# Building a Collective Strategy to Advance mCDR RD&D for Climate-Relevant Solutions

A summary of data collection and analysis developed by Merdian Institute through May 2025

October 2025

Summary authored by CEA Consulting in partnership with Ocean Visions

## About this Document

In late-2024, Ocean Visions, in partnership with the Carbon Technology Research Foundation, hired Meridian Institute to lead development of a collective strategy for the marine carbon dioxide removal (mCDR) field. The ambitious goal of this endeavor was to build a unified five-year strategy in the mCDR field that if executed, would produce a level of evidence sufficient for policy-makers and society to make decisions about the use of mCDR approaches. This goal would be achieved by creating a shared agreement around a clear set of critical priorities and by fostering aligned efforts among mCDR actors to address these priorities.

Meridian led a multi-month process that included an extensive literature review and garnering insights from over 150 actors from across the mCDR field through interviews, in-person workshops, and a virtual webinar. The Meridian project team produced a draft report in May 2025 which documented and synthesized the outcome of their work to that date.

Unfortunately, Meridian Institute closed its doors in July 2025 and so was not able to drive the strategy to completion. Ocean Visions is grateful to the Meridian team for its work, to the Advisory Group which helped guide the project, and to the experts across the mCDR field who contributed to Meridian's data collection process. That work and those contributions provided a comprehensive gap analysis and generated a foundational dataset upon which a strategy can now be built.

### The path ahead

The following document summarizes the key findings of Meridian's report and was created to share a consolidated overview of key gaps identified by Meridian. It was drafted by Amy Dickie of CEA Consulting who Ocean Visions contracted with in the wake of Meridian's closure. We are providing it to the field for its utility as a comprehensive review of gaps and needs in the space. Meridian's more expansive original overview of 11 priority areas can be found here and their entire initial draft report can be found here.

Ocean Visions maintains the conviction that a collective strategy for the mCDR field is critical to accelerating progress and compiling the needed evidence about its potential role as a climate solution, a precursor to any decisions about climate-relevant scales of deployment, should viable mCDR pathways meet their burden of proof. The overarching goal for a collective strategy is to prioritize those actions that get to the heart of the most critical uncertainties and answer them as effectively and efficiently as possible. Many of these sit outside of specific mCDR pathways and would be of benefit to the entire field

(e.g., data sharing infrastructure, pre-permitted sites, aligned narrative, cross-regional and cross-sectoral collaborations).

Ocean Visions intends to continue working toward this collective strategy for the mCDR field. Our next steps are:

1) With support from CEA, identify specific proposed actions and strategies to address the highest priority areas of collective action based on Meridian's findings and OV/CEA's existing knowledge of the field.
2) Develop five-year objectives and provisional milestones.
3) Engage a small set of mCDR field leaders and practitioners to review the strategy draft and suggest refinements.
4) Share the draft strategy with the broader mCDR field for commentary before finalizing.
5) Build engagement and working groups for specific action areas or workstreams with key actors in the mCDR field, and adjacent sectors. Our intention is to conclude this process in time to finalize the strategy in Q1 2026.

## Final reflections

There have been seismic shifts in the funding and political realities for climate work since Ocean Visions began this effort 18 months ago, most acutely in the U.S. context. These shifts only serve to heighten the imperative for our field to act strategically and collaboratively. Collectively, we must remain bold in our ambitions – because none of the realities or harsh consequences of climate change have diminished. But we must also be more intentional in our application of limited resources so that we can move urgently, decisively, carefully, and in a manner that gathers resources and support, in hopes of adding a set of powerful climate solutions to the most important fight of our generation.

## Introduction

National and sub-national governments, financial institutions, and corporations have the moral imperative and legal obligation to make *and meet* commitments aligned with the 2015 Paris Agreement[1]. Climate change is unfolding around the world in the form of increasingly intense heatwaves, droughts, floods, wildfires, sea-level rise, and expanding disease vectors, among other crises. There is a need to make dramatic cuts to greenhouse gas (GHG) emissions across all sectors and to halt and reverse deforestation and destruction of other carbon rich ecosystems such as grasslands, wetlands, and mangroves.

Yet, even in the best-case scenarios of deep emissions cuts, carbon dioxide removal (CDR) is still needed to remove legacy emissions and achieve the Paris Agreement commitments. Indeed, the Intergovernmental Panel on Climate Change Sixth Assessment Report (IPCC AR6) marked a pivotal shift in global climate strategy by unequivocally stating that CDR would be necessary to achieve global net zero GHG emissions.[2]

Marine carbon dioxide removal (mCDR) is a nascent portfolio of strategies with the potential to enhance the ocean's role as carbon sink. MCDR gained significant attention and traction following the publication of a pivotal report from the National Academies of Sciences, Engineering and Medicine (NASEM) in 2022, which suggests that collectively, mCDR pathways could potentially achieve gigaton-scale CDR.[3]

Since 2022, work on mCDR has proliferated across academia, philanthropy, and the private sector. Entities, such as Ocean Visions, have published numerous road maps for advancing foundational science on different mCDR pathways (e.g., ocean alkalinity enhancement, electrochemical removal, nutrient fertilization, macroalgae cultivation) and an ethical framework for climate intervention. Additionally, a handful of major research programs commenced to pursue answers to foundational research questions about efficacy, additionality, durability, and safety of specific mCDR solutions (e.g., OceanNETs, NOAA/NOPP, CDRmare, SeaO2, Carbon To Sea, The LOC-NESS Project at Woods Hole Oceanographic Institution). Over 50 mCDR companies also launched, securing over $200M in venture capital from sources such as Frontier—a billion-dollar program that supports offtake agreements.

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[1] The international treaty which calls on national governments to work together to limit global temperature rise to well below 2$^{O}$C, preferably to 1.5$^{O}$C, compared with pre-industrial levels.
[2] For the full report, see *Climate Change 2023 Synthesis Report: Summary for Policymakers* (2023) and IPCC Special Report: Global Warming of 1.5
[3] 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.

Currently, the scientific research, technology development, and supporting activities (e.g., policy advocacy, community engagement, MRV protocol development) for each mCDR solution are operating largely in their own silos, lacking coordination both within the mCDR field itself and with other ocean-based activities or terrestrial CDR. At best, continuing to mature in an uncoordinated and siloed manner risks making inefficient use of valuable time and resources. At worst, society could dismiss mCDR as a viable climate solution, even if safety and efficacy are proven sufficient. A collective strategy that provides a high-level goal and framework for aligned action around dimensions of mCDR that cross multiple pathways, could be highly catalytic in advancing the evaluation of mCDR as a climate solution.

Meridian's report represents another step toward fully establishing a collective strategy for the field. The objective of a collective strategy is to identify the highest priority actions that best advance the entire field to inform and enable decision-making about mCDR deployment at climate relevant scales in the future. Moreover, a collective strategy aims to create favorable enabling conditions so that the research, development, and demonstration (RD&D) pursued by each singular mCDR pathway can proceed toward safe and ethical gigaton-scale deployment or a clear decision not to advance (based on lack of effectiveness, safety, and/or desirability). Ultimately, Ocean Visions hopes that the mCDR field can develop a shared five-year strategy that provides a road map for collective action on shared priorities, a framework and catalyst for both expanded inter-mCDR collaboration and expanded collaborations with other fields, and a guide for funders interested in building soft and hard infrastructure for responsible mCDR research, development, and deployment, in anticipation of viable solutions emerging.

## Priority Elements and Gap Analysis

Meridian Institute's process included an expansive literature review, interviews with 37 experts representing a range of sectors and geographies, two participatory workshops, a virtual webinar, and review of their key findings by an Advisory Group.

This process found strong agreement among the consulted experts that having shared goals to align and guide the mCDR landscape is valuable. Meridian proposed the following Long-Term Vision and Near-Term Goal, based on their research:

- **Long-Term Vision:** Scaled deployment of mCDR pathways that are proven safe and effective to remove carbon at climate-relevant scales.
- **Big Picture Near-Term Goal:** Efficiently and expeditiously evaluate mCDR technologies for their additionality, durability, safety, and scalability to determine their viability to contribute to carbon removal at climate-relevant scales.

Meridian's report also calls for interim milestones – to be co-designed by relevant actors – to characterize stages of progress in the mCDR field's development towards the Big Picture Near-Term Goal.

The principal output of Meridian's research and the body of the project team's report are 48 "critical gaps" nested under 11 "priority areas". Together, these elements represent a comprehensive assessment of gaps and needs in the mCDR space. Individually, they present a host of important insights and suggest some concrete actions for the field.

A few data points in the Meridian report suggest first-order prioritization and sequencing among the 11 "priority areas" and subsidiary "critical gaps":

- In an expert workshop run by Meridian as part of the data collection process, informants created strategic frameworks for the field. Most frameworks generated during this exercise indicated a first order priority on ethical research and a second order priority on market and implementation-related activities.
- Most of the workshop-generated frameworks indicated activities such as RD&D and market development following a linear progression, proceeding in a stepwise fashion and making cumulative progress over time, while priorities like social science, engagement of key actors, public messaging, and governance and permitting were described as activities that need to be attended to at any maturity level or scale of jurisdiction, in iterative and on-going cycles.

- Meridian found that of the 11 priority areas identified, there was most alignment[4] around: Scaling, Life Cycle Analyses, and Deployment Preparation; Social Science, Public Engagement, and Social License; Field Building and Collaboration; and Synergy with Other Fields. Alignment was weakest around the priority element of Ethics and Community Engagement.
- **Meridian's report repeatedly underscored the need for a collective strategy for mCDR to be dynamic and to reflect the complexity of the field.**

The remainder of this document provides short summaries of the 11 priority areas identified in Meridian's report.

[4] The Meridian report defines alignment as "How **aligned** stakeholders were in their perspectives of each area's status and what the five-year goal(s) should be."

*Table 1: Alignment, Confidence, and Specificity Overview*

The visual below provides an "at a glance" qualitative view of the status of each strategic priority area from informants' perspectives of the mCDR field in general (not for specific pathways), based on three criteria. For more information on scales and scoring, please refer to Meridian's full report.

- How **aligned** informants were in their perspectives of each area's status and what the five-year goal(s) should be.
- How **confident** informants were that meaningful progress can be made in the next five years.
- How much **specificity** informants shared about a clear, field-wide perspective on what is needed in the next five years, how it will be accomplished, and by/with whom.

| Strategic Priority Area | Alignment | Confidence | Specificity |
|---|---|---|---|
| Scientific Research (R&D) | Mostly aligned | Some confidence | Some specificity |
| Pilot Projects and Field Trials | Mostly aligned | Low confidence | Low specificity |
| Monitoring, Reporting, and Verification (MRV) | Mostly aligned | Low confidence | Low to no specificity |
| Standard Setting | Mostly aligned | Low confidence | Low to no specificity |
| Scaling, Life Cycle Analyses, and Deployment Preparation | Very aligned | Some confidence | Some specificity |
| Social Science, Public Engagement, and Social License | Very aligned | Low confidence | Low to no specificity |
| Ethics and Community Engagement | Not aligned | Some confidence | Low to no specificity |
| Governance, Regulation, and Permitting | Mostly aligned | Some confidence | Low to no specificity |
| Funding, Financing, and Market Infrastructure and Demand | Somewhat aligned | Low confidence | Low specificity |
| Field Building and Collaboration | Very aligned | Some confidence | Low to no specificity |
| Synergy with Other Fields | Very aligned | Some confidence | Some specificity |

### 1. *Scientific Research (R&D)*

The mCDR field faces myriad outstanding foundational questions relating to efficacy, additionality, durability, and safety for humans and the environment. These questions must be answered by scientific research, including climate modeling, laboratory and mesocosm research, and field trials. However, **mCDR pathway specific efforts would benefit from better cross-pathway alignment and coordination to achieve timely decisions on global viability.** In particular, the field would benefit from (i) improved agreement about research timelines, (ii) collaboration with the integrated assessment modeling community (IAMs), and (iii) laboratory and mesocosm experiments that are regionally tailored and methodologically standardized in order to ensure that research is both locally relevant and comparable across studies.

Consulted experts agreed that messaging should emphasize that efforts to validate mCDR pathways as carbon removal solutions should not be seen as an implicit endorsement of deployment of those solutions. **There is an overwhelming emphasis on decoupling RD&D for mCDR pathway validation from any reference to deployment in both strategy and messaging**. A critical challenge for the mCDR field is balancing a precautionary approach with the urgency of some form(s) of carbon removal to meet the climate crisis.

### 2. *Pilot Projects and Field Trials*

Meridian's report addresses pilot projects and field trials as a separate priority to draw attention to this critical research step. Currently this work is inhibited principally by insufficient funding. The report assessed that **field trials are necessary and there are many other critical gaps which could be advanced in parallel to securing public and private funding sources for field trials**. These include development of infrastructure and incentives for data sharing, particularly between academia and private sector actors; multidisciplinary research teams and holistic research design that includes decision-makers and community representatives; a global network of pre-permitted test sites; facilities and infrastructure for long-term management of research sites.

### 3. *Monitoring, Reporting, and Verification (MRV)*

Expert informants were mostly aligned on the critical importance of advancing MRV protocols, technologies, and standards, but there is debate about the specific priority needs. In particular, experts disagree on whether the current priority ought to be on developing MRV for open ocean contexts or for coastal areas.

Barriers to conducting MRV include a lack of access to affordable high-performance computing systems, a lack of a common understanding of data needs, and a need to improve data management and enable data sharing within the scientific community. A few

informants specifically called for interoperable modeling systems. **Others hold the perspective that high resolution measurement of carbon uptake by/in the ocean is a gap that is not possible to fill, suggesting instead that the focus be on quantifying the level of uncertainty.**

### *4. Standard Setting*

Most expert informants see the need to create various standards across the field of mCDR to support collective decision-making. This includes establishing metrics and standards for evaluating durability, additionality, ecological, and socio-economic impact, as well as establishing stage-gates and criteria-based protocols to pause or terminate projects if risks (ecological, social, or technical), costs, or scalability factors are prohibitive, and/or if there is insufficient durability or additionality as informed by adaptive thresholds (off-ramps). The field also needs to establish acceptable thresholds for uncertainties and margins of error, especially regarding open system research, and time-bound targets.

**There is little agreement on specific metrics for either the efficacy (in terms of additionality and durability of carbon removed) or environmental and social impact of mCDR methods.** Expert informants also noted insufficient research, data, and standards and metrics for evaluating the social, economic, and intergenerational impacts of mCDR.

A lack of uniform standards, criteria, and protocols is likely to make decision-making processes challenging and ambiguous, risks delayed timelines, and could undermine public confidence in the mCDR field. Standards are lacking in part because MRV protocols are largely still underdeveloped, but also because the field has not yet organized to advance these conversations.

### *5. Scaling, Life Cycle Analysis (LCA), and Deployment Preparation*

**Expert informants are very aligned on the need to develop holistic life cycle assessments (LCAs)[5] that cover multiple benefits, conduct scalability analyses that address environmental and social factors, and address supply chain infrastructure gaps.**

Specifically, there is a need for 1) evaluation of technical, economic, and environmental feasibility for scaling mCDR to gigaton levels, 2) holistic assessment of resource needs and constraints (e.g., energy, minerals), supply chains, and environmental, social, and economic impacts across mCDR value chains, including multi-benefits and trade-offs, and

[5] A Life Cycle Assessment (LCA) is a comprehensive methodology that evaluates the environmental impacts of a product, process, or service across its entire lifespan, from raw material extraction through manufacturing, use, and disposal.

3) deployment of infrastructure (e.g., mineral processing, offshore platforms, pipelines) to support mCDR operations at scale.

Other specific recommendations included advancing interdisciplinary approaches to better understand the full life cycle of mCDR interventions; securing more field data to feed into LCAs; expanded research on multiple benefits of mCDR; improved data management, sharing, and prioritization for LCA modeling; and analysis of infrastructure development needs for mCDR. Finally, scalability analyses should account for ecological and social factors and complex scenarios where multiple mCDR pathways are deployed or in which mCDR is deployed in tandem with terrestrial CDR.

### 6. *Social Science and Social License*

There is a clear need for the mCDR field to develop social research, communication strategies, and public engagement that: builds societal awareness, participation, and support for mCDR research; counters disinformation that could derail mCDR research and potential deployment trajectories; addresses the "moral hazard" that mCDR may represent; and communicates mCDR risks and potential multiple benefits. Expert informants also agreed with the need to develop more social standards, metrics, and indicators (about status, level, or condition of social readiness), including defining societal readiness levels (SRL).[6] However, **expert informants consistently had low confidence in the mCDR sector's ability to implement priorities around social science and social license in the short term and only a few informants offered concrete ideas for key messages or engagement strategies.**

Additionally, expert informants highlighted the importance of the following approaches to building social license:

- Aligned messaging, clearly communicating that mCDR research does not imply an endorsement of scaled deployment, and utilizing trusted, appropriate messengers.
- Targeted communications for policy- and decision-makers.
- Engagement strategies that involve both impacted communities and broader society, which stands to potentially benefit from mCDR.
- A process for continuous engagement and monitoring of support for mCDR as the field grows.
- Expanded legal and social science research for mCDR.
- Expanded communications around costs, benefits, trade-offs, and risks.

[6] Societal Readiness Levels (SRL) assess a society's preparedness to accept and integrate an innovation, complementing Technology Readiness Levels (TRL) by evaluating social, ethical, and economic factors alongside technical maturity. An example SLR framework from the Innovation Fund Denmark can be found here.

### *7. Ethics and Community Engagement*

**The Ethics and Community Engagement priority area had the least alignment across expert informants, of the 11 highlighted in Meridian's report.**

Some expert informants hold the view that mCDR presents complex ethical and environmental justice questions that have not been adequately addressed, including intergenerational justice considerations. **While informants were very aligned about the need for inclusive and early engagement processes for communities that will be directly impacted by mCDR research and potential mCDR deployment there is a lack of strategic clarity on the most effective strategies for conducting it.** Some argued that regional-scale engagement could be more effective than project-specific approaches.

**There is also little to no alignment on the best approach to capacity building to ensure informed participation by impacted communities in decision-making processes.** Furthermore, there is a notable lack of specificity regarding how to address scenarios involving ethical dilemmas (e.g., uneven distribution of adverse and beneficial impacts).

Those informants with expertise in community engagement noted that **community engagement takes years and requires continuous engagement.** Others emphasized the importance of participatory-research and decision making and that having neutral parties resource and facilitate engagement efforts is a useful approach to building trust and transparency. To the later point, there is concern that under the current U.S. administration, federal funding for social research and specifically community engagement will be eliminated and the gap likely filled by the private sector (not a neutral party).

### *8. Governance. Regulation, and Permitting*

International governance and domestic legislation and frameworks will be essential to advancing mCDR research (and potential deployment) and building social license, while ensuring safeguards are in place to protect people and the environment. This is because, should mCDR be deployed at scale, decisions and impacts are unlikely to remain within a single country's jurisdiction. However, the field currently lacks a comprehensive international legal framework for mCDR research and deployment.

The negotiation of international agreements and policy development takes extensive time and enormous political will.[7] Expert informants expressed the need for mechanisms to encourage and enable coordination within and between governments to expedite the development of enabling policy environments for mCDR research and preparation for

[7] For challenges relating to ocean governance, see *A code of conduct for marine carbon dioxide removal research*, (2023).

potential deployment. **Some consulted experts emphasized the importance of policies striking a balance between precaution and action.**

Expert informants were somewhat aligned about the usefulness of codes of conduct in the absence of legal frameworks. However, **expert informants expressed little to no confidence in actors relying on (or adhering to) codes of conduct or principles to guide their work** and were unable to provide specificity on alternative approaches to encourage the adoption of such codes or principles.

### 9. *Funding, Financing, and Market Infrastructure and Demand*

Funding for mCDR is arguably the biggest bottleneck for advancing research in the field and is necessary across the different priority areas. **With limited funding from governments and philanthropies, there is clearly a need for a coordinated process to decide on the priorities for the field to guide what funding exists in the most strategic way possible** – to the extent this is possible given competing agendas and priorities of actors in the field.

Many expert informants noted that developing market infrastructure and demand are necessary both to fund RD&D as well as to prepare for the potential future deployment of mCDR at climate-relevant scales. **There is a general assumption that funding for scaled mCDR deployment will come from carbon markets. However, carbon markets will not be feasible until mCDR technologies and companies can produce high-quality and high-integrity carbon credits. Moreover, market infrastructure is currently underdeveloped, and demand signals remain weak.**

Some private sector entities are generating demand through advanced market commitments (AMCs). Expert informants had mixed perspectives on the benefits and risks of AMCs and other early-stage investment pathways to build demand. In the process of identifying market strategies, there was a general sense that mCDR practitioners should evaluate the risks and benefits of leveraging commercial deployments to generate demand and develop the market for mCDR.

Additionally, expert informants highlighted the importance of the following actions for engaging funders:

- Articulating interim RD&D targets and associated costs
- Mapping the funder landscape, particularly the international public funding landscape
- Developing multi-benefit funding strategies
- Developing blended finance solutions

### *10. Field Building and Collaboration*

Expert informants are very aligned on the importance of advancing coordination, collaboration, knowledge sharing, and building both international and domestic partnerships within the field. In particular, **informants cited the need for more trust building, transparency, information sharing, and coordination between industry, government, academia, and non-governmental organizations.** Additionally, informants called for greater collaboration across international, national, and sub-national fora.

Some noted that the relatively small size of the field and its early stage of development make now an opportune time to invest in more field-building and collaborative processes. Informants agreed that increased collaboration would also support more strategic utilization of scarce funding and serve a critical role in successfully developing technical and social aspects of mCDR in tandem.

To improve collaboration and communication, the field must explore methods and incentives for building strategic partnerships and networks. For example, **the U.S. National mCDR Research Strategy (which may now be defunct) proposes the creation of mCDR research hubs which could support pooled funding, promote innovation and collaboration, support capacity building, and leverage efforts in related fields, a model which could also be adopted in other countries.**

### *11. Synergies with Other Fields*

**Expert informants repeatedly described the mCDR field as existing in an "echo chamber". Informants are generally aligned regarding the need to build synergies between the mCDR community and broader scientific and climate communities (in particular oceanographic and climate change mitigation), and various marine industries, as well as with the integrated assessment modeling community.**

There are potential synergies and learnings to be gained between mCDR and other ocean-dependent activities such as offshore wind, marine energy, desalination, ecosystem restoration, and fisheries for sharing offshore infrastructure. There may also be a need to analyze the benefits, risks, and impacts of mCDR in the context of other climate change solutions and mitigation strategies such as terrestrial CDR.

MCDR has a number of characteristics that create barriers to collaborating with other fields, such as bespoke technological requirements and regulatory barriers**. Nevertheless, there may be readily accessible opportunities to exchange lessons learned in community capacity development, building social license, market development, and standard setting across adjacent fields.**