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Recommendations for Responsible Assessment of Engineered Marine Carbon Dioxide Removal Approaches

The world urgently needs effective and safe climate solutions that prioritize deep emission cuts to meet global climate targets and investment in adaptation and building resilience. However, achieving the climate targets at the heart of the Paris Agreement will likely require 7 to 9 gigatons of CO_2 removal (CDR) annually by mid-century[1]. Global CDR currently totals only 2 gigatons per year, mostly through conventional land-based methods like planting trees. Global annual greenhouse gas emissions reached a high of over 57 gigatons of CO_2 released in 2023[2]. Engineered marine carbon dioxide removal (mCDR) approaches[3] are being advanced as potential ways to address the gap in CDR needs, but these approaches remain at early stages of development. While mCDR could play a role in addressing the climate crisis, its effectiveness and safety are not yet established and require rigorous, transparent, and well-governed research. Funding for this research is key, but it is critically important that we should not divert significant funds from the climate finance sector that is scaling proven and available solutions – mCDR funding should be additive. mCDR approaches vary widely in their mechanisms, scales, and potential impacts, and existing evidence is insufficient to determine whether any can reliably deliver durable climate mitigation benefits without unacceptable risks to marine ecosystems, coastal communities, and ocean-dependent livelihoods.

> **Without strong, scientific evidence generated in a well-regulated environment, policymakers and communities cannot judge whether mCDR approaches can contribute meaningfully to climate mitigation goals and protect ecosystems and people.**

Gathering the needed evidence will require field trials during the research and development process, as modeling efforts are not solely sufficient. Existing modeling capabilities are insufficient to test all assumptions and variables, and models require data for parameterization and to test and validate assumptions. Field trials require robust and effective governance including processes for evaluation, decision-making, environmental liability, and input from interested parties, which are critical for balancing the risks and opportunities. As commercial momentum in the field builds, governance and oversight of the research needed becomes even more critical to ensure key gaps and concerns are addressed.

Premature deployment could undermine ocean health, public trust, and climate integrity, while also crowding out or deterring proven emissions reduction solutions. Failure to build public trust during field research and experiments could undermine results and slow or halt critical areas of mCDR research.

While we expect that any field experiment will, at minimum, be subject to applicable permitting processes, the following principles outline what a rigorous regulatory process should entail to ensure responsible field research and where companies should be voluntarily taking action to fill the gap. A more comprehensive application of these considerations across the board, whether it be through funding requirements and/or more robust governance mechanisms, will help ensure that the field moves forward and scales in a responsible manner. For these reasons, building upon previous work,[4] we recommend the following principles and safeguards to guide research, oversight, and decision-making so that any consideration of mCDR proceeds responsibly, transparently, and in public interest.

Recommendations for mCDR field experiments

Consultation and Ethical Approaches

1. **Adhere to existing ethical codes of conduct.** Companies, funders, and researchers conducting field experiments should voluntarily adopt a guiding code of conduct, such as the one developed by the American Geophysical Union, *Ethical Framework for Climate Intervention*[5] or by the Aspen Institute, *A Code of Conduct for Marine Carbon Dioxide Removal Research*[6], which focuses on ensuring that "decisions regarding whether, when, where, and how to conduct mCDR research are informed by relevant ethical, scientific, economic, environmental, and regulatory considerations." Such codes of conduct purposefully garnered diverse expert perspectives to establish robust principles underlying their guidelines.

2. **Protect the rights of Indigenous Peoples, local communities, and fisherfolk.** Regulators should ensure access to information, benefit-sharing, fair and equitable participation in designing experiments and activities, decision-making, and adherence to environmental justice principles. Adherence to Free, Prior, and Informed Consent principles should be prioritized[7]. Potentially affected communities have an ethical and/or legal right to assess and refuse projects that they deem unwanted or too risky. Governments should require robust consultation and impact assessment along the path to field trial permitting and deployment to reinforce protections for potentially impacted parties.

3. **Ensure research efforts around the globe include appropriate local experts and ensure local perspectives genuinely inform decisions. Companies**, researchers, and research teams should include experts—natural scientists, social scientists, Indigenous and local knowledge holders—to inform planning and any implementation throughout the marine and coastal areas where work is proposed. Importantly, these partners should be invited to and fully included as codevelopers in discussions early and often and compensated at a rate commensurate with other project partners providing expertise.

Responsible Field Experiments

4. **Demonstrate low environmental and social risks.** Regulators should carefully assess the risks involved in field experiments, taking into account internationally agreed [to] frameworks or guidelines, feedback from public consultations, and any impacts of markets and incentives.

5. **Prioritize low-risk projects with the highest potential climate benefits, and all projects should provide clear mitigation measures as needed.** Any potential harmful impacts to marine and coastal ecosystems and communities must be understood by stakeholders prior to implementation and a stage-gated approach should be used, requiring projects to prove safety at small-scale before scaling up. Projects should be informed by the full weight of available knowledge rather than selective results, recognizing the importance of scientific consensus.

6. **Ensure independent monitoring, reporting, and verification (**MRV) to avoid potential conflicts of interest. If the field trial is run by a for-profit company, they must utilize independent MRV companies that are paid based on the process of conducting the work and not the success of the project or potential validation of the mCDR approach. Field trial results need to confirm the viability of engineered mCDR activities as an effective mitigation pathway, specifically net CO_2 removal (including the implementation emissions in the total mitigation value) and the durability of carbon removal, in addition to demonstrating no harm to the marine environment, biodiversity, and local communities.

7. **Require open-access data from trials to ensure transparency, replicability, and independent scrutiny.** Funders and regulators should ensure that project findings are made publicly available and, where possible, published in peer-reviewed journals and data repositories with open access, helping to limit bias, manage conflicts of interest, and situate results within broader scientific literature. Data should be reported in a consistent format using community metadata standards to enable comparison across projects and robust enough to support evaluations of long-term carbon storage and to comprehensively assess both short term and long-term environmental, ecological, and social impacts.

Building Trust through Public Financing

8. **Seek and prioritize government and public financing.** Governments should be working in collaboration with research institutions and should prioritize unbiased public funding to help ensure public trust in the results of any experiments. Ensuring that public funding is included, even if combined with private funds, will support independent research on mCDR and should help to avoid conflicts of interest and build trust in the field. While philanthropy continues to shoulder the burden of investment in the field, government oversight and investment should be encouraged to help research and test new technologies and to set the stage for blended finance to help scale the most promising pathways or solutions in the future.

9. **Provide funding for baseline development and longevity of assessment needed.** Regulators and research teams should ensure that the research horizon and associated budget demonstrate a commitment and financial ability to build relevant baselines and establish an ongoing monitoring and assessment of short term and long-term impacts, as well as efficacy, scalability, and durability of carbon removal.

10. **Agree that mCDR trials should not generate carbon credits.** Companies, funders, and research teams should avoid early carbon credit sales unless or until independent, peer-reviewed science demonstrates robust MRV and credits can meet high-integrity standards. As this portion of the field is in development, standards for issuing credits may adjust over time. Premature issuance of carbon credits will undermine the integrity of future carbon markets and will lead to distrust of associated mCDR approaches. Public and blended financing opportunities (as outlined above) should be prioritized instead of early credit sales to ensure system integrity.

Disclaimer

This list of recommendations focuses on current or planned field trials exploring the potential of marine carbon dioxide removal to store, sequester or remove carbon from the ocean and seawater both domestically and globally. It is expressly focused on providing consensus recommendations to guide field trials related to engineered, or non-blue carbon, marine carbon dioxide removal (definition footnote) and does not serve as an endorsement of any pathway or of large-scale, commercial marine carbon dioxide removal projects.

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[1] 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)

[2] United Nations Environment Programme (2023). Emissions Gap Report 2023: Broken Record – Temperatures hit new highs, yet world fails to cut emissions (again). Nairobi. https://doi.org/10.59117/20.500.11822/43922

[3] Engineered mCDR refers to approaches that use anthropogenic interventions to remove and store CO2 in the ocean, including through intensification of the ocean's natural sequestration capacity. Engineered mCDR is sometimes differentiated into biotic, referring to the use of biological processes or organic materials to remove CO_2, and abiotic, which refer to mechanically or chemically driven interventions. Ecological mCDR refers exclusively to the conservation or restoration of coastal and marine (blue carbon) ecosystems. These actions protect and re-establish the natural ability of blue carbon habitats (salt marshes, seagrasses, mangroves and select others) to sequester carbon, resulting in the removal of CO2 from the atmosphere and ocean.

[4] https://oceanconservancy.org/wp-content/uploads/2023/06/Precautionary-Principles-for-Ocean-Carbon-Dioxide-Removal-Research.pdf

[5] https://www.agu.org/learn-about-agu/about-agu/ethics/-/media/a8f267f3216d4bd7af49607ddc7940d4.ashx

[6] https://www.aspeninstitute.org/publications/a-code-of-conduct-for-marine-carbon-dioxide-removal-research/

[7] https://www.nwf.org/-/media/Documents/PDFs/Climate/Marine-Carbon-Dioxide-Removal-Best-Practices-Tribal-and-Indigenous-Engagement.pdf