

Marine Carbon Dioxide Removal (mCDR) research

At Plymouth Marine Laboratory



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There is growing interest in carbon dioxide removal (CDR), both on land and in the ocean, driven by increasing urgency to act on climate change. As a result, there has been a surge in discussion around CDR, including which technologies may be required; how CDR efficacy can be monitored and verified; potential environmental impacts; funding and financing considerations; and the ethical implications of manipulating natural systems at the scales required. A number of institutes, organisations and groups have released statements outlining their positions and proposing roadmaps for progress in this area.

It is within this context that Plymouth Marine Laboratory (PML) defines its role in engaging with marine CDR. Here, PML outlines what marine CDR is, why it is being considered, and the scientific challenges it presents, including PML's role in providing scientific evidence and guidance on what responsible research should look like moving forward.

What is marine Carbon Dioxide Removal (CDR)?

The IPCC defines CDR as:

"Anthropogenic activities removing CO₂ from the atmosphere and durably storing it in geological, terrestrial, or ocean reservoirs, or in products. It includes existing and potential anthropogenic enhancement of biological or geochemical sinks and direct air carbon capture and storage, but excludes natural CO₂ uptake not directly caused by human activities."

Marine CDR (mCDR), sometimes referred to as ocean-based CDR (oCDR), describes CDR activities that take place in the ocean or aim to enhance the ocean's carbon sink.

There is sometimes confusion between mCDR and Blue Carbon, which the IPCC defines as:

"The carbon captured by living organisms in coastal (e.g. mangroves, salt marshes, seagrasses) and marine ecosystems, and stored in biomass and sediments."

In some instances, there is overlap between these concepts. However, Blue Carbon activities typically focus on the restoration or preservation of natural systems, often delivering co-benefits such as biodiversity enhancement, rather than the intentional anthropogenic enhancement of carbon removal processes that characterise CDR.

Why is mCDR being considered?

mCDR is being explored by some governments and sectors as a possible mechanism for removing CO₂ from the atmosphere. The IPCC has stated that, to meet the Paris Agreement goal of limiting global warming to *“well below 2°C, with efforts to limit warming to 1.5°C”*, global society must reach net-zero carbon emissions by around 2050, followed by net-negative emissions for the remainder of the century.

The scale of this challenge is immense, potentially requiring the removal of up to 12 billion tonnes of CO₂ per year – equivalent to more than 25% of current global emissions. Evidence shows that emissions reductions must remain the primary means of achieving climate targets, followed by the protection and enhancement of natural sinks, with CDR playing an unavoidable but secondary role.

The ocean currently absorbs around 25% of anthropogenic CO₂ emissions each year and contains approximately 150 times more carbon than the atmosphere, due to a combination of physical, chemical, biological and microbial carbon pumps. Covering around 70% of the Earth’s surface, the ocean therefore has considerable theoretical potential to contribute to CDR at scale. mCDR approaches aim to manipulate or enhance these natural processes to increase carbon uptake and long-term storage.

mCDR techniques include (definitions adapted from the National Academies report on mCDR)

- **Nutrient fertilisation**
The addition of micronutrients (e.g. iron) and/or macronutrients (e.g. nitrogen or phosphorus) to surface waters to stimulate phytoplankton growth, increasing CO₂ uptake and export of organic carbon to the deep ocean, where it may be stored for decades to centuries.
- **Ocean Alkalinity Enhancement (OAE)**
The chemical alteration of seawater through the addition of alkalinity, via processes such as enhanced mineral weathering or electrochemical reactions, to increase the ocean’s capacity to absorb and store CO₂.
- **Electrochemical ocean CDR / Direct Ocean Carbon Capture and Storage (DOCCS)**
CO₂ removal through electrochemical manipulation of seawater chemistry within controlled systems, capturing released CO₂ for geological storage and returning low-carbon water to the ocean to enhance CO₂ uptake.
- **Seaweed cultivation and sinking**
The production of macrophyte biomass through photosynthesis, followed by transport of this carbon to long-term reservoirs such as deep waters or sediments.
- **Artificial upwelling and downwelling**
The mechanical transport of water between depth layers to influence nutrient supply, carbon export, or oxygenation. These techniques have been proposed both for enhanced carbon uptake and for mitigating coastal hypoxia.

PML rising to the scientific challenge of mCDR

PML is committed to providing independent scientific insight into all aspects of human interaction with the marine environment, including mCDR, in support of a healthy and sustainable ocean. We have a strong track record in relevant areas and are well positioned to contribute scientific knowledge and advice.

Our expertise includes ocean carbon biogeochemical observations, fine-scale and regional modelling, development of monitoring, reporting and verification (MRV) frameworks, environmental impact assessment, ocean acidification research, socio-economic analysis, and field trials related to OAE and DOCCS. This positions PML to advise on the balance between the potential role of CDR and the need to safeguard the marine environment.

PML makes a clear distinction between **research activities** – trials and tests designed to assess efficacy, impacts and MRV methods – and **operational CDR**, which may seek to deliver commercial carbon removal or offsetting. While early-stage research may require proportionate MRV approaches, field trials must demonstrate, at a minimum:

- A theoretically robust CO₂ uptake potential
- Extremely low risk of environmental disruption, or adherence to an appropriate governance framework

PML applies a phased and gated research approach, progressing from laboratory experiments to mesocosm studies and carefully controlled field trials, supported throughout by numerical modelling. Decision gates are applied at each stage. Reducing uncertainty and informing risk mitigation are core scientific objectives, particularly given the inherent complexity of CDR techniques.

Key scientific questions that must be addressed before deployment at scale

- Does the technique deliver long-term (century-scale or longer) carbon storage with sufficient certainty and at a scale relevant to climate mitigation?
- Can storage and efficacy be monitored or modelled over long timescales to enable robust verification?
- What is the net radiative forcing impact, including emissions of non-CO₂ greenhouse gases (e.g. methane or nitrous oxide)?
- What are the environmental impacts and potential co-benefits?
- What are the impacts and co-benefits for humans and society?
- Does whole-life-cycle assessment support a conclusion of net carbon removal?

Technique-specific considerations include, for example:

- **OAE:** ecological impacts of mineral addition, metal toxicity risks, material sourcing and scalability
- **Nutrient fertilisation:** permanence of storage and impacts on oxygen, acidification and non-CO₂ greenhouse gases
- **Seaweed cultivation:** permanence versus redistribution of carbon, and downstream biogeochemical effects
- **Artificial upwelling/downwelling:** long-term storage capability and impacts on oxygen and greenhouse gas production

PML's position

PML supports mCDR research that is:

- Open, transparent and independent
- Inclusive of a broad range of stakeholders, particularly local communities, alongside regulators, policymakers and operators
- Underpinned by rigorous, standardised MRV
- Multidisciplinary, addressing whole-system impacts
- International, contributing to consistent regulation and best practice
- Focused on producing robust evidence to inform any future decisions on deployment at scale