BUILDING A RESEARCH AND INNOVATION FRAMEWORK FOR MARINE CARBON DIOXIDE REMOVAL IN EUROPE

CARBON GAP RESPONSE TO THE EUROPEAN COMMISSION CALL FOR EVIDENCE ON THE EUROPEAN OCEAN AND WATER RESEARCH AND INNOVATION STRATEGY

Key recommendations

To ensure the European Ocean and Water Research and Innovation Strategy supports the development of robust, safe and effective marine carbon dioxide removal methods, the strategy should:

1. Adopt a dedicated research and innovation agenda for marine carbon dioxide removal.

- Develop an EU mCDR research roadmap prioritising the most pressing knowledge gaps.
- Dedicate sufficient funding for mCDR through FP10 and the European Competitiveness Fund. Approximately **€2.6 billion** in R&I support will be needed across the wider CDR portfolio, of which a meaningful share should support mCDR.
- Generate the evidence base required to unlock robust and safe CRCF certification.

2. Ensure coordination with broader ocean governance

- Align the Strategy with the Ocean Act so that scientific progress is accompanied by clear governance principles, permitting pathways, and safeguards.
- Integrate mCDR data and monitoring needs into the European Ocean Observation System and the OceanEye.

GENERAL ASSESSMENT

According to the IPCC, achieving climate goals will require **4000–8000 $MtCO_2$ of removals annually by 2050**. The European Commission's Impact Assessment for the 2040 target similarly indicates that around **400 $MtCO_2$** will need to be removed annually, including **75 $MtCO_2$ from permanent CDR**. At the same time, CDR represents a significant economic opportunity, with the potential to become a **€220 billion annual market and creating 670,000 jobs in Europe**.

The ocean is an important climate regulator, and currently absorbs about 25% of anthropogenic CO_2 emissions each year through air-sea exchange at its surface and uptake by photosynthetic organisms. This natural capacity to buffer some of global warming's impacts can be enhanced via human intervention by increasing the ocean's ability to take in and store carbon in its waters and sediments, methods collectively known as **marine carbon dioxide removal (mCDR).**

Marine CDR has certain advantages over land-based methods due to the ocean's enormous surface area and massive biogeochemical potential. MCDR is a good complement to land-based methods because it can help reduce land-use conflicts and lessen dependence on limited geological CO_2 storage. These advantages mean that large-scale marine CDR could be a game-changer for keeping 1.5 °C within reach and a critical pillar of the EU's carbon removal strategy.

Although many mCDR techniques show promise, most are still very new. Scientists agree that we need more research into their storage potential, monitoring best-practices, and environmental and social risks, and bringing the technologies out of the lab and into open-ocean field trials to test real-world conditions. Europe is particularly well placed to lead on marine CDR, given its favourable geography, strong research base, and existing maritime infrastructure. But realising this potential will require a coordinated research effort to address the open questions, close the policy gaps, build robust monitoring, and supercharge innovation.

Currently, the EU faces two main risks when it comes to marine CDR:

1. **Inaction:** the development of mCDR should not be indefinitely delayed. Outstanding scientific and policy questions must be actively researched, and field tests are needed to either prove or disprove the various mCDR approaches.

2. **Rushing ahead:** most mCDR approaches still involve significant uncertainties, while public awareness and acceptance of these methods remain low. This calls for a cautious, stepwise approach grounded in robust scientific evidence and strong environmental safeguards.

Europe's challenge is to balance these two risks: ensuring that sufficient efforts are made to advance knowledge and determine which mCDR approaches have the most potential to contribute to climate goals, while maintaining high and robust environmental standards.

With the European Ocean and Water R&I Strategy and a new EU budget and Framework Programme for R&I on the way, the EU has a one-in-a-seven year opportunity to invest in ocean research and innovation. This includes the research needed to either approve or disprove the potential of innovative ocean technologies such as marine carbon removal.

Carbon Gap estimates that approximately **€2.6 billion** in research and innovation support will be needed across the wider CDR portfolio to prepare promising methods for scale-up in time to help Europe reach net zero by 2050 and net-negative emissions thereafter. A meaningful share of this investment should be dedicated to advancing marine CDR.

Carbon Gap recommends that the European Ocean and Water R&I Strategy prioritises two areas:

1. Adopt a clear mCDR research agenda

Scientific questions remain open for mCDR, including regarding environmental impacts, MRV, permanence, and scalability. EU research and innovation funding remains **fragmented and insufficient** to address these challenges in a timely manner. Without a more coordinated R&I framework, the EU risks falling behind in generating the evidence base needed to develop these methods.

This is particularly relevant in the context of the Carbon Removal and Carbon Farming Regulation (CRCF). In 2025, the Commission started evaluating the possibility of developing certification methodologies for marine CDR methods, such as Ocean Alkalinity Enhancement (OAE) and Direct Ocean Carbon Capture and Storage (DOCCS), alongside closely related methods, such as Enhanced Rock Weathering and Mineral Carbonation. This evaluation was accompanied by the publication of technical scoping papers that examine the state of the science.

The Ocean and Water R&I strategy could support the development of a dedicated marine CDR research and innovation roadmap, leveraging the upcoming tenth Framework Programme for R&I (FP10), and formulating recommendations for national funding schemes,

with clear milestones linked to unlocking robust certification schemes MRV under the CRCF. This would help ensure that policy, science, and funding evolve in a coordinated and mutually reinforcing way.

The research roadmap must ensure four things:

1. **Define the key research gaps** that remain for each mCDR method, and how they should be addressed across the time horizon.
2. **Direct sufficient funding** towards answering the most pressing questions.
3. Provide a guide that can **align research priorities** across the ecosystem. EU funds alone will not answer all the open questions.
4. **Mobilise private investment** by de-risking the transition from laboratory research to controlled field trials and demonstration. A clear research agenda, supported by Horizon Europe and the European Competitiveness Fund, can help close this critical funding gap and coordinate efforts across the ecosystem.

The following is a (non-exhaustive) list of research and innovation priorities focused around OAE and DOCCS given the Commission's process on the CRCF, but note that the majority of these questions are cross-cutting to the rest of the family of mCDR methods. This list lays out the questions that remain open and that could unlock full certification under the CRCF if addressed timely and properly. The list is the result of Carbon Gap's analysis and the input of the European Marine CDR Working Group chaired by Carbon Gap, composed of 32 organisations ranging from civil society, to companies, to academics and the scientific community. For access to the full database, please visit this link.

Table 1: Research priorities for Ocean Alkalinity Enhancement & Direct Ocean Capture

Knowledge gap	Objectives
Quantification	
Improve quantification of ocean carbon removals and develop reliable, standardised and transparent MRV systems for mCDR, including reducing uncertainty in key processes such as air–sea CO_2 flux and validating models through coordinated in-situ measurements.	Improve models and measurements options to bring the uncertainty in predicting and measuring the CO2 uptake by alkalinity enriched or CO2 depleted waters, down to levels compatible with the Q.U.A.L.I.T.Y criteria for certification under the Carbon Removal Carbon Farming (CRCF) regulation.

Improve understanding and quantification of processes affecting OAE/DOCCS efficiency, including mineral dissolution, secondary precipitation and carbonate system responses.	Increase understanding and prediction power (to levels of precision relevant to certification) on the impacts of chemistry alteration on the efficiency of the CDR process in a variety of conditions.
Develop methodologies to define baselines reflecting local specificities while preserving comparability, and evaluate implications in terms of the need for regular independent ocean monitoring systems.	Enable robust and comparable quantification of additional carbon removal by establishing fit-for-purpose baselines that account for local variability and support certification requirements.
Determine the sensitivity of project level removals calculation to assumed atmospheric CO2 concentrations and develop best practices for certification frameworks where expected and observed concentrations mismatch.	Reduce uncertainty in credit issuance by establishing how certification frameworks account for variability in modelled CO_2 removal linked to atmospheric CO_2 changes.
Understand and quantify potential indirect impacts on biogeochemical cycles that could result in reversals or reduction in natural uptake of atmospheric CO2.	Define conditions in which the implementation of OAE could indirectly tamper with natural biogeochemical processes (including in remote areas) and result in reduced natural uptake of CO2 or reversals.
Sustainability	
Evaluate benefits beyond carbon of OAE and DOCCS on ecosystems (e.g., mitigating acidity, fertilization) and document conditions required for those benefits to materialize at significant levels.	Provide an evidence base to determine when and where ecosystem co-benefits of OAE and DOCCS are significant and can be credibly considered in deployment and certification.
Evaluate negative impacts of OAE and DOCCS on ecosystems (e.g. toxicity, reduced productivity due to altered conditions, and mechanical effects such as impingement/entrainment or burial) and document conditions required for those impacts to remain below significance.	-Characterize and quantify impacts of OAE on ecosystems — both chemical/toxicological and mechanical/physical — under conditions relevant to ongoing and planned field trials. -Define safe thresholds (compared to baseline) for variables like pH, alkalinity, turbidity, and heavy metal concentrations.
Governance & local impacts	
Develop coherent governance and legal frameworks for mCDR research and deployment	Provide legal clarity and governance coherence to support responsible mCDR research and deployment across international, EU, national, and regional levels.
Codify appropriate use cases and associated liability mechanisms for carbon removal certificates according to method maturity level.	Develop standardised, science-based practice for registries to differentiate how carbon removal certificates from lower-maturity methods (such as OAE and DOCCS) may be used, and to define the liability mechanisms associated with each use case, so that certification reflects the uncertainty in a method's efficiency and permanence.

A clear research agenda would direct limited resources towards the most pressing open questions and determine whether — and under what conditions — the potential of mCDR methods can be realised. By aligning priorities and clarifying the pathway from laboratory research to demonstration, it would accelerate progress, improve coordination, and provide greater certainty for funders and investors. It would also generate the evidence base and MRV approaches needed to unlock certification under the CRCF.

2. Ensure coordination with broader ocean governance

Marine CDR sits across different legislations: biodiversity, marine and climate. If innovation policy is to be effective for emerging technologies such as mCDR, it cannot work in isolation of the rest of the ocean governance, especially in the midst of numerous ocean initiatives such as the upcoming Ocean Act and the OceanEye initiative which tackle key barriers for marine removals.

For example, robust ocean observation and monitoring systems are a prerequisite for any responsible approach to mCDR. Robust monitoring, reporting and verification (MRV) remains a challenge, and without it, mCDR cannot be credibly integrated into EU climate targets or markets.

The European Ocean Observation System and the newly announced OceanEye are therefore highly relevant for mCDR. They must ensure that emerging climate-relevant uses of the ocean, including mCDR, are explicitly considered within ocean observation governance. This includes supporting the data collection, modelling, and monitoring capacities needed to inform and support the development of methodologies under the Carbon Removal Carbon Farming Regulation (CRCF).

The Ocean Act on the other hand needs to address the need for a dedicated EU mCDR strategy that explicitly covers both nature-based and engineered approaches, while ensuring alignment with biodiversity protection, marine environmental objectives, and climate targets. Such a strategy would help reduce fragmentation, clarify responsibilities, and provide a coherent framework for responsible research, assessment, and potential future deployment.

In addition, there is currently limited legal clarity at EU level regarding engineered mCDR approaches. Existing international frameworks only partially address these activities, and no

comprehensive EU regulation sets out how such methods may be researched, assessed, or, if proven safe and effective, deployed responsibly. Ecosystem restoration and blue carbon frameworks tend to favour nature-based solutions, while marine protection, waste, and anti-dumping rules can create barriers for permitting research pilots and demonstration projects involving engineered methods. The Ocean Act offers an opportunity to provide EU-level clarity on governance principles, permitting pathways, and safeguards, grounded in precaution, scientific evidence, and transparency.

The Ocean Act and the Ocean R&I Strategy are two sides of the same coin and must be designed in tandem: the R&I Strategy must generate the evidence base that advances mCDR methods, while the Ocean Act must provide legal clarity and governance coherence. Neither delivers on its own. Aligned in turn with ocean observation initiatives such as the OceanEye, they would ensure that scientific evidence, monitoring capacity, and legal frameworks develop together, reducing fragmentation and establishing a credible basis for responsible research, assessment, and any future deployment.

CONCLUSION

The European Ocean and Water R&I Strategy represents a timely opportunity to establish a coherent framework for advancing mCDR research in Europe. By prioritising a coordinated research agenda and ensuring alignment with broader ocean governance, the Strategy can generate the evidence needed to determine which mCDR approaches can contribute safely and effectively to Europe's climate objectives.

A precautionary approach should not mean inaction. Through sustained investment in research, monitoring and governance, the EU can reduce scientific uncertainty, uphold high environmental standards, and position Europe to lead the responsible development of marine carbon dioxide removal where it proves safe, effective and societally beneficial.

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