PERSPECTIVE ON MARINE CARBON DIOXIDE REMOVAL AND RELATED RESEARCH

OA ALLIANCE
INTERNATIONAL ALLIANCE TO COMBAT OCEAN ACIDIFICATION

MARINE CARBON DIOXIDE REMOVAL AND OCEAN ACIDIFICATION

Anthropogenic emissions of carbon dioxide (CO_2) impact the ocean through climate change driven ocean warming and through increased ocean acidification (OA).

Atmospheric CO_2 levels have reached historically unprecedented levels, higher than at any time in the past 800,000 years. High end emissions projections for the end of this century indicate that the acidity of global ocean surface waters could be 150 percent higher than at the start of the Industrial Revolution as a result of increased CO_2 emissions being absorbed by the ocean. [1]

Halting the ongoing release of anthropogenic CO_2 and other greenhouse gas emissions is the first and most important action needed to combat climate change and ocean acidification. This means that ambition and urgency for actions that reduce ongoing CO_2 and other greenhouse gas emissions is paramount and cannot be substituted. And the Intergovernmental Panel on Climate Change (IPCC) tells us that in addition, some carbon dioxide removal (CDR) will be needed to achieve the temperature goal set forth in the Paris Agreement. These strategies include exploring land-based, atmospheric, and ocean-based or marine approaches to CDR. [2]

Pathways to achieving the 1.5°C temperature goal all require 100-1000 Gt removal of CO_2 already in the atmosphere by the end of the century, with rates of removal of at least 10 Gt CO_2 per year until 2050 and rising to at least 20 Gt CO_2 a year through 2100. [3]

Effects of increasing ocean acidification will continue from the CO_2 that is actively being added to the ocean now from the burning of fossil fuels. Meaning, even if the Paris Agreement temperature goal is met, further acidification is inevitable, although the rate and extent will depend on the effectiveness of ongoing mitigation and adaptation strategies.

Some ocean-based or marine CDR (mCDR) strategies may be needed in specific cases to:

- Assist in carbon removal and sequestration efforts.
- Limit or reduce ongoing ocean acidification.
- Contribute to coastal adaptation and resilience building actions that help us achieve global climate, marine and biodiversity goals.

RESEARCH IS NEEDED TO EVALUATE RISK AND EFFICACY OF MCDR STRATEGIES

mCDR strategies and associated techniques will take time and – like many infrastructure projects – will carry a potential for negative impacts to the ocean and marine life, while also carrying a potential for providing solutions to the increasing challenge of climate change and ocean acidification. Testing and evaluation of strategies is needed to identify a range of potential risks to marine organisms, ecosystems, and human communities. Therefore, more research is needed to assess these strategies to understand and evaluate the potential trade-offs, uses and far-field effects of mCDR and how these techniques might influence ocean acidification.

mCDR STRATEGIES DIFFER AND SO DO THEIR POTENTIAL EFFECTS ON OCEAN ACIDIFICATION

Not all ocean-based or mCDR strategies are the same, nor do they uniformly affect ocean acidification.

Some mCDR strategies might:

1. Increase the ocean's ability to draw down atmospheric CO_2.
2. Limit or reduce ocean acidification.
3. Increase CO_2 in the ocean, further contributing to—or accelerating—ocean acidification

It is critical that ocean acidification scientists, technical experts and multi-discipline practitioners come together with policy makers, resource managers, public and private sectors to collectively outline, prioritize, and conduct the research and evaluation needed to assess the implications of different mCDR strategies for ocean acidification.

Particularly, this should result in a better understanding of which strategies are:

- **measurable** with existing technologies and have robust monitoring, reporting and verification plans in place.
- likely to be most **effective** for the long-term removal and sequestration of carbon dioxide from the atmosphere or seawater.
- likely to meet **additionality** criteria that ensure validity of carbon offsets associated.
- **safe** to deploy, and protective of marine systems and humans, at different scales.
- **practical** to implement at different scales.
- **inclusive** of and **equitable** for coastal communities and marine resource user priorities and needs.
- **responsive** to jurisdictional governance, oversight, and risk management tools including the sovereign rights of Tribal governments and human rights of First Nations and indigenous communities.

The National Academies of Sciences, Engineering and Medicine identified six ocean-based and marine CDR (mCDR) approaches that need further research. These biotic and abiotic approaches can be understood as part of a broader land-based, atmospheric, and ocean or mCDR research agenda to help meet the Paris Agreement temperature goal. [4]

Approaches to mCDR include:

- **Ocean fertilization** adding micronutrients or macronutrients to stimulate photosynthesis and phytoplankton growth in the surface ocean. This would increase carbon fixation of organic matter in the deployed location, helping to draw down CO_2 from the atmosphere, though long term storage of this draw down or impacts far-afield are not certain.

- **Artificial upwelling/downwelling** using pipes to bring up cooler, nutrient-dense water to the surface to stimulate phytoplankton growth and downwelling CO_2 rich water).

- **Ecosystem recovery** including the restoration of vegetation in coastal systems that absorb CO_2 in the atmosphere and the water column (sometimes called blue carbon ecosystems).

- **Seaweed cultivation** whereby seaweed are cultivated in surface waters, drawing CO_2 out of the ocean, then are sunk into the deep ocean for sequestration. Harvesting seaweed at key times in the carbon cycle may also support local scale removal of CO_2 in seawater.

- **Ocean alkalinity enhancement** adding alkaline liquid or solid minerals/ substances to seawater to promote air to sea CO_2 drawdown, potentially increase the pH, and potentially buffer against coastal acidification at local scales.

- **Electrochemical methods** including electrochemical ocean alkalinity enhancements (processing or treating seawater to separate acid and base streams, returning more basic waters to coastal areas and resulting in an acid byproduct that must be disposed of.)

OA ALLIANCE PERSPECTIVE ON EXPLORING mCDR

While the OA Alliance does not endorse any specific mCDR strategy or proposal, we know that...

Exploring ocean-based and mCDR Strategies Should **Not**:

- **Diminish ambition, urgency, or funding for actions that reduce CO_2** and other greenhouse gas emissions and continue our just transitions to a global net-zero and renewable energy society.

- **Change marine or coastal environments** in a way—or on a compressed timescale— that poses undue risks or harm to marine species, ecosystems, or human communities.

- **Further contribute to, or accelerate, ocean and coastal acidification.**

- **Exclude sociological and cultural elements of project design or evaluation**; this means ensuring local community and resource user priorities, concerns and potential impacts are part of project design or planning, monitoring, evaluation, and reporting schemes. This also includes aspects of environmental justice, ensuring testing of mCDR strategies are not taking place in locations that have not developed structures for consultation and regulatory oversight.

- **Override necessary monitoring, reporting, evaluation or permitting requirements** from applicable legal or regulatory bodies or sovereign governments.

- **Be advertised or communicated as a "silver bullet" for addressing climate change, mitigating, or remediating OA.**

Exploring ocean-based and mCDR Strategies **Should**:

- **Be prioritized realistically**, beginning with those that have fewer risks and more co-benefits. Not all mCDR approaches are the same and therefore have different technology and equipment needs, monitoring and evaluation schemes, potential risks and benefits, scales of impact and costs. We should be working towards resolving which approaches are worth the upfront investment in research, given the potential co-benefits, risks and associated costs.

- **Demonstrate the ability for long-term carbon storage potential** and evaluate far-afield impacts in addition to cite specific impacts. This includes oceanographic, chemical, and biological impacts.

- **Define and delineate goals for global and local scale outcomes and timeline assumptions.** Large scale efforts may have greater potential to remove CO_2 from the atmosphere, though will be slower to achieve. Local scale actions may not drastically reduce atmospheric CO_2 but could result in localized remediation of OA that may have co-benefits and more quickly support species or ecosystem resilience in a particular area.

- **Understand the biological impacts of mCDR strategies to marine species.** Speeding up natural processes, including weathering, to remove CO_2 from the atmosphere or water column still changes the marine environment from its current state. Understanding species biological response under these accelerated conditions must be considered as well as the ability to apply adaptive management measures.

- **Take advantage of existing experts and partners working on this topic by region**—perhaps in the form of localized mCDR hubs. The successes or potentially negative consequences of different mCDR strategies will vary by method and region. It is important that proposed mCDR strategies are being designed, monitored, and evaluated in the context of the actual environment and community they could be deployed in.

- **Be supported by coastal communities and marine resource users**' perspectives, tolerance to risk, and specific needs (including free, prior informed consent). This includes being responsive to jurisdictional governance and oversight including the sovereign rights of Tribal governments and human-rights of First Nations and indigenous communities.

- **Be properly authorized, permitted and regulated by relevant government authorities or regulatory bodies** depending on the mCDR strategy being proposed, possible impacts and desired policy outcomes. This includes aspects related to monitoring, verification and reporting standards, risk assessments, and quantifying benefits of proposed projects. Pilot projects should not take place in areas that have no official oversight, permitting or regulating mechanism.

- **Follow standardized, commonly accepted, and clear Codes of Conduct** developed for mCDR research and project evaluation. Codes of Conduct should apply precautionary approaches to guide responsible research, apply common protocols and measurements, support data quality and comparability and ensure open access to results, especially related to impacts assessed.

References and Resources:

https://www.fisheries.noaa.gov/insight/understanding-ocean-acidification

IPCC, 2023: Climate Change 2023: Synthesis Report. A Report of the Intergovernmental Panel on Climate Change. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland, (in press)

Rogelj, J., D. Shindell, K. Jiang, S. Fifita, P. Forster, V. Ginzburg, C. Handa, H. Kheshgi, S. Kobayashi, E. Kriegler, L. Mundaca, R. Séférian, and M.V. Vilariño, 2018: Mitigation Pathways Compatible with 1.5°C in the Context of Sustainable Development. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 93-174, doi:10.1017/9781009157940.004.

National Academies of Sciences, Engineering, and Medicine. 2022. A Research Strategy for Ocean-based Carbon Dioxide Removal and Sequestration. Washington, DC: The National Academies Press. https://doi.org/10.17226/26278.

Ethical framework for climate intervention; draft principles developed by the American Geophysical Union:
https://www.agu.org/learn-about-agu/about-agu/ethics/ethical-framework-for-climate-intervention