paris Agreement's long-term temperature goal.
- Westbury, P., Arlinghaus, A., Bellamy, R., Butnar, I., Cox, E., Fankhauser, S., Gilbert, A., Hepburn, C., House, J., Lynch, J., Martirosian, N., Mouchos, E., Rodway-Dyer, S., Smith, S., Waller, L. and Workman, M. (July 2024), Delivering Greenhouse Gas Removal in the UK: Priorities for the new government, Policy Briefing, CO2RE The Greenhouse Gas Removal Hub.

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