OCEAN ENTERPRISE INITIATIVE

mCDR Dialogue Synthesis

New Markets: Opportunities and Challenges in Marine Carbon Dioxide Removal Research and Development

Workshop at Oceanology International, London. March 2024

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I. Dialogue Purpose

The Marine Technology Society (MTS), the Global Ocean Observing System (GOOS), and the National Oceanic and Atmospheric Administration (NOAA), in collaboration with industry partners Kongsberg Discovery and L3Harris have launched the Ocean Enterprise Initiative. This was based on the successful *Dialogues with Industry* series, which involved consultations with stakeholders in the Ocean Enterprise. The Dialogue with Industry Roadmap (hereafter Roadmap) emphasizes an integrated approach that enhances all facets of the Ocean Enterprise along the Ocean Information Value Chain.

An integral aspect of the *Dialogues with Industry* Series is its focus on a cohesive set of prioritized action pathways that bolster every aspect of the Ocean Enterprise, rather than isolated initiatives. To guide these efforts, three interdependent goals have been defined:

1. Establishing a robust Ocean Enterprise recognized as essential to lives and livelihoods.
2. Enhancing the visibility of the Ocean Enterprise as a significant contributor to the global Gross Domestic Product (GDP).
3. Identifying the ocean observing, products, and services sector as a distinct market sector attracting investment.

Recognizing the importance of "Collaboration to Grow and Impact Change" and "Improving the Marketplace" priority areas from the *Dialogues with Industry* Roadmap, MTS, GOOS, NOAA, Kongsberg Discovery, and L3Harris co-hosted strategic dialogues at Oceanology International (Oi). These dialogues focused on two areas to maturing the Ocean Enterprise: Standards and Marine Carbon Dioxide Removal (mCDR). By addressing both standards and market development, these strategic dialogues exemplify the power of collaboration in propelling the Ocean Enterprise forward.

New Markets: Opportunities and Challenges in mCDR Research and Development

With new markets emerging in the Ocean Enterprise, the mCDR dialogue at Oi focused on "Improving the Marketplace" by exploring strategies for aggregated demand for existing and innovative ocean observing technology, services, data, and information from both public and private sectors.

II. mCDR Dialogue

mCDR refers to a set of strategies and technologies aimed at mitigating climate change by removing carbon dioxide (CO_2) from the atmosphere through processes occurring in the ocean. Recent research indicates that the ocean has the potential to hold 17 times more carbon than soil and land biota combined.[1] As the concentration of CO_2 in the atmosphere continues to rise due to human activities such as burning fossil fuels and deforestation, mCDR offers a promising avenue for reducing atmospheric greenhouse gas concentrations and combating climate change. These approaches leverage the ocean's natural capacity to absorb and store CO_2 and innovative techniques to enhance this process. By capturing and sequestering CO_2 in marine environments, mCDR has the potential to play a significant role in efforts to achieve carbon neutrality and mitigate the impacts of climate change globally.

mCDR techniques are in their infancy and can be subdivided into categories ranging from restoration to engineering. mCDR techniques include coastal Blue Carbon, ocean alkalinity enhancement, macroalgal cultivation and fertilization, and electrochemical methods.

NOAA issued a white paper titled "Strategy for NOAA Carbon Dioxide Removal Research" and identified these four assess:

- Observing networks
- Modeling, scaling, and projection of mCDR pathways
- Environmental impacts
- Decision support

mCDR strategies hold immense potential in addressing global climate change. Ongoing research and development efforts in the mCDR domain underscore the pivotal role of innovation and technological advancements. Innovation in the mCDR space can make an impact through technology readiness, observing system coverage, and model development. Central to the scalability and effectiveness of mCDR initiatives is the establishment of robust monitoring, reporting, and verification mechanisms. These frameworks are essential for ensuring the accuracy, transparency, and accountability of mCDR processes, paving the way for their widespread adoption and impact. Innovation offers fertile ground for exploration and discovery in the quest for sustainable solutions to mitigate climate change's adverse effects on our planet.

III. State of mCDR

The mCDR Dialogue commenced with insightful presentations from two esteemed experts, **Dr. Liza Wright-Fairbanks** and **Dr. Chris Pearce**, who provided insights into the status and

1 Friedlingstein, Pierre, et al. "Global carbon budget 2022." Earth System Science Data Discussions 2022 (2022): 1-159

advancements in mCDR. Dr. Wright-Fairbanks brings a wealth of expertise to the discussion as the Field Research Manager for NOAA's Ocean Acidification Program in the United States. Dr. Pearce has extensive experience as a Principal Marine Scientist at the National Oceanography Centre in Southampton.

The progression of mCDR necessitates concerted national and international cooperation to foster comprehensive research initiatives, exploring both the efficiency and ecological impacts of mCDR interventions on marine environments and ecosystems. Close collaboration between academic institutions and commercial entities is paramount in evaluating the scalability potential of various mCDR techniques. It is imperative to establish robust frameworks for monitoring, reporting, and verifying the efficacy and impacts of mCDR interventions, ensuring transparency and accountability in their implementation. Clear and transparent communication channels must be maintained with the public, regulators, and all relevant stakeholders to foster understanding and garner support for mCDR initiatives. Additionally, meticulous stewardship and governance of marine environments are essential to safeguarding their integrity and resilience in the face of evolving mCDR strategies and practices.

Persistent knowledge gaps in mCDR underscore the need for further research and experimentation to enhance our understanding of its efficacy and potential impacts. While certain mCDR techniques, such as ocean iron fertilization, artificial ocean upwelling, and ocean alkalinization, inspire confidence for their potential on a millennium timescale, in-situ, small-scale controlled field trials are deemed essential to validate their effectiveness under real-world conditions across diverse ocean settings. These trials are imperative to evaluate the performance and operational requirements of mCDR approaches and comprehensively assess their environmental and societal ramifications.

Such research endeavors are approached with caution, inclusivity, and meticulous planning to mitigate potential harm to environmental and social systems. Compliance with existing regulatory frameworks, including those outlined by the permitting authority or the London Protocol[2], is paramount to ensure responsible and ethical conduct in mCDR experimentation and deployment. Robust monitoring, reporting, and verification (MRV) approaches are indispensable in meeting regulatory requirements set by both the carbon market and the permitting authority, encompassing monitoring of carbon uptake and monitoring of ecological effects. These approaches necessitate cost-effective and climatically efficient observational capabilities spanning from the seafloor to space, complemented by integration with suitable ocean biogeochemical models. Initial field trials should prioritize over-parameterization to identify reliable observation metrics and uncertainties, with consistent re-evaluation of MRV approaches as knowledge and technologies evolve to ensure their continued suitability.

Moreover, equitable governance structures are indispensable to ensure transparency, fairness, and the equitable distribution of benefits derived from mCDR initiatives. Meaningful engagement, consultation, and consideration of local communities at proposed sites of mCDR implementation are essential to address concerns and ensure their participation in decision-making processes. Data accessibility, reporting mechanisms, and visualization

2 Resolution LP.4(8), 2013. https://www.gc.noaa.gov/documents/resolution_lp_48.pdf

processes should adhere to F.A.I.R. principles[3] and be guided by stakeholder requirements to facilitate transparency and accountability. Effective and responsible governance frameworks must delineate interaction points across social, regulatory, political, economic, international, and ethical dimensions, prioritizing distributive justice choices between generations. It is imperative to recognize that ocean carbon removal technologies will have varying environmental justice implications based on deployment methods, supporting policies, and the actors' motivations.

Meeting global climatic targets and commitments over the coming decades will require the implementation and upscaling a portfolio of mCDR approaches. The ocean is poised to play an essential role in contributing to global mCDR, but further scientific and socio-economic research is required to ensure that, where appropriate, mCDR techniques are deployed in an environmentally safe, socially acceptable, and economically viable manner. Open communication and collaboration between all parties are essential for ensuring mutually compatible advances in MRV and regulatory requirements. This is currently being supported through the SEAO2-CDR program and other initiatives. The UK marine scientific community is well positioned to lead and contribute to assessing mCDR strategies, but more significant funding investment is needed to facilitate independent evaluations.

IV. Expert Panel Discussion

The expert panel discussion and Q&A revolved around the challenges and opportunities in mCDR technologies, focusing on various perspectives from industry, academia, and regulatory bodies. During the panelist introductions at the recent event, several key players in mCDR shared insights into their respective initiatives.

Anna Madlener, representing Carbon to Sea, shed light on the nonprofit's endeavors to fund and support research and technology for mCDR. She emphasized the crucial need for field trials to understand the process better and mitigate costs. Madlener highlighted a mismatch between scientific standards and the operational capacities of commercial activities, stressing the necessity for comprehensive comparisons among various sensors and platforms.

Sophie Gill, representing Isometric, delved into the realm of carbon credit registry and verification. Isometric's focus is ensuring the robust and rigorous verification of carbon removal, emphasizing transparent data sharing as vital for building trust within the industry. Gill emphasized their active engagement with academic communities and stakeholders, underscoring their commitment to fostering collaboration.

Emma Heslop, representing GOOS Ocean Observing Co-Design Programme, provided insights into the global efforts to establish standards for the ocean observing system. She highlighted the increasing societal demands driven by climate change and coastal

3 Wilkinson, M., Dumontier, M., Aalbersberg, I. et al. The FAIR Guiding Principles for scientific data management and stewardship. Sci Data 3, 160018 (2016). https://doi.org/10.1038/sdata.2016.18

development, with an emphasis on the significance of carbon observations. Heslop outlined collaborative efforts with the UN Ocean Decade to ensure effective data dissemination and utilization. Another GOOS initiative, CoDesign, is working at the global level to coordinate the development standards, many of which are directly applicable to mCDR. They hope to engage with the mCDR community to align and leverage global efforts.

Mónica Larrazábal, representing SeaO2, discussed their innovative approach to ocean-based CO_2 removal. SeaO2, a Netherlands-based mCDR supplier, employs electrochemistry to remove CO_2 from water, returning low CO_2 water to the ocean for further atmospheric absorption. Larrazábal emphasized the critical role of MRV in scaling operations and revealed plans for a facility capable of removing 250 tons of CO_2 annually by 2024.

The discussion began with exploring the biggest bottlenecks in mCDR initiatives. Speakers highlighted the lack of baseline data for effective regulation, stressing the need to develop knowledge within the industry and modeling community to inform regulatory frameworks. There was a consensus on the importance of simultaneous action across various fronts, including baseline development, sensor creation, and sector-level development.

Participants emphasized the critical role of public and regulator trust, advocating for scientifically based registry systems to build trust and facilitate market structures. The intersection of science, technology, and business in MRV was also highlighted, focusing on the need for practical financing and public-private partnerships to drive progress.

The discussion delved into scaling challenges, jurisdictional complexities, and the urgency of addressing climate change. Funding, public engagement, and interdisciplinary collaboration emerged as crucial factors in advancing mCDR initiatives. The participants emphasized the importance of efficient data gathering, pragmatic approaches to regulation, and alignment with international standards.

The dialogue concluded with a call to action, stressing the need for continued collaboration, rigorous MRV standards, and effective science communication to drive progress in mCDR and ocean restoration initiatives. The interconnectedness of social, economic, and environmental factors was recognized, underscoring the importance of addressing these challenges collectively.

Additional Audience Questions and Comments

1. On ocean carbon registry, do you anticipate a potential need to change/improve the MRV methodology if/when voluntary carbon markets evolve into mandatory ones?

2. Protecting current existing carbon sinks, e.g. mangroves, seagrass, wetlands, etc. is the fastest and cheapest solution. We are still losing these carbon sinks that we already have.

3. Speakers have urged developing tech with good business models, but engineering firms can't move beyond POCs without more regulatory guidance/protocol—which wants all the science first? What are your thoughts on how we balance the research and scaling phases?
4. Answer to the question about time. We don't have any. We are behind, we are already experiencing the negative impacts and costs of climate change. It's a matter of moving ASAP and mitigating. The key question is what the most cost effective and fastest way is to make progress and the ocean is an undervalued and uninvested solution. We have a collective mission to get this to policymakers.
5. How do you balance the governance need and complexity vs. limited resources within early-stage start-ups? How does the size of a trial impact the level of governance?
6. When asking for more sensors and floats to cover the ocean, will a policy/protocol be in place to prevent old, broken, or rogue floats from adding to debris in the ocean?
7. How do we ensure that regulation and governance are not suffocating innovation, and when evaluating the tech risks, ignoring the risk of doing nothing?
8. Note re: monitoring surface oceans - where will we start to see any negative environmental effects?
9. On the roadmap to scaled ocean mCDR, when do scalable MRV sensors and platforms need to be prioritized to meet a timeline for industrial scale mCDR?
10. Why do we prejudice the ocean's upper layer regarding the CO_2 captured in the air-sea carbon exchange? It might take time to equilibrate with the atmosphere, but the benefits to pH levels are immediate, for example. Is this just an unnecessary area of complexity to measure?
11. For Isometric - do you see a market for carbon credits?

V. Primary Themes

The mCDR Dialogue convened experts and stakeholders to explore the urgent need and promising potential of leveraging the ocean's capacity to combat climate change through carbon removal. Through collaborative efforts and innovative research, the session underscored the importance of advancing mCDR techniques while addressing regulatory compliance, technological readiness, and responsible governance. The primary themes and outcomes emphasized the critical role of comprehensive research, transparent communication, and equitable engagement in driving progress in mCDR initiatives and achieving global climate objectives.

- **Urgency and Importance of mCDR:** mCDR presents a critical opportunity to mitigate climate change by leveraging the ocean's capacity to absorb and store CO_2. With the potential to hold 17 times more carbon than land biota, the ocean offers a promising avenue for reducing greenhouse gas emissions and achieving global carbon neutrality.

- **Technological Advances and Research Efforts:** Ongoing research efforts, supported by organizations like NOAA through initiatives such as the National Oceanographic Partnership Program (NOPP), are exploring various mCDR techniques, including coastal Blue Carbon, ocean alkalinity enhancement, macroalgal cultivation, and electrochemical methods. Innovation in technology readiness, observing system coverage, and model development are crucial for advancing mCDR initiatives. CoDesign, an initiative within GOOS, is working at the global level to coordinate the development standards, many of which are directly applicable to mCDR. In addition, several private companies, such as Carbon to Sea, Isometric, and SeaO2 are building the commercial capacity and processes to bring mCDR to scale.

- **Scalability:** The mCDR Dialogue highlighted the necessity for comprehensive research initiatives to evaluate the efficiency and ecological impacts of mCDR interventions. Collaborative efforts between academia, industry, and regulatory bodies are essential for assessing the scalability potential of mCDR techniques and establishing robust frameworks for monitoring, reporting, and verifying their efficacy and impacts.

- **Observations:** The importance of advanced ocean observing technologies, such as sensors, for mCDR was a key topic during the dialogue. The need for better, rapidly deployable sensors that can quickly collect necessary data was highlighted, from both the US and UK perspectives. For instance, in 2023, only 7% of U.S.-based ARGO Platforms included pH monitors. The UK is primarily using existing sensors, but these have had limited success due to the depth of many mCDR projects extending beyond their technical capacity. Ongoing trials led by Carbon to Sea are using highly specialized sensors, but the expansion of these technologies is challenging due to their high cost. The majority of funding currently comes from venture capital, which operates on highly accelerated timelines. Additionally, there's a pressing need for global coordination on standards for the global ocean observing system, as emphasized by CoDesign's work. Ultimately, sufficient funding is required to propel this forward.

- **Challenges and Opportunities:** Persistent knowledge gaps underscore the need for further research and experimentation to validate the effectiveness of mCDR approaches under real-world conditions. Compliance with existing regulatory frameworks and responsible governance are paramount to ensure ethical conduct in mCDR experimentation and deployment. Equitable governance structures and meaningful engagement with local communities are essential to address concerns and ensure their participation in decision-making processes.

- **Expert Panel Discussion:** Insights from panelists representing organizations like Carbon to Sea, Isometric, CoDesign-GOOS, and SeaO2 provided valuable perspectives on funding, carbon credit registry, global ocean observing systems, and innovative mCDR approaches. Discussions centered on addressing bottlenecks, building public and

regulator trust, scaling challenges, and the urgency of addressing climate change through collaborative efforts and effective science communication.

Ongoing Efforts

Panelists and participants also shared several ongoing initiatives related to mCDR that may be leveraged to support the greater effort. Collaboration across efforts will be integral for addressing challenges and optimizing mCDR scaling across the globe.

Carbon to Sea

- Funding and support for research and technology for mCDR.
- Trials related to sensors, methods, field research, and observational tools.

Isometric

- Carbon credit registry and verification service.
- Transparent data sharing and robust verification for building trust with buyers.
- Engagement with academic communities and stakeholders.

CoDesign

- Coordination on standards for GOOS
- Addressing the growing societal need for ocean observing, particularly in the context of carbon observations.
- Engagement with the mCDR community and leveraging global efforts.

SeaO2

- Direct ocean capture approaches, such as electrochemistry, to remove CO2 from water.
- Milestone achievement of a facility capable of capturing 250 tons of CO2 removal per year by 2024.

NOAA

- Advancing mCDR technologies without bias towards specific methods.
- Strategy development and federal funding allocation ($24.3M) for researching mCDR efficacy, risks, and co-benefits.
- Emphasis on MRV as essential for scalability and success.
- Need for high-fidelity monitoring capabilities and innovation in sensor technology.
- Collaboration with 79 researchers across various fields to address emerging needs in mCDR.

UK Oceanographic Center

- Engaging regulators, policymakers, and key stakeholders for holistic discussions on mCDR.
- Transparency in communication and public engagement regarding mCDR.

- In situ research efforts in the UK, including trials in UK waters with regulators.
- SeaSinc project: Research on macroalgae sinking to understand methods and sequestration potential.
- Autonomous methods for MRV and sustainable government structures.
- Strategies for evaluating and assessing mCDR, including identifying monitoring sensor needs and engaging commercial bodies and regulators.

The dialogue concluded with a call for continued collaboration, rigorous MRV standards, and effective science communication to drive progress in mCDR and ocean restoration initiatives. Emphasis was placed on the interconnectedness of social, economic, and environmental factors, underscoring the importance of collective action in addressing climate change challenges.

Acknowledgements

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We would like to thank Sea & Shore Solutions, LLC., for supporting the facilitation and logistical requirements that went into hosting and preparing the mCDR Dialogues Synthesis.

Thank you for your continued support, interest, and commitment to making the pathways effective and impactful across private, government, and science. We look forward to your participation in the Dialogues as they continue.

Appendix 1: Dialogue Materials

- Presentation Slides
- *Dialogues With Industry* Roadmap

Appendix 2: Dialogue Agenda

Time	Agenda Item
1:30 PM – 1:35 PM	Welcome & Introduction
1:35 PM – 1:50 PM	NOAA: mCDR Overview and State of the Science
1:50 PM – 2:05 PM	UK Oceanographic Center: State of the Science
2:05 PM – 3:05 PM	Panel: Bringing mCDR to Commercial Scale
3:05 PM – 3:55 PM	Open Q&A
3:55 PM – 4:00 PM	Closing Remarks & Adjourn

Appendix 3: Participant & Speaker Directory

Speakers

Name	Title	Affiliation
Liza Wright-Fairbanks	Field Research Manager	National Oceanic and Atmospheric Administration
Chris Pearce	Senior Marine Geoscientist	National Oceanography Centre
Sophie Gill	Marine Carbon Removal Lead	Isometric
Mónica Larrazábal	Head of Commercialization	SeaO2
Emma Heslop	Programme Specialist	GOOS
Anna Madlener	MRV Fellow	Carbon to Sea

Participants

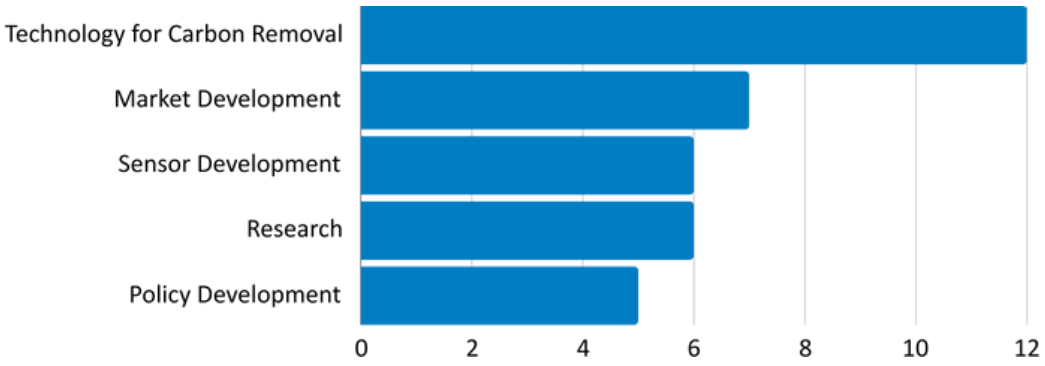
Name	Affiliation	Sector
Garry Glass	Kings College London	Academic
Tom Newton	Seafields LTD	Non-Profit
Renan Mukerjee	Green Tech Entrepreneur	Private
John Huthnance	National Oceanography Center	Non-Profit
Randall Purcell	Seafields LTD	Non-Profit
Karey Billyard	Open Ocean Robotic	Private
Gina Zeelie	Fugro	Private

Name	Affiliation	Sector
Leonardo Tamborrino	PlanBlue	Private
Mike Lee	PlanBlue	Private
Robin Sielken	TransMartech Schleswig-Holstein GmbH	Private
Florian Klabes	TransMartech Schleswig-Holstein GmbH	Private
Chris Ostrander	Marine Technology Society	Professional Society
Peer Fietzek	Kongsberg Discovery	Private
Titia Sjenitzer	Wild Ocean Consultancy	Private
Achim Hoffman	WaterWattS LTD	Private
Francesco Suzzi	Sea the Change S.r.l.	Private

Appendix 5: Slido Result

At the beginning of the workshop, Slido software was utilized to explore the participant's current engagement with mCDR. Feedback gathered from this tool is provided below.

How do you engage with mCDR?



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