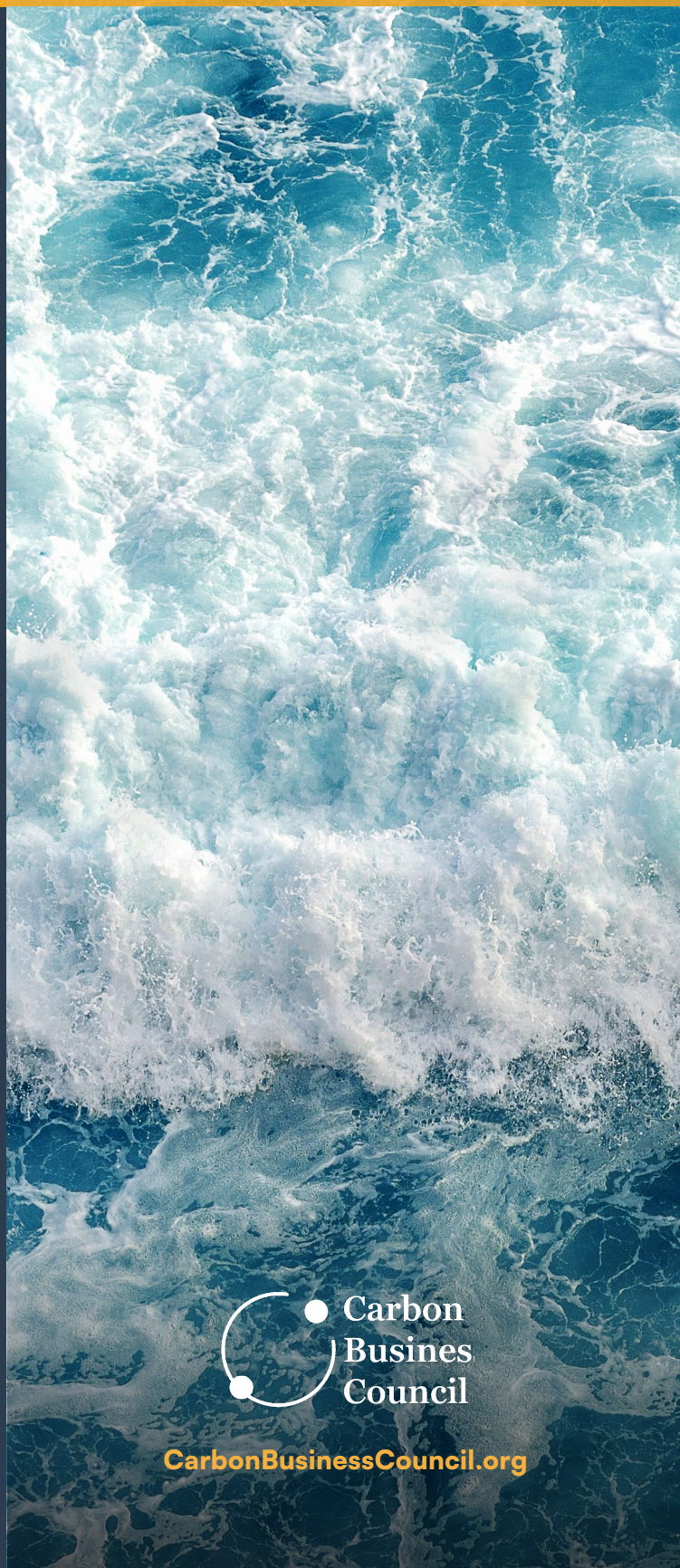
Marine Carbon Dioxide Removal

Issue Brief



Introduction

There is clear scientific consensus that carbon dioxide removal (CDR) — alongside a strong prioritization of greenhouse gas emissions reduction — will be required at an immense, multi-gigatonne (Gt) annual scale by mid-century to limit warming to 1.5 or even 2°C.[1] Covering 71% of the planet's surface, the ocean has served as a critically important sink for anthropogenic carbon dioxide (CO_2), absorbing over 25% of annual emissions.[2] The ocean has also absorbed about 90% of the heat that has accumulated in the Earth system due to rising atmospheric CO_2.[3] The ocean thus provides a vital climate mitigation function, but this has come at significant, and increasing, cost to ocean health, marine ecosystems, and biodiversity.[4]

Given its enormous scale, the ocean has an outsized potential role to play in advancing CDR to the level required to meet Paris Agreement targets. Marine CDR (mCDR) has the potential, when responsibly deployed and scaled, to offer significant climate benefits, while also contributing to sustainable economic development for coastal communities, maritime nations, and small island developing states (SIDS). Additionally, certain mCDR approaches may yield co-benefits such as improvements to ocean health, via local mitigation of ocean acidification, to coastal ecosystems and commercial aquaculture.

1 IPCC AR6 Synthesis Report p 50, 2023.
2 Friedlingstein et al., Global Carbon Budget 2023. *Earth Systems Science Data*, 2023.
3 Why Ocean Heat Matters. NASA Global Climate Change: Vital Signs of the Planet.
4 Accelerating Ocean and Climate Restoration: Ocean-Based Climate Solutions. Ocean Visions, October 2023.

Carbon Busines Council
CarbonBusinessCouncil.org

Examples of mCDR include:

- Ocean alkalinity enhancement (OAE) via electrochemical systems, or the physical application of clean alkaline minerals to coastlines, coastal watersheds, or the open ocean;
- Electrochemical or photochemical systems that directly remove CO_2 from the ocean;
- Dedicated cultivation or harvesting of aquatic biomass, including macroalgae and microalgae (for sinking to the deep ocean, long-duration terrestrial storage, or potential incorporation into long-lived products); and
- Restoration, enhancement, and scaling of carbon sinks associated with seagrass, mangroves, and other coastal marine ecosystems (coastal "blue carbon").

The CDR sector is evolving and scaling quickly. While both governments and private investors have started to provide funding support to certain (mainly terrestrial) CDR approaches, mCDR has to date remained relatively neglected in terms of policy, permitting pathways, and resources for research, innovation, and initial deployments. In September 2023, more than 400 scientists from around the world released a letter calling for accelerated research into mCDR pathways.[5] And in October 2023, the White House Office for Science Technology and Policy (OSTP) launched a Fast-Track Action Committee (FTAC) on Marine Carbon Dioxide Removal "to shape relevant policy and research on safe and effective [mCDR]."[6] Given the significant climate mitigation benefits the ocean can offer, alongside the substantial potential co-benefits to ecosystems and communities, it is essential that policymakers place greater emphasis on and consideration to mCDR.

In this Issue Brief, a working group of Carbon Business Council mCDR member companies and partners highlight the mCDR opportunity; identify pathways to enable research, development, and deployment; and offer a set of focused recommendations for policymakers and other CDR ecosystem stakeholders to responsibly accelerate the advancement of mCDR.

5 OceanCDRScience.org. Ocean Visions, 2023.
6 Doney and Lubchenco, "Marine Carbon Dioxide Removal: Potential Ways to Harness the Ocean to Mitigate Climate Change." White House OSTP Blog, October 2023.

The mCDR Opportunity

- **Scalability and low cost potential.** The immense scale of the ocean in terms of surface area, volume, coastline, and existing carbon storage capacity make it a clearly integral part of the portfolio of CDR pathways necessary to meet global climate targets.[7] This represents a particularly compelling opportunity for the U.S., owner of the world's largest Exclusive Economic Zone (EEZ), which extends 200 nautical miles from the nation's extensive coastline.[8] Many mCDR approaches are hybrids to varying degrees of technology and nature, seeking to harness, enhance, and scale natural biotic and/or abiotic ocean processes to remove CO_2 from the atmosphere and store it in the ocean's massive carbon sink. The ability to leverage the vast scope of these natural ocean processes gives mCDR significant advantages in terms of scalability and potential for low cost.

- **Ecosystem co-benefits.** Because the ocean has absorbed so much anthropogenic CO_2, ocean acidification has increased to unprecedented levels and continues to worsen, endangering critical marine ecosystems, commercial fisheries, and aquaculture. While the ocean is too large for anthropogenic carbon removal to meaningfully reduce ocean acidification at a global level in the near term, a number of mCDR approaches can reduce acidification on a sustained basis locally — thereby contributing to the protection and potential restoration of near-shore marine ecosystems and fisheries, as well as to the enhanced productivity of commercial aquaculture.[9,10] Additionally, restoring and scaling lost "blue carbon" ecosystems can increase coastal resilience to storm surge and other impacts of our changing climate.

---

7 Strategy for NOAA Carbon Dioxide Removal and Research. NOAA PMEL, 2023.

8 "What Is the EEZ?" U.S. National Ocean Service, NOAA.

9 "SBU Study Shows Kelp Can Reduce Ocean Acidification and Protect Bivalves." June 2022.

10 Albright et. al., "Reversal of Ocean Acidification Enhances Net Coral Reef Calcification." *Nature* (2016).

- **Economic co-benefits.** CDR is forecast to be a trillion-dollar market by 2050,[11] and the Carbon Business Council expects the ocean to fulfill its immense potential and significantly contribute to the sector. In addition to ecosystem co-benefits (several of which additionally offer potential economic benefits to aquaculture, commercial fisheries, and tourism), responsible deployment and scaling of mCDR has the potential to make substantial contributions to a sustainable ocean economy in terms of direct job creation, as well as growing tax bases in coastal jurisdictions. Scaled deployment of mCDR will additionally require massive supply chains, which will result in significant indirect job creation, such as what we've seen with offshore wind.[12] Moreover, these economic benefits have the potential for broad geographic distribution — for example from the provision of mineral feedstock for OAE — and not just to coastal jurisdictions.[13]

- **Leveraging marine infrastructure.** In the U.S. alone, there are over 15,000 wastewater treatment plants; 1,400 desalination plants; and 55,000 offshore oil and gas wells (55% of which are currently abandoned).[14,15,16] By 2030, the U.S. is planning to deploy more than 2,000 offshore wind turbines on the Atlantic coast, with additional development of offshore floating wind along the Pacific coast.[17] As mCDR scales, U.S. ports and shipyards will become integral hubs for commerce and material flow to support the sector.[18] This existing (and future) marine infrastructure represents a massive platform opportunity to deploy and scale certain mCDR approaches. Such co-deployment would create new revenue streams (and increase climate-positive impact) for infrastructure owners while lowering capital expenditure, potentially facilitating permitting, and accelerating deployment and scaling for mCDR project developers.[19] A significant opportunity exists as well for certain types of mCDR projects to serve as demand sinks to drive new and additional marine renewable energy deployment.[20]

- **Policy leadership.** U.S. federal and state governments can assume global leadership in shaping the nascent mCDR market with science-based regulatory policy and funding support for research, field trials, and responsible early deployments. Effective mCDR policy should seek to balance the imperative to act on climate and the mCDR economic opportunity with clear guardrails for ecosystem and community safety. Jurisdictions that move first to create regulatory clarity and establish tight and dynamic coupling between supportive policy and evolving scientific understanding will attract high-quality projects and capture outsized economic benefit – in terms of direct jobs creation, manufacturing and supply chains, tax revenue, etc. — as the mCDR sector scales.

Enabling Responsible Deployment

- **Monitoring, reporting, and verification.** High-quality monitoring, reporting, and verification (MRV) is essential to building the market trust necessary for CDR to achieve gigatonne scale in the coming decades. As outlined in the Carbon Business Council's May 2023 Issue Brief, MRV is a complex and multi-faceted set of

11 Mannion et. al., Carbon Removals: How to Scale a New Gigaton Industry. McKinsey Sustainability, 2023.
12 NREL Study Charts Path Toward Significant Growth in Offshore Wind Workforce. DOE, October 2022.
13 Renforth, "The Negative Emission Potential of Alkaline Materials." Nature Communications, 2019.
14 Report Card for America's Infrastructure. American Society of Civil Engineers, 2021.
15 Future of Desalination in the United States. American Membrane Technology Association, 2018.
16 Fixing Abandoned Offshore Oil Wells Can Create Jobs and Project the Ocean. Center for American Progress, April 2022.
17 Top 10 Things You Didn't Know About Offshore Wind Energy. U.S. Department of Energy, August 2023.
18 Study Identifies Needs and Opportunities for West Coast Ports to Support Offshore Floating Wind Energy. U.S. Department of Energy, September 2023.
19 Bryce, "Offshore Wind: A Platform Opportunity for Carbon Removal." Illuminem, March 2022.
20 Niffenegger et. al., Mission Analysis for Marine Renewable Energy to Provide Power for Marine Carbon Dioxide Removal. NREL Technical Report 5700–87165, September 2023.

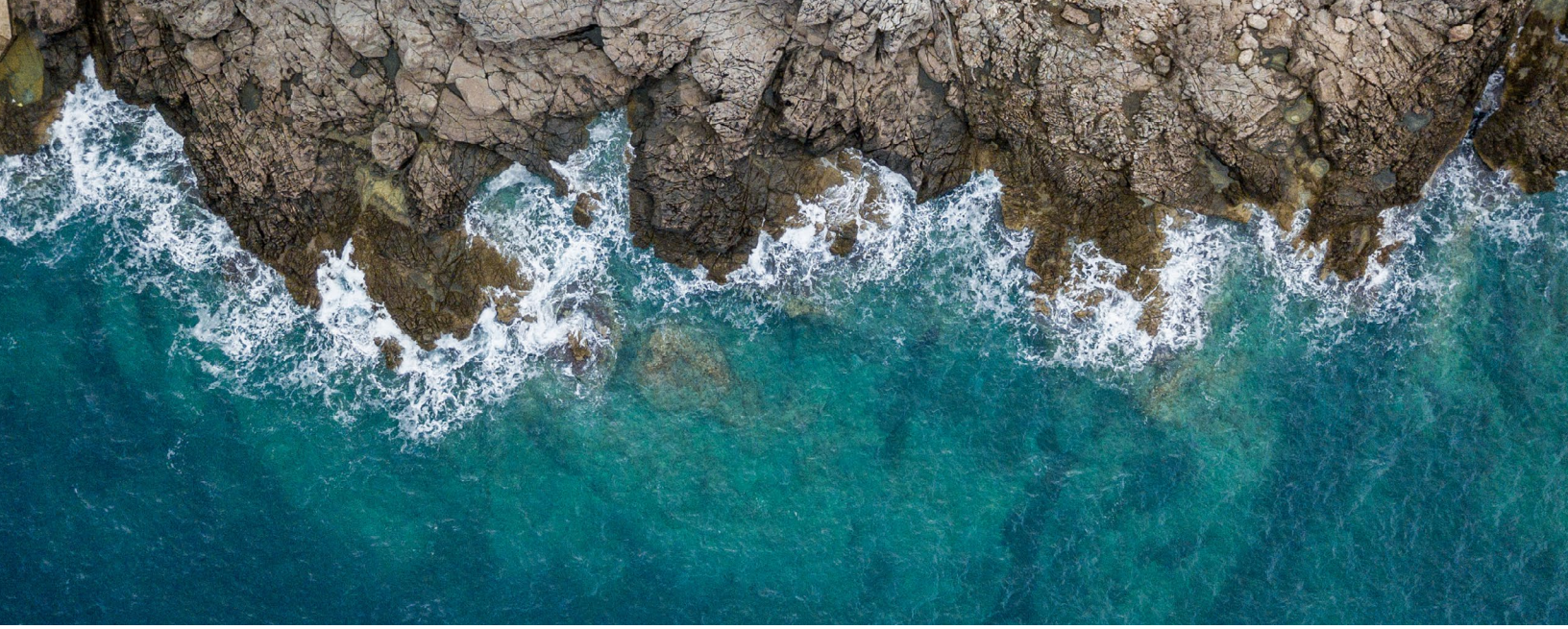
processes. The core of MRV is the quantification of a project's efficacy in terms of net removal of CO_2 from the atmosphere. This can be challenging for CDR approaches which leverage open-system biogeochemical processes that cannot always be clearly or easily measured, and may occur over varying time intervals.[21] These open-system approaches — which include a number of mCDR methods — have great potential for scalability at low cost. The mCDR community should continue collaborating to develop workable operating protocols for MRV based on the best available science, which is expected to dynamically advance over time.

- **Assessing ecosystem interactions.** Given the critical importance of ocean health to coastal communities, ecosystems, and the global economy, there is understandable concern about the deployment and scaling of mCDR. Fully assessing the ecosystem effects of mCDR deployment is essential, and project benefits must be evaluated alongside potential adverse impacts, as well as in the context of the rapidly worsening effects of climate change. Due to the complexities of ocean circulation, these effects can be both local and global in nature. The tools needed to assess them substantially overlap with those needed for MRV, and will require significant investment. It is crucial to leverage field trials and early deployments as learning opportunities, and to create flexible policy mechanisms that are responsive to scientific learning over time and proportionate to project scale and the scope of potential impact.

- **Public engagement.** Robust public engagement will be a key enabling factor for the testing, demonstration, deployment, and scaling of all CDR pathways. mCDR is no exception to this, and as we seek to create a potentially massive new commercial sector, we must seize the opportunity to do so in a manner that is sustainable, just, and equitable. In addition to minimizing ecosystem harm, disturbance to human populations, and other negative externalities, CDR project developers should seek to prioritize community engagement "from the ground up," and make a genuine and sustained effort to listen to, understand, and address community concerns.[22] This will be a work in progress for the foreseeable future as companies deploy projects, learn, and grow. While current public awareness of mCDR is low, initial polling suggests that coastal communities are open to the opportunity, and concerned about the effects of climate change.[23] Clear, evidence-based communication, transparent data sharing, and inclusive decision-making — supported by high-quality MRV — will be key to ongoing public engagement regarding mCDR.

- **Permitting.** Permitting mCDR research, field trials, and early deployments has proven challenging due to the lack of fit-for-purpose legal and regulatory frameworks.[24] Project developers currently must navigate and negotiate a complex patchwork of laws and regulations developed for other coastal and marine activities, in many cases subject to unclear jurisdiction, authority, and administration. Clear, relevant, and science-based regulatory frameworks will enable responsible and sustainable deployment of mCDR; their lack will not only slow mCDR's advancement, but have the potential to push projects to deployment in less robust governance regimes. In the meantime, mCDR researchers, companies, and project developers must collaborate with relevant international, federal, state, and local authorities, along with community members, to navigate and adapt existing regulations to the best extent possible.

21 Ellis and Sanchez, "Quantification Uncertainty and Discounting," The Great Unwind, March 2023.
22 Aronowsky et. al., "From the Ground Up: Recommendations for Building an Environmentally Just Carbon Removal Industry." XPRIZE and Carbon180, 2023.
23 Coastal Americans Overwhelmingly Support Ocean-Based Carbon Dioxide Removal, and Are Alarmed About Climate Change Impacts, Climate Netus, March 2022.
24 Ocean CDR Permitting and Regulations 101. ClearPath, June 2023.



- **Funding.** mCDR will require significantly increased funding over the next decade in order to reach its potential. Philanthropic capital, along with some federal funding, have provided valuable early financial support for field-building non-profit organizations such as Carbon to Sea and [C]Worthy, and the Biden administration has committed an initial $60 million to support mCDR research and MRV development.[25] However these investments are not yet commensurate with mCDR's potential climate impact, and fall far short of the $10 billion the National Academies of Science estimate will be needed to fully assess the mCDR opportunity.[26] Funding needs for mCDR range from fundamental scientific research, to the development of ocean monitoring systems and tools, to field trials and early commercial projects. In the coming years, significant financial capital will be needed to continue to develop promising novel mCDR approaches and MRV tools and infrastructure, as well as to scale project deployment of proven mCDR approaches. It is essential that funding for CDR not be viewed as a zero-sum game: the entire sector needs increasing levels of support this decade, and a method-neutral portfolio approach that prominently includes mCDR is key.

Recommendations

- **Advance method-neutral policy.** U.S. federal and state governments should seek to implement method-neutral, criteria-based policies and funding support for CDR. The key criteria for high-quality CDR, and the importance of a method-neutral framework, are outlined in Carbon Business Council's Defining Carbon Dioxide Removal Issue Brief. There have been some hopeful initial signs of this policy approach. In October 2023, the U.S. Department of Energy (DOE) announced a $35M CDR Purchase Pilot Prize, which specifies that CDR can occur via the "upper hydrosphere" and is a positive step. Proposed legislation such as the federal CREST Act and the Massachusetts Carbon Dioxide Removal Leadership Act – which would both enact method-neutral, criteria-based public procurement programs for long-duration CDR – offer similar promise. However, more is needed. Achieving gigatonne-scale CDR will require a portfolio approach; policy should be reflective of this reality and scaled accordingly. An important next step for Congress would be the creation of a

25 Mazurek, et. al., "The State of Philanthropic Funding for Carbon Removal." Climateworks, May 2023.
26 Research Strategy for Ocean Carbon Dioxide Removal and Sequestration. NASEM, 2022.

method-neutral tax credit for long-duration CDR, either by expanding 45Q or implementing a new structure. Third Way's October 2023 report "Scaling to the Skies" offers suggestions as to policy design options.

- **Support high-quality, operable MRV.** Development, implementation, and iterative use of scientifically robust, but operationally tractable MRV approaches will be essential to the responsible research, development, and deployment of mCDR. It is important to establish early approaches to MRV for mCDR that quantify but tolerate reasonable levels of uncertainty, with a goal of ongoing refinement, and line-of-sight toward tightening standards as scientific capacity increases over time. Public-sector support for this will be crucial, both in terms of funding support as well as engagement with national labs, public universities, and other federal research institutions. Promising initial steps include NOAA's September 2023 award of $24M to 17 projects; ARPA-E's October 2023 $36M funding of 11 research projects; and the European Union's interdisciplinary multi-stakeholder SEAO2-CDR initiative. Carbonplan's CDR Verification Framework offers a promising prototype for how this might be implemented in practice, and members of the CDR community are in strong agreement as to the importance of high-quality MRV.[27]

- **Implement fit-for-purpose mCDR regulatory frameworks.** Policymakers should, in consultation with mCDR sector actors from industry, science, and advocacy communities, rapidly assess the applicability of current law (international, federal and state, including existing outfall regulation) for permitting mCDR field trials and early deployments, and propose enhancements where applicable and new regulatory frameworks as needed. Organizations such as Columbia University's Sabin Center are doing valuable work to initiate this conversation, and it will be critical for U.S. federal and state governments, as well as the mCDR research community, commercial sector, and climate advocates to engage.[28,29] The OSTP FTAC represents another productive step in this direction. Robust, safe, and operable permitting frameworks will be key to vital mCDR research and field trials, responsible early deployments, and to unlock scale in the coming years.

- **Incentivize mCDR co-deployment with infrastructure.** Policymakers should seek to create incentives for owners of coastal and marine infrastructure – including shipyards and ports; marine renewable energy; stranded offshore oil-and-gas platforms; and outfalls from wastewater treatment, power, desalination, and other industrial facilities – to partner with mCDR companies and project developers for field trials, pilots, demonstrations, and early deployments. Additionally, the coastal protection industry deploys 60 million tonnes of sediment per year to protect coastal communities, creating opportunities to integrate enhanced weathering materials into their operations.[30] Potential synergies exist as well between certain mCDR approaches and commercial fisheries and aquaculture. Co-deployment incentives could initially come in the form of performance-based grants for hosting field trials and early commercial deployments, then transition to an investment tax credit, or similar mechanism, as the sector scales. DOE's $1.7 million Power at Sea Prize is an exciting initial step in this regard, and further policy development would be highly impactful to the responsible development and deployment of mCDR.

27 Hausfather et. al., "Industry Call for CDR Standards Initiative," February 2023.
28 Silverman-Roati and Webb, "Developing Model Federal Legislation to Advance Safe and Responsible Ocean Carbon Dioxide Removal Research in the U.S." Climate Law, March 2023.
29 Webb and Silverman-Roati, "Executive Actions to Ensure Safe and Responsible Ocean Carbon Dioxide Removal Research in the United States." Climate Law, November 2023.
30 ASBPA National Beach Nourishment Database.

- **Maintain focus on responsible deployment.** Stakeholders across the sector strongly agree on the need to maintain a keen focus on the responsible development and deployment of mCDR. In September 2023, a group of leading CDR companies published the Reykjavik Protocol, a set of principles that seek to guide the equitable and responsible go-to-market and environmental credit generation for "nature-deployed" climate interventions, including mCDR. In October 2023, the Carbon Business Council launched its CDR Responsible Deployment Training as a free community resource to support XPRIZE Carbon Removal competitors and other CDR project developers with the responsible deployment of their solutions. And in 2024, the U.S. DOE will be inaugurating the Responsible Carbon Management Initiative to encourage and guide project developers "to pursue the highest levels of safety, environmental stewardship, accountability, community engagement, and societal benefits in carbon management projects." These resources contribute to a growing toolkit for mCDR project developers as they advance from field trials to pilot and demonstration projects, and eventually to scaled deployments.

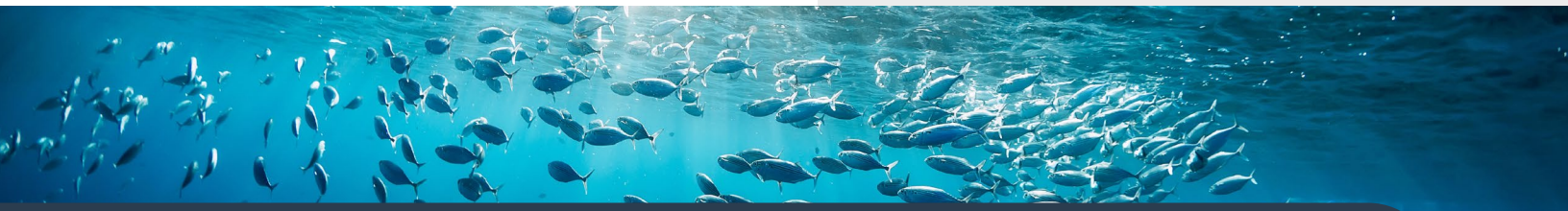
Credits

This issue brief is developed by a working group of the Carbon Business Council. Toby Bryce served as lead author. Co-authors include Ben Rubin and Isabella Corpora of the Carbon Business Council.

Working group members include: Ashritha Karuturi, Carbon Business Council; Brad Rochlin, Running Tide; Douglas Edwards, Vesta; Edward Sanders, Equatic; Frances Simpson-Allen, Ebb Carbon; Garrett Boudinot, Vycarb; Jeanine Ash, Capture6; Julian Sachs, Banyu Carbon; Kelly Erhart, Vesta; Leo Park, Capture6; Pete Chargin, Planetary; Tara Bojdak, Captura; Zach Cockrum, Vesta.

Internal reviewers include: Ben Swainbank, OceanidMRV; Nico Julian, Phykos; Paddy Estridge, Seaweed Generation.

Observers include: Christopher Mann, Carbon to Sea; Diane Hoskins, Carbon to Sea; Jill Storey, World Ocean Council; Matthew Long, [C] Worthy; Paul Holthus, World Ocean Council; Romany Webb, Sabin Center for Climate Change Law at Columbia University; Wil Burns, Institute for Carbon Removal Law and Policy at American University.



About the Carbon Business Council

The Carbon Business Council (CO2BC), a member-driven and tech-neutral trade association of companies unified to restore the climate, is the preeminent industry voice for carbon management innovators. Together, the nonprofit coalition represents more than 100 companies across six continents with more than $16.5 billion dollars in combined assets.

CarbonBusinessCouncil.org | Info@CarbonBusinessCouncil.org