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Carbon Dioxide Removal

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Despite extensive efforts, greenhouse gases continue to be emitted in vast amounts, with potentially devastating consequences around the world. This is why targeted interventions in the climate system, known collectively as ‘climate engineering’, are receiving increased attention. Proposed approaches are often divided into two groups: those intended to remove carbon dioxide from the atmosphere and those intended to reduce the amount of solar energy that reaches the Earth’s surface or is trapped in the atmosphere. There are some similarities between the two classes of activities, but they often raise different physical, political, and governance concerns. This series provides an introduction to each set of approaches.



What is carbon dioxide removal?

Carbon dioxide removal (CDR) refers to a set of proposals for actively removing carbon dioxide from the atmosphere to limit global warming and its effects. Also known as negative emissions technologies, these proposals would, if implemented on a global scale, reduce the rate at which the climate is warming, as well as limiting ocean acidification. The main proposed technologies include afforestation, bio-energy with carbon capture and storage, biochar, direct air capture, enhanced weathering, and ocean fertilisation.

Why is carbon dioxide removal being discussed?

To limit the threat of global warming, at the 2015 United Nations Climate Change Conference in Paris, world leaders agreed to limit temperature rise to well below 2°C above pre-industrial levels. This goal presupposes a peak in global greenhouse gas emissions by around 2020, followed by rapid decarbonisation to net zero emissions and the stabilisation of greenhouse gas levels by the second half of the century. Yet none of the major emitter countries has stringent mitigation incentives or regulations in place that would put it on track to achieving such a drastic transformation of its economy within this timeframe. Given this disparity between the Paris Agreement goals and the societal difficulties anticipated with rapid emissions reductions, it is often assumed in socio-economic scenarios consistent with the 2°C limit that some forms of carbon dioxide removal will be needed to

achieve the goals. Yet it is still unclear whether any of the proposed technologies, or a combination thereof, could be deployed on the scale and within the time-frame required to make a meaningful contribution to achieving the Paris Agreement targets.

What is the state of research?

Natural sciences and engineering

All of the proposed carbon dioxide removal technologies are still in early stages of development. Some exist as prototypes; others have been the subject of small-scale field-experimentation. Yet carbon dioxide removal in quantities that would contribute significantly to the Paris Agreement goals would require infrastructures comparable in scale to the major global carbon dioxide-emitting sectors, i.e. energy, agriculture, mining, and mass manufacturing.

In many cases the individual components of this system – for example, mineral extraction facilities, pipelines, shipping, forestry, crop harvesting and processing – are already in place. However, the establishment of integrated systems, e.g. for direct air capture, followed by the instalment of mass production facilities to enable large-scale deployment is likely to take several decades. Existing research in the natural sciences also points to other uncertainties, including potential changes to marine and terrestrial ecosystems due to the energy, land, and water requirements of the various proposals.

Technology	Brief description
Afforestation	Large-scale planting or replanting of forests
Bioenergy with carbon capture and storage (BECCS)	Burning biomass for energy generation and capturing and geologically storing the resulting CO ₂
Biochar	Biomass burning under low-oxygen conditions (pyrolysis) to produce charcoal, which is then mixed in with soils to increase the soil carbon content
Direct air capture (DAC)	Capturing CO ₂ directly from the ambient air using chemical processes, followed by long-term storage, for example in underground reservoirs
Enhanced weathering	Enhancing natural weathering processes by extracting, grinding, and dispersing reactive minerals on land or the ocean
Ocean fertilisation	Fertilising parts of the ocean with nutrients to increase algal growth and CO ₂ uptake in an attempt to increase the rate at which carbon sinks to the seabed in dead algae and is thus removed from the climate system

Table 1: Summary of technologies for removing atmospheric carbon dioxide (CO₂)

Source: IASS

Social sciences and governance

Socio-economic research has largely focused on two approaches: bioenergy with carbon capture and storage and, to a more limited extent, afforestation and reforestation. This has been supplemented by solicitation of views from public and expert groups.

Researchers highlight the need for further investigations into land-use constraints and other repercussions for crop production, food pricing, and land management and ownership. Other open questions concern the possibility that the promise of carbon dioxide removal could delay or impede immediate and comprehensive mitigation efforts by reducing incentives to switch to renewable energy sources.

Research in the social sciences on direct air capture or marine-based approaches like enhanced weathering is almost non-existent, with assessments generally limited to calculations of costs, energy demand, and technical feasibility.

An exception is ocean iron fertilisation, which has received attention due to 13 scientific field experiments conducted in the 1990s and 2000s, as well as high-profile campaigning and attempted demonstrations in ocean waters by private companies hoping to use ocean iron fertilisation towards earning carbon credits. Besides this, most other social science research has been conducted in the form of case studies that explore more general issues in relation to the development of controversial technologies rather than contemplating the concrete application of carbon dioxide removal technologies.

Future research fields

Further exploration of the environmental and economic implications of deployment is likely to draw on earth systems models, impacts and integrated assessment models, and calculations of investment and infrastructural needs. This will need to be complemented by critical assessments of the assumptions

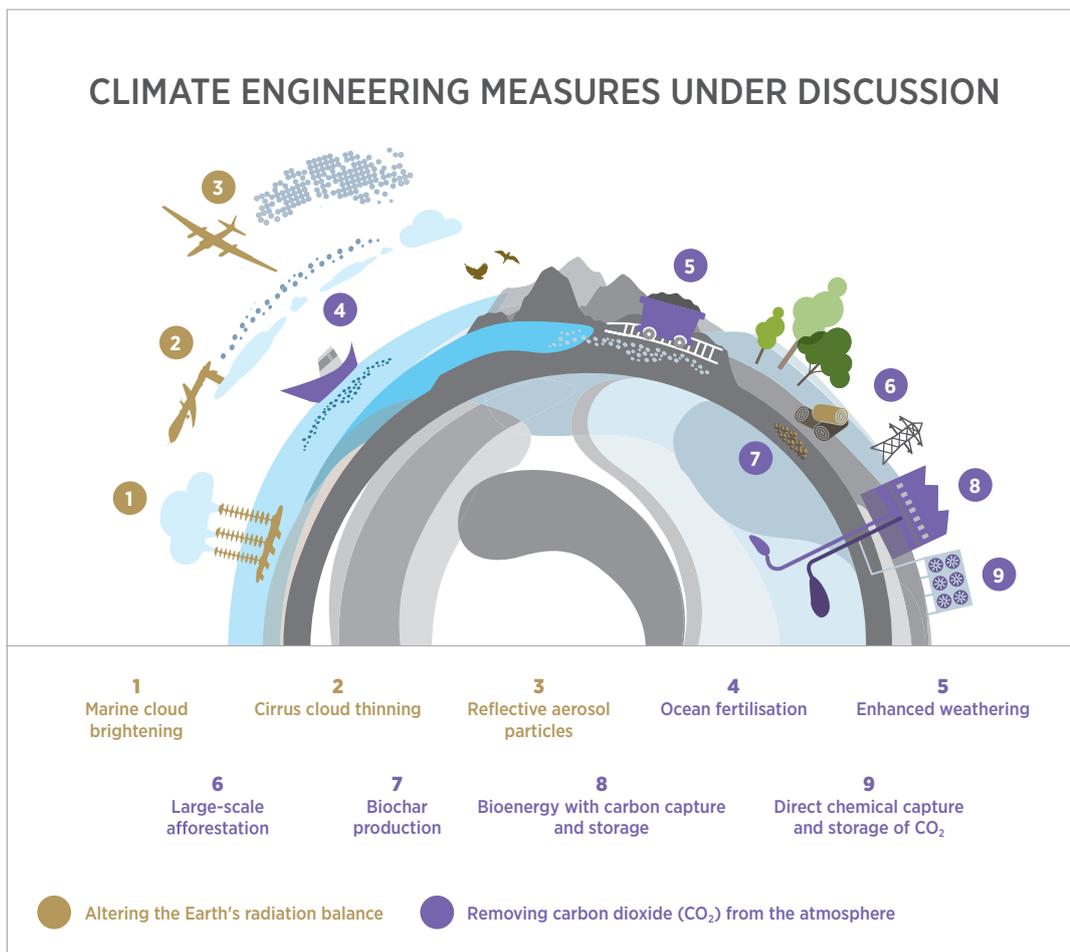


Figure 1: Climate engineering measures can be divided into two groups: those intended to remove atmospheric carbon dioxide and those intended to alter the Earth's solar radiation balance.

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underlying model calculations of large-scale deployment from the perspectives of the different stakeholders that would be affected by each approach. Comparatively more advanced debates on carbon capture and storage, biofuels, and forest carbon projects can also be examined as analogies for many carbon dioxide removal technologies, especially in light of overlaps in technological approaches, risk profiles, and relevant stakeholders.

Are the proposals technically and politically feasible?

While numerous technologies for removing carbon dioxide have been proposed, it is at present unclear whether any individual technology or set of technologies could be deployed on the scale and within the timeframe that is implicitly assumed in scenarios consistent with the 2°C limit. Even if this were possible in principle, the costs – both operational and societal – and the possible risks and benefits beyond climate stabilisation are uncertain. There is, however, a broad scientific consensus that while carbon dioxide removal may complement mitigation efforts, none of the technologies can substitute for them or obviate the need for some adaptation to climate change.

How could carbon dioxide removal be governed?

The large-scale deployment of measures that alter biological processes to remove additional atmospheric carbon dioxide, such as afforestation, ocean fertilisation, or growing biomass for bioenergy with carbon capture and storage is likely to alter local and regional ecosystems. This may have complex effects on human and state security, water availability, food production, biodiversity, and energy. Approaches that are not based on biological processes, such as direct air capture and storage, are expected to have their own governance challenges related in particular to their expected high energy requirements and elevated cost. Although in many cases the governance of carbon dioxide removal activities is likely to fall under national regulatory frameworks, some large-scale approaches may have transboundary effects and could therefore require forms of internationally coordinated governance. In addition, incentivising the effective large-scale deployment of all carbon dioxide removal technologies would probably require the establishment of an international price on carbon.

There are already growing calls for coordinated national and international governance frameworks for research into the associated risks and benefits of the suite of carbon dioxide removal technologies. Such governance could not only ensure that research is conducted safely and transparently, but also help to mobilise the necessary funding for applied research and testing and point science towards policy-relevant research.

Ocean fertilisation has served as an entry point for analyses of international governance. The London Convention and Protocol on Marine Pollution prohibits ocean fertilisation for reasons other than “legitimate” scientific research and provides assessment frameworks for such activities. Although these developments are currently relevant only to marine environment-based approaches, the possibility of them serving as templates for the international governance of a wider raft of technologies has been raised.

Several initiatives are currently examining governance options for research into, and the potential deployment of, a variety of climate engineering approaches. These range from the development of broad guiding principles and more specific codes of conduct to assessments of how existing international and national regulatory mechanisms could apply to research and deployment. However, most efforts in this area have been focussed on solar radiation management, and very little analysis of governance for individual carbon dioxide removal technologies has been carried out to date.

What role could carbon dioxide removal play in achieving the goals of the Paris Agreement?

Recent assessments conclude that a combination of the different carbon dioxide removal technologies could make it possible to stay within the 2°C limit, assuming that large emissions cuts are made at the same time. However, this is at the upper end of what most estimates consider feasible and depends on overcoming numerous challenges, including: technology development, upscaling, infrastructure construction, resource extraction and availability, carbon or carbon dioxide storage site identification and total capacity, earth system and environmental side effects, economic costs, competition for resources such as biomass for fuel and food production, public acceptance, and international cooperation on implementation and governance.

The value of critical global discussions

We are at an early stage in our understanding of the potential role of carbon dioxide removal in climate policy, and in this situation the value of open and critical global discussions on the topic cannot be underestimated. To date, the development of climatic scenarios, technical assessments, and prototypes has not been accompanied by corresponding discussions among policymakers and publics on the societal implications of deploying such

technologies on large scales or on how – and even if – carbon dioxide removal could be incorporated into strategies to achieve the ambitious targets of the Paris Agreement. Models and assessments can provide a basis for collective reflection and discussion, but decision-making on the potential future role of carbon dioxide removal in climate change policy will need to be informed by a variety of perspectives on the means, ends, and challenges of each approach.

SUMMARY

- Interest in carbon dioxide removal has grown due to concerns that emissions reductions strategies might not be enough, or take place too slowly, to keep the climate within the level of warming agreed to in the Paris Agreement.
- Nearly all socioeconomic scenarios consistent with achieving the Paris Agreement goals rely heavily on some kind of carbon dioxide removal deployment.
- The state of research and potential readiness varies greatly from one technology to the next. It is at present unclear whether any individual technology or set of technologies could be technically and politically feasible on large scales.
- Key uncertainties revolve around the capacity of sinks to safely sequester carbon, the likelihood of conflicts over land use for agriculture or biodiversity preservation, ecosystem impacts, and the question as to whether the development of carbon dioxide removal technologies may reduce incentives to switch to renewable energies.
- In addition to extensive further research, broad societal engagement will be required to establish whether research on and the possible implementation of carbon dioxide removal technologies are consistent with broad societal norms.

Institute for Advanced Sustainability Studies Potsdam (IASS) e. V.

The Institute for Advanced Sustainability Studies (IASS) conducts research with the goal of identifying, advancing, and guiding transformation processes towards sustainable societies in Germany and abroad. Its research practice is transdisciplinary, transformative, and co-creative.

The institute cooperates with partners in academia, political institutions, administrations, civil society, and the business community to understand sustainability challenges and generate potential solutions. A strong network of national and international partners supports the work of the institute. Among its central research topics are the energy transition, emerging technologies, climate change, air quality, systemic risks, governance and participation, and cultures of transformation. The IASS is funded by the research ministries of the Federal Government of Germany and the State of Brandenburg.

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