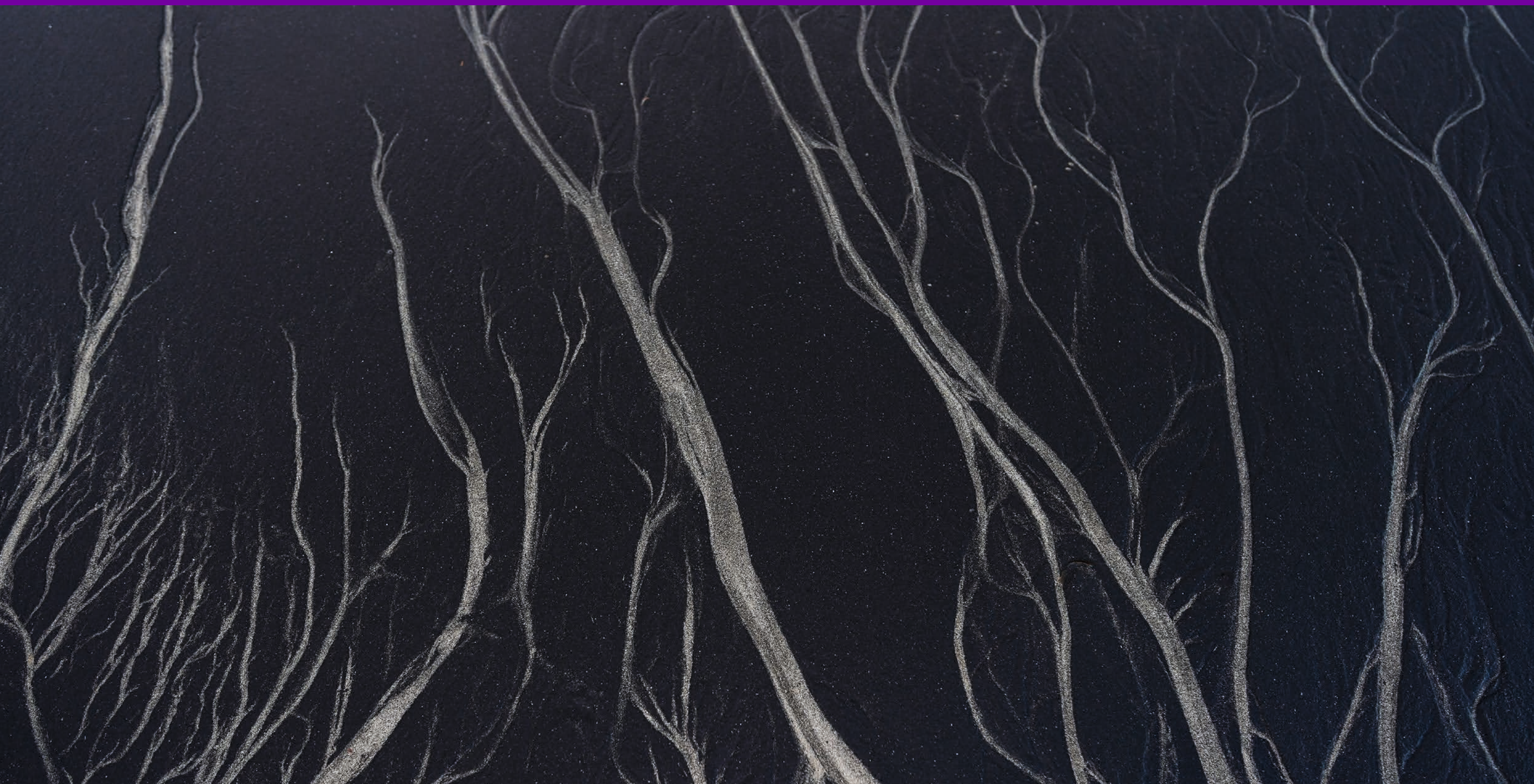
4 Ocean-based CDR – research under massive expectations

> In the search for ways out of the climate crisis, attention is increasingly focused on ocean-based methods to boost the removal of CO_2 from the atmosphere. However, much of the knowledge about the potentialities, feasibility and impacts of ocean-based CO_2 removal (CDR) is theoretical. Marine research is now expected to deliver solutions as swiftly as possible, but faces criticism, as well as competition from businesses whose primary goal is to generate revenue from ocean-based CDR.



An ocean of opportunity – or harmful hype?

> Climate change is inflicting ever more loss and damage around the globe – and while policy-makers and businesses seek ways to reduce emissions, they are still reluctant to take radical action. New research on ocean-based CDR now faces a challenge: it must develop a comprehensive approach to this multi-faceted topic as swiftly as possible. But can this be achieved without commercial interests coming to the fore? A code of conduct will be needed to avert unwanted developments.

A tension-filled research area

Although policy-makers and scientists have been discussing the potential and feasibility of land-based CDR for more than 15 years, the notion that the ocean may also offer opportunities for targeted action to mitigate climate change has only recently gained traction. While scientific experiments on ocean fertilization were already being conducted in the late 1990s and early 2000s, research on ocean-based CDR methods was not scaled up until after the signing of the Paris Agreement in December 2015.

Critics attribute this development to the fact that land-based climate intervention approaches are increasingly encountering practical obstacles (land-use competition, local protests, etc.) and are therefore viewed with growing scepticism by society at large. Putting it bluntly, these land-based interventions are practically impossible to push through at the political level, or require major effort. Interventions at sea, by contrast, are less likely to encounter opposition from the public – at least, that is the hope; this applies particularly to techniques that support natural processes of carbon capture and storage. Critics also note that shifting the climate policy focus towards the ocean fits into the "blue economy" narrative which claims that the limits to land-based resources and development can be circumvented in future by upscaling the extraction of food, raw materials and energy from the sea. Arguably, the expansion of fish farming in marine aquaculture is evidence of this trend, as are the moves to commence deep-sea mining.

Weighing far more heavily, however, is the claim that the entire debate about CDR is merely a stalling exercise that shifts genuine, life-changing emission reduction measures into the future, invariably on the grounds that technical options for regulating atmospheric carbon dioxide concentrations will be available one day in any case. Critics therefore claim that the political debate about CDR is nothing more than climate policy hype backed by a raft of empty promises.

In response, others argue that the increasingly dramatic impacts of climate change amplify the urgent need for effective climate change mitigation actions, and so ocean-based carbon dioxide removal methods can no longer be dismissed out of hand. However, they point out that there is an equally urgent need to close the numerous knowledge and regulatory gaps in this area: most ocean-based CDR methods – other than the restoration of devastated coastal ecosystems – are comparatively new. As they have rarely been tested, there is a general absence of detailed data on their effectiveness, potential costs, risks and impacts on the environment and society. Critics also point to the legal aspect: it is already clear that the existing international conventions and national legislation pertaining to marine governance are inadequate as they can neither safeguard the reliability and transparency of research on ocean-based CDR nor properly regulate its use on an industrial scale.

Ocean fertilization

Phytoplankton need nutrients such as iron, nitrogen and phosphorus compounds in order to grow. However, there is a deficit of these nutrients in many ocean regions. Scientists have therefore developed the concept of ocean fertilization; this involves seeding the ocean's surface with iron to encourage phytoplankton growth. In theory, more phytoplankton would remove more carbon dioxide from the atmosphere and convert it into carbohydrate, which would then sink into the deeper ocean. Thirteen research experiments conducted at sea confirm that increased nutrient input does indeed lead to more phytoplankton growth. However, the scientists have been unable to find firm evidence of increased carbohydrate transport into the deeper ocean. What's more, there is still a lack of comprehensive data on the potential risks of ocean fertilization and its impacts on humans and nature.

For that reason, a regulatory mechanism was established to prohibit ocean fertilization for commercial purposes (e.g. sale of emissions allowances) in international waters, although it is still permitted for research. This regulatory mechanism is based on an amendment to the 1996 London Protocol, which updates and is intended to replace the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (London Convention) in the long term. However, as only six countries have ratified the new version of the London Protocol thus far, it has not yet entered into force under international law.

4.1 > The international climate change conferences, which are held annually, look at which specific climate change mitigation actions are being planned and implemented by individual countries. Scientists are under growing pressure to identify carbon dioxide removal techniques that are particularly effective, equitable and sustainable.

Investors – the main drivers of research

For these reasons, and despite all the criticism, the number of research projects on ocean-based carbon dioxide removal is steadily growing. US investors are a driving force here: they have a commercial interest in ocean interventions for climate change mitigation and are willing to commission studies on this topic. The first research project funded by the German government to identify the most promising ocean-based carbon dioxide removal methods began in August 2021. At EU level, selected ocean-based CDR processes have been investigated in joint studies involving various research institutes since 2020, again with public funding.

The data gathered so far, however, do not provide an adequate basis for a comprehensive assessment of key factors such as carbon dioxide storage potential, technical feasibility and effectiveness, or of the costs, risks and possible positive impacts of these techniques. There is thus a concern among specialists and environmental activists that the intense pressure to take action, combined with burgeoning economic interests, could prompt decision-makers to endorse the use of ocean-based CDR before the numerous knowledge gaps have been closed. Furthermore, if research studies are commissioned and funded by companies, the possibility that investors will seek to influence the interpretation and assessment of the collected data cannot be ruled out.

A code of conduct for climate intervention research

Leading scientists in the US have therefore drafted a code of conduct to guide research on ocean- and land-based CDR. It consists of five key points which, the experts say, should be adopted and implemented as an ethical framework for any research project in this field. These five key points are:

- *Prioritize collective benefit:* The collective benefit to humankind and the environment must be the primary purpose of research conducted to develop and evaluate the potential for climate intervention technologies to moderate or reverse human-induced climate change.
- *Establish responsibility:* Governments and public agencies must clarify responsibilities for and, when necessary, create new mechanisms to govern and oversee large-scale climate intervention research activities that have the potential or intent to significantly modify the environment or affect society. These mechanisms should build upon and expand existing structures and norms for governing scientific research and, in the event of damaging outcomes, establish who would bear the cost.
- *Commit to open and cooperative research:* Research should be conducted openly and cooperatively, preferably within a framework that has broad international support. Research activities with the potential to affect the environment in significant ways should be subject to risk assessment, considering the risks and their distribution associated with both the activity itself and the ongoing limits to understanding if the experiment is not conducted.
- *Perform evaluation and assessment:* Iterative, independent technical assessments of research progress on climate intervention approaches will be required to meet societal goals. Assessing any intended and unintended consequences, impacts and risks will be critical to providing policy-makers and the public with the information needed to evaluate the potential for climate interventions to be implemented.
- *Engage the public:* Public participation and consultation in research planning and assessments, and in the development of decision-making mechanisms and processes, must be enabled to ensure consideration of the international and intergenerational implications of climate intervention strategies and activities.

4.2 > A diver collects research samples at a macroalgae farm off the East Coast of the United States. Scientists are attempting to identify species of macroalgae that are fast-growing, hardy and resilient.

For opponents of ocean-based CDR, this code of conduct is inadequate. They reject further human interventions in the ocean as a matter of principle and point to climate change, overfishing and marine pollution as indications that there has already been too much human interference in the marine environment.

In view of the predictable controversy surrounding the pros and cons of ocean-based climate intervention technologies, researchers are working to systematize the multiple issues and apply an integrated, trans- and interdisciplinary approach to research on this complex topic. In addition to the technological, environmental, economic, legal and regulatory aspects, a key question arising in this context is whether a national population or region affected by such measures would actually consent to and support relevant interventions aimed at offsetting residual emissions.

It is already clear that small-scale actions will not be sufficient to effectively halt climate change. If the ocean is to make a significant contribution to offsetting residual emissions (for reaching the 1.5-degree target: 420 to 1100 billion tonnes of carbon dioxide), a new carbon dioxide removal industry will need to be established and the appearance of the landscape in affected marine and coastal regions will change accordingly. In other words, using ocean-based CDR for effective offsetting of residual emissions will require massive intervention in the ocean's natural processes – across large areas and for a long time.

Many parallels and additional challenges

A comparison of land- and ocean-based climate intervention technologies reveals numerous parallels between them. In both spheres, experts distinguish between biological, chemical and geochemical CDR methods, with hybrid forms also possible. The key processes are similar as well. In essence, the restoration and expansion of vegetation-rich coastal ecosystems such as mangrove forests, salt marshes and seagrass beds are mirror images of land-based methods for the (re)forestation and restoration of carbon-rich woodlands, wetlands and grasslands. Techniques to boost the alkalinity of seawater are based on accelerated weathering of rock, while processes which involve large-scale algaculture for bioenergy production require a carbon capture and storage (CCS) component, analogous to BECCS.

However, the ocean poses a particular challenge: its sheer size, global currents and complex systemic interactions make it difficult to measure how much carbon dioxide it can naturally capture and store, and for how long. If ocean-based CDR is to be deployed, other challenges will arise: measuring and verifying the additional human-induced carbon dioxide that is captured, attributing it to specific processes or actions, and monitoring the duration of storage, as well as assessing the potential environmental impacts of each individual measure over long periods of time. How will this work? This is a key question for research, given that properly functioning and, ideally, standardized measuring and monitoring systems do not exist for most CDR methods at present.

The same applies to solutions aimed at limiting any potentially negative impacts of specific CDR methods to a small area of the sea. As the currents form a connecting link between all the ocean regions, the possibility that CDR interventions in a country's coastal waters may ultimately impact on areas thousands of kilometres away cannot be ruled out.

A wide range of ocean-based CDR methods are currently being researched. Most rely either on marine biology – in other words, the conversion of carbon dioxide into biomass by photosynthesis and storage of this biomass in the deep ocean – or on chemical and physical processes in which more carbon dioxide is dissolved in surface waters and then transported to greater depths by the ocean currents.

The carbon dioxide removal techniques discussed most frequently or intensively by scientists and climate policy-makers are described in the following pages. This overview looks at how each method works, its potential to store carbon dioxide and for how long, its technological development status, and whether it offers scope for upscaling. It also includes a cost-effectiveness analysis, identifies the benefits and disbenefits for people and nature, if known, and outlines the key social, legal and political frameworks.