

# THE OCEAN CARBON DIOXIDE REMOVAL DECISION-MAKING LANDSCAPE

Who is involved?  
Who should be?  
What do they want to know?  
What do they worry about?

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# Executive Summary

Ocean carbon dioxide removal (OCDR) research is advancing rapidly as part of a global hunt for effective climate mitigation actions. Currently, knowledge about OCDR is primarily technical, although a broader range of people with ocean interests will soon need different information about OCDR to help them make decisions about the intersection of this ocean use with their activities. This report evaluates the perspectives and concerns of different groups currently or imminently involved in OCDR in the U.S. and outlines the information they seek.

This report examines 12 interest groups in the U.S. OCDR community, spanning from specialists like academic researchers to general information users in civil society. We evaluated public-facing products from each interest group, then conducted semi-structured interviews and informal conversations with interest group members to learn about their interests, activities and concerns. Following the analysis of each interest group, we synthesize the most prominent themes.

Almost every group has considered their engagement with OCDR, inspiring conversations about the desire for precautionary research, transparency and ethical behavior, as well as concerns about reputational risk from engaging on the topic. Some information needs emerged across nearly every interest group, while other concerns were limited to just a few interest groups. Knowledge creators, including researchers and community-facing science organizations, have thought deeply about elements of the OCDR research process; they seek to join multidisciplinary collaborations, secure funding and leverage existing assets following applicable rules and regulations. Some of the OCDR interest groups have also thought about how to grow a community of practice that will endure. Interest groups focused on eventual OCDR implementation were keenly interested in verifying carbon removal, minimizing environmental and social impacts, and understanding interactions with other ocean uses and goals, including international climate commitments.

Nearly all groups stated a desire to avoid unregulated pilot tests.

This research found that opportunities exist to support the growth and development of OCDR research, particularly through community building. However, trust is low between many OCDR interest groups. Engagement on OCDR is not equitable; there is a relatively small and privileged OCDR community with limited racial, disciplinary, geographic or economic diversity. A few organizations have started to create bridges between groups, but it will take dedicated effort to develop trust that supports multidisciplinary, equitable collaboration. Depending on the prioritization of transparency and data sharing around OCDR, some entities may never become highly trusted. We need coordination to ensure OCDR interest groups are pursuing compatible goals and standards, and we are seeing encouraging signs of progress, especially from community-led, bottom-up initiatives. However, there are significant ethical risks related to privatization and liability, which must be addressed before implementation of any OCDR technique.

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# Introduction

This report defines the OCDR community as broadly as possible, including everyone who currently has an interest in OCDR.

The Intergovernmental Panel on Climate Change (IPCC) has reaffirmed that climate change is happening, and it is unequivocally due to human influence (IPCC, 2021). Current national greenhouse gas emissions commitments put the planet on track to warm 2.7°C by 2100 (UNEP, 2021), despite the Paris Agreement goal of limiting warming to 1.5–2°C. All climate scenarios that limit warming to 1.5°C with little or no temperature overshoot require atmospheric carbon dioxide (CO<sub>2</sub>) removal (IPCC, 2018). Since the release of the IPCC Special Report on 1.5°C (IPCC, 2018), there have been substantial U.S., E.U. and private research investments in ocean carbon dioxide removal (CDR). Ocean CDR methods seek to enhance one or more natural biological or geological processes to increase the ocean’s uptake and/or storage of anthropogenic CO<sub>2</sub> from the atmosphere.

The U.S. National Academies of Sciences, Engineering, and Medicine (NASEM) published “A research strategy for ocean-based carbon dioxide removal and sequestration”

in 2022;<sup>1</sup> this report provides an essential review of six main approaches to OCDR and includes research recommendations to close knowledge gaps. We refer the reader to the NASEM report for definitions and discussions of OCDR approaches, and background about the ocean’s role in planetary climate regulation. Among other things, the NASEM report concludes that the technical details of OCDR are better understood than the ecological and social outcomes.

At this early stage in OCDR research, targeted business interests and/or researchers are the ones primarily producing information. Natural scientists are more involved than any other group; but, as OCDR technologies are researched and tested, additional people with ocean interests—including marine resource-dependent businesses (e.g., fisheries and ecotourism), resource managers, government representatives and citizen groups—will more frequently need information about OCDR to make decisions about this new ocean use. The following report evaluates the perspectives of people involved in OCDR now, primarily in the U.S.,

<sup>1</sup> 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.



to identify the emerging information needs of major interest groups.

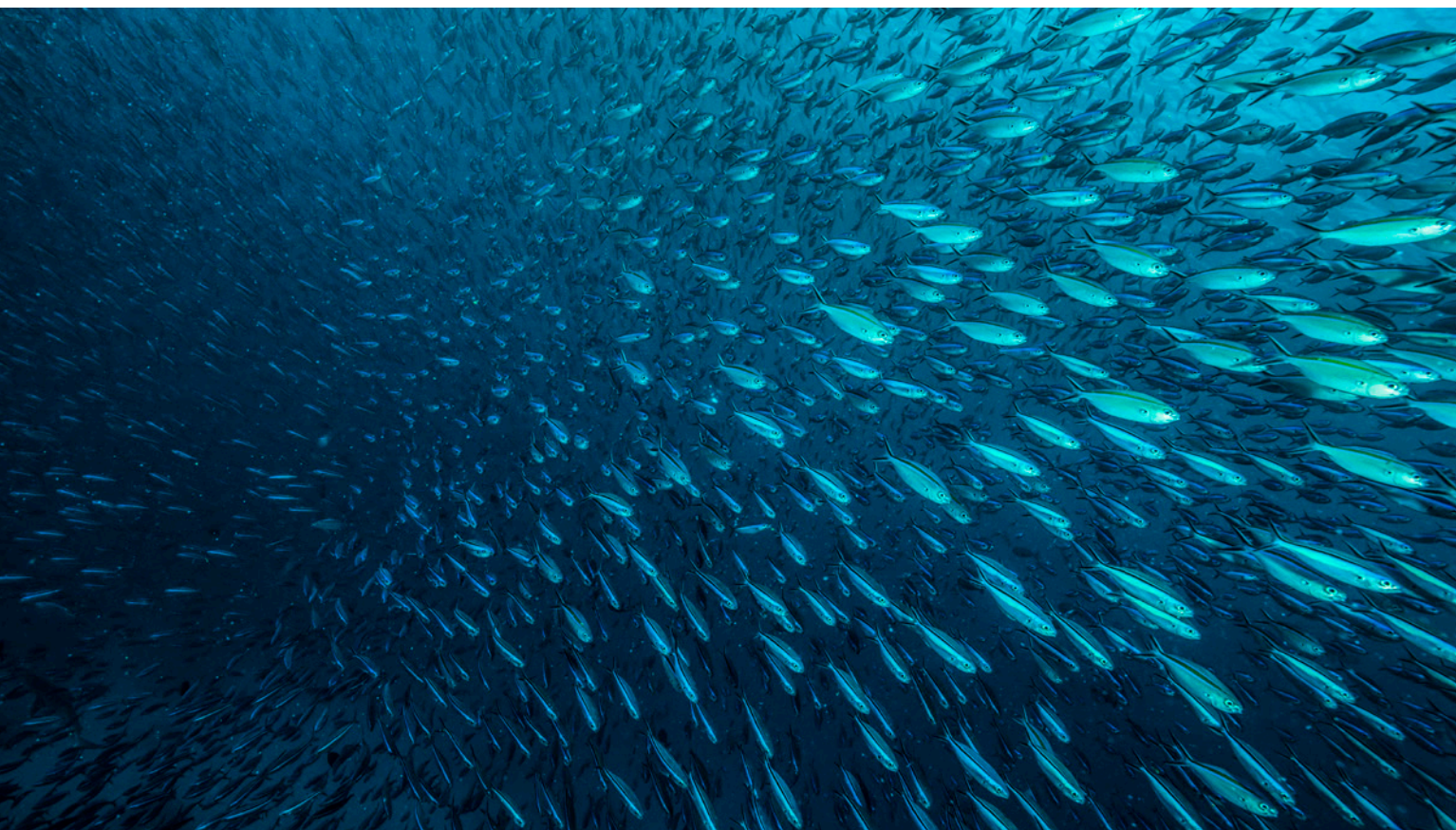
This report defines the OCDR community as broadly as possible, including everyone who currently has an interest in OCDR. Interest groups, or subgroups, within the OCDR community include researchers, research consortia, funders (including industry, philanthropic, and federal funders) and organizations building the regulatory environment for OCDR. If OCDR research or implementation affects other ocean uses or ocean ecosystems, civil society groups active on those topics will eventually also be important to decision-making about OCDR. These groups could include coastal communities, Indigenous peoples, labor organizations and more, who

all have an interest in the ocean's well-being but who are not routinely included in decision-making about new ocean uses. Presently, these groups are less identifiable than other OCDR stakeholder groups because connections between OCDR and other ocean issues are still being established. To gather information about the extent of the OCDR community, we reviewed the public-facing materials created by different interest groups, and we interviewed representatives of as many interest groups as possible for greater insight.

The next section of this report describes the different OCDR community interest groups that are currently following or involved in OCDR. It evaluates their current engagement, future directions and

the concerns or obstacles that affect their involvement with OCDR. This report relies on information gathered during workshops, literature reviews, internet searches, public presentations and individual conversations with ocean and OCDR leaders. We focused primarily on OCDR research, not implementation, because the community is still far from implementing any OCDR technique at scale for the sole purpose of removing anthropogenic carbon.

The final section of this report synthesizes the common concerns and information needs expressed by interest groups. The information gathered provides a much clearer picture of the major entities involved in OCDR, the information they seek, and their concerns.



# Interest Group Analysis

Organization type strongly influences people's interests

## METHODS

This analysis of the U.S. OCDR community was conducted from March to December 2022. We defined the U.S. OCDR community as including anyone based in the U.S. who has engaged on OCDR in public or semi-public forums ranging from webpages to small-group expert meetings.

First, we investigated how to define interest groups within the OCDR community. We hypothesized that the breadth and duration of experience with OCDR (knowledgeability and longevity) would most strongly influence information needs and concerns. Instead, the type of organization to which people belonged was the primary controller of interest groupings within the OCDR community. We found that most individuals' engagement with the topic is greatly shaped by their organization's mission and ways of working. Different perspectives and approaches to OCDR existed across the interest groups we identified, but within interest groups, views and concerns most frequently agreed. This report evaluates 12 interest groups in the U.S. OCDR community (presented below, alphabetically).

Second, we evaluated public-facing materials and public activities from within the 12 interest groups

we identified. We evaluated OCDR-specific content, organizational philosophy and topically relevant content. We sought to understand the landscape in which these groups were operating, their history on the topic and their future aspirations.

Third, we spoke to a wide range of OCDR community members informally and formally throughout the research project to learn more about their interests, their activities and their concerns. We were able to speak informally to many attendees of several OCDR- or climate intervention-focused convenings. These events provided a more comprehensive view of the perspectives held by organizations and the knowledge gaps they encountered, and they acquainted us with a wider array of interest groups and representatives. We conducted more formal semi-structured interviews with 15 selected leaders representing different interest groups. Interviews discussed their OCDR decision-making and involvement; OCDR research collaborations; rules, regulations and ethics considerations; and overlaps between OCDR and other issues they are following. To allow interviewees the ability to speak more candidly, we paraphrase



and anonymize their remarks in this report. The semi-structured interview questions and interviewees are listed in the Appendix.

Finally, we synthesized all the information gained from literature reviews and from informal and semi-structured conversations into this report. Each interest group is discussed separately, and the final synthesis identifies common themes, concerns and opportunities for future community-development activities. Addressing these needs now will contribute to improved information about OCDR that will support evidence-based decision-making in the future.

## INTEREST GROUPS

### Academic Institutions

A few academic institutions are embracing OCDR research, including Woods Hole Oceanographic Institution (WHOI) and GEOMAR-Helmholtz Center for Ocean Research (GEOMAR). Academic institutions' engagement in OCDR research is multi-dimensional: they support and promote the engagement of their researchers on OCDR; they help disseminate knowledge created by their researchers; they secure funding to support longer-term research; and they train the next generation of experts.

Academic institutions that are applying their scientific expertise, research capabilities and facilities to OCDR have noted that several of their research specialties align with OCDR research needs. For example, WHOI plans to continue basic research on ocean carbon cycling and applied research on technologies like sensors, remotely operated vehicles and numerical modeling.<sup>1</sup> WHOI has also developed a multi-year partnership with the Propeller Fund, a venture capital firm (also see *Industry Funders* below),<sup>2</sup> to support development of ocean-based climate solutions, including OCDR.<sup>3</sup> In Europe, GEOMAR

<sup>1</sup> WHOI. 2021. *Vision 2030: Ocean Science for the Global Good*. <https://www.whoi.edu/wp-content/uploads/2021/11/WHOI.Vision.2030.pdf>

<sup>2</sup> <https://www.propellercv.com/>

<sup>3</sup> WHOI, 2022. *Propeller Announces \$100 Million Fund to Invest in Ocean-Climate Companies*. <https://www.whoi.edu/press-room/news-release/propeller-announces-100-million-fund-to-invest-in-ocean-climate-companies/>



is leveraging decades of research on ocean ecosystems and ocean acidification to help answer questions about nature-based carbon removal and ocean alkalinity enhancement.<sup>4</sup> Other academic institutions are involved in research consortia like ExOIS and science programs like Ocean Visions (also see *Research Consortia* and *Science Programs* below) but have not established major OCDR initiatives.<sup>5</sup>

Representatives of academic institutions with whom we spoke underscored their dedication to understanding OCDR. They shared a commitment to collaboration and data sharing to support oceanographic research, which will likely remain central to the development of monitoring, reporting and verification (MRV)<sup>6</sup> strategies. Academic institutions have traditionally struggled to secure long-term funding for planetary baseline research or risky research (projects with a higher-than-normal possibility of failure), but the development of innovative OCDR research finance mechanisms by academic institutions may inspire novel pathways and partnerships to support other types of ocean and global change

research. With a shift towards more industry-research partnerships on OCDR, academic institutions may need to dedicate additional attention to legal agreements (e.g., intellectual property, memoranda of understanding) that will support fruitful partnerships and the development of related startup companies. Deeper involvement with industry may raise two questions for academic institutions: whether these agreements affect the objectivity of institutions' research, a question often asked about medical studies; and whether these agreements align with institutions' missions to increase public knowledge, and not to privatize information.

### Civil Society

During this project, we spoke with members of civil society—including coastal community members, civil society organizations (CSOs), local government officials and ocean-loving people, and we found that they are not generally aware of OCDR. Most people have not encountered OCDR yet as they have other emerging ocean and coastal topics like ocean renewable energy, climate-ready coastal communities

and shared ocean uses. As a result, the little information available about how people might perceive and support OCDR activities suggests that their views are more strongly influenced by their concern about climate impacts and their overall value systems than by tangible examples of OCDR in their communities.<sup>7</sup>

Ocean Conservancy spoke with representatives of a CSO that works with decision-makers who noted that OCDR will complicate the existing complex ocean policy landscape. It is already a challenge to ensure shared, sustainable uses of the ocean (e.g., aquaculture expansion, research, cultural activities, environmental restoration, “blue economy” development) within a variety of overlapping governing policies administered by a range of agencies with different missions. Balancing rules and regulations about permitting, oversight, long-range planning, equity, decommissioning and conservation in the marine sector is already a slow, winding process. It is unclear how OCDR will interact with ongoing marine activities. This CSO concluded

<sup>4</sup> GEOMAR, 2023. *Ocean-based carbon dioxide removal strategies (CDRs)*. <https://www.geomar.de/en/research/fb2/fb2-bi/research-topics/tipping-points-2>

<sup>5</sup> <https://oceaniron.org/who-we-are/>, <https://oceanvisions.org/the-ocean-visions-network/>

<sup>6</sup> Monitoring, reporting, and verification (MRV) are required to demonstrate that removal of carbon by any OCDR technique is additional to carbon removal by natural processes, and to prevent “double counting” of any carbon removals. MRV is explained in plain language here: <https://www.worldbank.org/en/news/feature/2022/07/27/what-you-need-to-know-about-the-measurement-reporting-and-verification-mrv-of-carbon-credits>

<sup>7</sup> Cooley SR, Klinsky S, Morrow DR, Satterfield T. 2023. Sociotechnical Considerations About Ocean Carbon Dioxide Removal. *Annual Review of Marine Science* 15:1 <https://www.annualreviews.org/doi/10.1146/annurev-marine-032122-113850>; Bertram C and Merk C. 2020. Public Perceptions of Ocean-Based Carbon Dioxide Removal: The Nature-Engineering Divide? *Frontiers in Climate* 2:594194. doi: 10.3389/fclim.2020.594194; Veland S and Merk C. 2021. Lay person perceptions of marine carbon dioxide removal (CDR). Working paper D3.3. OceanNETs, Kiel, Germany, 24 pp. DOI 10.3289/oceannets\_d3.3; Climate Nexus 2022. Coastal Americans Overwhelmingly Support Ocean-Based Carbon Dioxide Removal & Are Alarmed About Climate Change Impacts; <https://climatenexus.org/media/pdf/Ocean-Poll-Press-Release.pdf>.



that OCDR approaches with potentially significant conservation improvements or public co-benefits would be more likely to gain public support than other approaches.

People have repeatedly expressed concerns about the motivations of various interest groups, the transparency of research and whether investments in OCDR will divert attention or resources from emissions reduction. Other concerns focused on how OCDR decision-making can be made inclusive, especially to involve underrepresented communities, and how liability for adverse OCDR outcomes can be assigned. Researchers have repeatedly called

for climate intervention research to include vulnerable communities, both for moral reasons and to make research more comprehensive; neither has been accomplished consistently within climate intervention research<sup>8</sup> or OCDR research.

### Industry Funders

There are several groups of funders engaging in the OCDR community, including those associated with industry (e.g., most commonly, e-commerce). Some venture capital firms seek to directly support development of ocean solutions by funding individual projects. However,

many industry funders are developing climate action and carbon removal priorities in addition to their main business. Rather than fund research projects individually, several of these businesses have collaborated to create Frontier, a nonprofit “focused research organization”<sup>9</sup> that provides advance market commitments (AMCs) to purchase carbon removal, which connects purchasers of carbon removal with carbon removal companies. This format creates time-bound goals that accelerate development of carbon removal techniques and verification of the quantity of CO<sub>2</sub> removed. Carbon removal payments from Frontier,

<sup>8</sup> Carr WA. 2015. Vulnerable Populations’ Perspectives on Climate Engineering. Dissertation, University of Montana. <https://scholarworks.umt.edu/cgi/viewcontent.cgi?article=11911&context=etd>

<sup>9</sup> Marblestone A, Gamick A, Kalil T, Martin C, et al. 2022. Unblock research bottlenecks with non-profit start-ups. *Nature*. <https://www.nature.com/articles/d41586-022-00018-5>



provided by these industry funders, are awarded to startups that are expected to deliver a specific amount of carbon removals by a certain date, based on Frontier's scientific and business evaluations. Some of the startups that have received awards from Frontier<sup>10</sup> are developing OCDR techniques. However, a universal challenge for OCDR is verifying that carbon removals induced by the particular intervention supported are in fact additional to carbon removal by natural processes; this is especially salient for funding approaches where financial support is connected to achievement over time.

Industry funders feel that the AMC approach is especially useful in engaging industries interested in contributing to climate solutions, while not requiring each business to have carbon removal experts on staff. Venture capital funders, in contrast, more frequently retain issue experts to guide their investing. The AMC funding structure is thought to incentivize the whole OCDR community to progress competitively towards quantifiable carbon removal,<sup>11</sup> while also accommodating risk of failure or incomplete achievement of goals. Additionally, this approach to incentivizing OCDR research could permit new discoveries to evolve the field rather than bet on one type of technique early in research and development. Industry funder representatives did express

concerns about the need for research transparency and attention to environmental and ethical outcomes of any OCDR technique that was funded, partly to make sure outcomes remained aligned with funders' sustainability principles. Although this approach could rapidly advance OCDR research, it also seems likely to keep OCDR highly privatized and controlled by groups with the most resources, connections and ability to create a winning proposal.

### Industry Researchers

Dozens of companies have been founded in the last few years to research, develop and scale OCDR techniques. No two are exactly alike; startups are pursuing countless variations in OCDR methods, research and locations. Many companies are approaching OCDR through activities such as macroalgal culture, electrochemistry, enhanced circulation (e.g., artificial down/upwelling), CO<sub>2</sub> removal from water or alkalinity enhancement/enhanced weathering. Most companies appear to be privately held, whereas a few are public benefit corporations or nonprofit organizations. Some have spun off from academic research institutions.

Presently, many startups are engaged in OCDR research and are gearing up toward pilot-scale studies; some have competed successfully for prizes<sup>12</sup> and AMCs to purchase carbon

removal.<sup>13</sup> Many startups rely heavily on collaborations or partnerships with academic researchers. If OCDR techniques can scale up, it is likely that startups and private companies would conduct carbon removal activities directly. However, they will require external partnerships (with federal science agencies, for-profit companies, or to-be-established regulatory entities) to monitor, report and verify carbon removal.<sup>14</sup>

Industry researchers believe—personally and organizationally—that the urgency of climate change requires quick solution development. In our conversations, they all noted that they feel pressure to move quickly but cautiously. They have been expected to advance OCDR research along a specific timeline and budget without turning public opinion against their company or OCDR broadly. Industry researchers expressed similar fears as other researchers and NGO representatives about “bad actors.” The majority of industry scientists we spoke to volunteered information on their efforts to operate safely and ethically within rules and regulations, but lack of clarity on OCDR-relevant policy makes it nearly impossible for them to do this with certainty. They also discussed related tensions regarding the need to develop proprietary offerings while also advancing knowledge collaboratively

<sup>10</sup> <https://frontierclimate.com/portfolio>

<sup>11</sup> <https://www.greenbiz.com/article/inside-frontier-fund-pioneering-new-model-carbon-removal-investments>

<sup>12</sup> <https://www.xprize.org/prizes/carbonremoval>

<sup>13</sup> <https://frontierclimate.com/portfolio>

<sup>14</sup> This idea was discussed at length during the Fall 2022 workshop hosted by the U.S. Ocean Carbon and Biogeochemistry Project: <https://www.us-ocb.org/marine-co2-removal-workshop/>

and demonstrating ethical behavior, both of which require transparency and data sharing. Concerning the environmental impacts of OCCR techniques, one industry researcher mentioned that their company was trying to measure “everything” at first, but then gradually streamlined monitoring as outcomes from their OCCR approach became clear. However, this approach will probably not provide all the details that some other interest groups need for their own decision-making about OCCR.

### **National Government & National Science Agencies**

The executive and legislative branches of the U.S. government, long responsible for overseeing stewardship and use of the nation’s

resources, are also responsible for delivering on the Paris Agreement commitments to mitigate global CO<sub>2</sub> emissions. As a result of a broader focus on decarbonizing the U.S. economy and Intergovernmental Panel on Climate Change (IPCC) advice on the need for carbon removal, the U.S. government has begun to dedicate assets and attention to mitigation research, and federal science agencies are beginning to help support and implement that research.

In late 2021 and 2022, the NASEM report kicked off a broad public conversation about OCCR by bringing together existing knowledge and charting a path for further research by U.S. scientific groups. In parallel, federal science

programs and agencies<sup>15</sup> began to evaluate how their missions and ongoing work relate to CDR and OCCR, participating in interagency discussions and creating agency products like the 2022 NOAA CDR Research Strategy.<sup>16</sup> NOAA’s ocean and carbon cycle observing activities provide the baseline information needed to support most OCCR research. NSF has long supported research on aspects of the ocean carbon cycle (e.g., physical and biogeochemical processes affecting ocean carbon movement and storage) and currently supports research on carbon dioxide removal.<sup>17</sup> In addition, DOE’s Fossil Energy and Carbon Management is the designated lead for carbon removal research nationwide.<sup>18</sup>

<sup>15</sup> At present, the list includes the National Oceanographic Partnership Program, the White House Subcommittee on Ocean Science and Technology Policy, the U.S. Global Change Research Program, the U.S. Carbon Cycle Science Program, DOE, DOI, EPA, NASA, NOAA, NSF, ONR, USACE, USDA, and USGS.

<sup>16</sup> Cross JN, Gledhill DK, Sweeney C, Butler J, et al. 2022. NOAA Carbon Dioxide Removal Research: A White Paper documenting a Potential NOAA CDR Science Strategy as an element of NOAA’s Climate Mitigation Portfolio NOAA draft strategy. <https://sciencecouncil.noaa.gov/Draft-CDR-Strategy>

<sup>17</sup> Several current NSF awards address “carbon dioxide removal,” as of 1/9/2023: <https://www.nsf.gov/awardsearch/advancedSearch>

<sup>18</sup> <https://www.netl.doe.gov/carbon-management>



Later in 2022, members of the 117<sup>th</sup> U.S. Congress introduced several pieces of legislation related to OCDR, seemingly in response to policymakers' broader overall interest in finding new climate solutions. For example, the Carbon Removal and Emissions Storage Technologies (CREST) Act of 2022<sup>19</sup> sought to add consideration of OCDR to existing federal CDR programs, and the Federal CO<sub>2</sub> Removal Leadership Act<sup>20</sup> required the Secretary of Energy to remove carbon dioxide from ambient air or seawater. Both bills placed a strong emphasis on DOE.

Representatives of most Congressional offices and federal science agencies we spoke to are new to OCDR. There are few introductory-style resources outside of the peer-reviewed literature available on OCDR, and legislative staff are seeking to learn more about specific OCDR techniques and how they differ from other carbon removal techniques. Staff also want to know how a research code of conduct could support or guide research activities, and which policies applicable to regulating OCDR are needed. Agency representatives noted the existence of barriers among agencies working on OCDR related topics, which could hinder research as well as coordination of multi-agency research, MRV and OCDR oversight. The interaction of OCDR research with other science

agency missions (e.g., resource management, permitting of ocean uses, environmental impact assessment) poses countless questions. For example, deciding which agency is responsible for researching or regulating various aspects of OCDR continues to be a topic of interagency discussions. We also heard about barriers like different ways of working, varying priorities and prior lack of collaboration on OCDR-related topics.

### **Nonprofit/Non-governmental Organizations (NGOs)**

Non-governmental organizations (NGOs) considered here include nonprofit organizations that advocate primarily for environmental conservation and relevant policies. These organizations sometimes engage in lobbying directly for policy changes, and they frequently use education and mobilization to advance conservation. For issues arising out of the geosciences, NGOs focus on their intersection with natural resource management, natural systems, environmental protection and governance/policy.

Until recently, most NGO attention has focused on terrestrial and atmospheric carbon removal. These techniques include atmospheric carbon capture (use) and sequestration (CCS/CCUS) or direct

air capture (DAC), and terrestrial nature-based and geologically based carbon removal. NGOs primarily advocate for direct CO<sub>2</sub> emissions cuts to address the source of climate change directly, while acknowledging the need for research on carbon removal technologies to address legacy emissions untouched by emissions cuts. Both climate- and environment-focused NGOs advocate for policies that address the causes and impacts of climate change in natural and social systems. Given their primary mission to protect biodiversity, many environmental conservation NGOs see nature as a multi-talented ally in building both climate resilience and storing carbon, rather than only offering storage.

A few NGOs are now focusing specifically on OCDR, calling for a precautionary approach that involves more multidisciplinary research, adoption of research codes of conduct, and dedicated attention to the interaction of OCDR with other marine policy and marine resource management topics. In 2022, Natural Resources Defense Council (NRDC), Environmental Defense Fund (EDF) and Ocean Conservancy collaborated on calling for a research code of conduct<sup>21</sup> and producing issue briefs describing OCDR techniques to influence the policy discussion.<sup>22</sup> Research codes of conduct are thought to decrease

<sup>19</sup> <https://www.congress.gov/bill/117th-congress/senate-bill/4420>

<sup>20</sup> <https://www.congress.gov/bill/117th-congress/senate-bill/4280/text>

<sup>21</sup> Loomis R, Cooley SR, Collins JR, Engler S and Suatoni L (2022) A Code of Conduct Is Imperative for Ocean Carbon Dioxide Removal Research. *Frontiers in Marine Science*. 9:872800. doi: 10.3389/fmars.2022.872800.

<sup>22</sup> <https://oceanconservancy.org/climate/publications/ocean-carbon-dioxide-removal-methods/>



the risk of unintended consequences and increase transparency. EDF produced a series of white papers on ocean-based pathways for climate mitigation, with an emphasis on nature-based processes.<sup>23</sup> World Resources Institute (WRI) also produced an issue brief on OCDR in 2022, which calls for a balanced approach to OCDR development and deployment that weighs the urgent need for CO<sub>2</sub> cuts against the environmental and social risks of OCDR.<sup>24</sup> Some NGOs had limited discussions about OCDR-relevant

legislation with Congressional staff in 2022 as well. OCDR governance seems like a natural focus area for NGOs in the future, given many NGOs' longstanding work on other marine policies and place-based marine resource use.

NGO representatives were particularly concerned that excitement around OCDR would undercut efforts to swiftly cut CO<sub>2</sub> emissions society-wide. Developing new technologies could divert resources needed to implement seemingly less exciting actions that

are ready now (e.g., system-wide electrical grid changes, shipping emissions reduction, renewables expansion).<sup>25</sup> In addition, NGO representatives worried that implementing new technological climate solutions instead of fixing unjust social systems increases the risk of shortchanging other goals around equitable human development and biodiversity conservation. There is also debate among NGOs about conservation strategy more broadly: how much emphasis to place on protecting

<sup>23</sup> <https://www.edf.org/sites/default/files/2022-10/Natural%20Climate%20Solutions%20in%20the%20Open%20Ocean%20-%20EDF.pdf>, <https://www.edf.org/sites/default/files/2022-10/Coastal%20Natural%20Climate%20Solutions%20-%20EDF.pdf>, <https://www.edf.org/sites/default/files/2022-10/Carbon%20Sequestration%20by%20Seaweed%20-%20EDF.pdf>

<sup>24</sup> <https://www.wri.org/research/responsible-informed-ocean-based-carbon-dioxide-removal>

<sup>25</sup> Personal communications and examples like <https://blog.ucsusa.org/peter-frumhoff/is-bp-finally-committing-to-ambitious-climate-action-or-about-to-fool-us-twice-five-things-to-look-for-in-its-climate-strategy/> and [https://oceanpanel.org/wp-content/uploads/2022/06/19\\_4PAGER\\_HLP\\_web.pdf](https://oceanpanel.org/wp-content/uploads/2022/06/19_4PAGER_HLP_web.pdf)



coastal ecosystems because of the carbon they may store, rather than because of the other vital ecosystem functions they provide.

Quantifying the magnitude of nature-based OCDR methods continues to be extremely difficult amid uncertainties related to scale, additionality and durability of carbon storage, and interaction with other drivers like sea level rise.<sup>26</sup> NGO representatives had varying levels of trust in other OCDR community interest groups, with the least trust in private industry (citing their prior experiences with industry on climate change<sup>27</sup> and ocean fertilization<sup>28</sup>). NGOs also expressed some skepticism about the motivations of academic researchers who focus on activities that might overstate the potential of specific OCDR techniques and thus insufficiently consider their ecosystem or social system risks. One person underscored how little is known even by ocean experts

about ocean baseline conditions and ocean-system feedbacks, yet some startups' plans seem overly optimistic about their ability to "hack" the ocean-climate system. NGO representatives also expressed concerns that the current lack of clarity on OCDR governance and permitting leaves limited authority to prevent unregulated or harmful experiments. Finally, NGOs were worried about the lack of inclusion of historically marginalized communities and ocean-dependent people in decision-making about OCDR research and scaling.

### Philanthropic Funders

Philanthropic funders, or organizations that disburse funds to support nonprofit organizations, have begun work on CDR. Frequently citing the IPCC's assessment that CDR will be required to reach a 1.5°C warming target,<sup>29</sup> these funders seek to advance the state of knowledge on

CDR and help scale successful CDR technologies. Fewer funders are involved in OCDR than in CDR overall, a trend that is in step with the emerging nature of OCDR.

Philanthropically funded OCDR activities mainly support research and development of CDR techniques, such as studies of enhanced weathering and alkalinity enhancement, electrochemistry and macroalgal culture.<sup>30</sup> They also support scientific community coordination<sup>31</sup> and guidance on research pathways. For example, a recent federal funding opportunity representing a partnership of ClimateWorks Foundation, DOE, NOAA, U.S. Navy and NSF will build partnerships among CDR community interest groups as well as advance the frontiers of knowledge on this topic.<sup>32</sup>

A major challenge facing philanthropic funders is deciding how to support wide-ranging research on OCDR without advocating which OCDR techniques, if any, should eventually be adopted. A second

<sup>26</sup> Le Cozannet G, Lawrence J, Schoeman DS, Adelekan I, et al. 2021. Cross-Chapter Box SLR | Sea-level Rise. In Cooley S, Schoeman D, Bopp L, Boyd P, et al. 2022. Oceans and Coastal Ecosystems and Their Services. In: *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Pörtner H-O, Roberts DC, Tignor M, Poloczanska ES, et al. (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 379–550, doi:10.1017/9781009325844.005.

<sup>27</sup> Oreskes N and Conway EM. 2010. *Merchants of Doubt: How a Handful of Scientists Obscured the Truth On Issues From Tobacco Smoke to Global Warming*. New York, Bloomsbury Press.

<sup>28</sup> Piper K. 2019. The climate renegade: What happens when someone wants to go it alone on fixing the climate? Vox. <https://www.vox.com/the-highlight/2019/5/24/18273198/climate-change-russ-george-unilateral-geoengineering>

<sup>29</sup> IPCC. 2018. Summary for Policymakers. 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, Zhai P, Pörtner H-O, Roberts D, et al. (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 3-24. <https://doi.org/10.1017/9781009157940.001>

<sup>30</sup> <https://www.xprize.org/prizes/elonmusk/articles/xprize-and-the-musk-foundation-award-15m-to-prize-milestone-winners-in-100m-carbon-removal-competition>, <https://www.climateworks.org/programs/carbon-dioxide-removal/oceans/>, <https://www.additionalventures.org/initiatives/climate-action/>

<sup>31</sup> <https://community.oceanvisions.org/dashboard>, <https://oceaniron.org/our-plan/#forums>

<sup>32</sup> <https://www.grants.gov/web/grants/view-opportunity.html?oppld=344632>



challenge is determining how these approaches should relate to emissions reduction. Philanthropic funders we spoke to discussed how they carefully evaluate which areas of OCDR research to support, considering their institution's philosophies and interests, appetite for risk, existing knowledge on the topic and the activities of other funders. All representatives desired to spark innovation and support the highest-quality early studies, then pass longer-term initiatives to other supporting entities, such as federal science agencies. Perhaps due to the relatively small amount of funds flowing to OCDR research compared to other decarbonization activities, funders were also conscious of, but not overly constrained by, the difficulty of funding OCDR research in

ways that do not take emphasis away from other decarbonization activities.

### Professional Societies

As interest in climate intervention and carbon removal have grown, so has attention by professional scientific societies, such as the American Meteorological Society (AMS), the American Geophysical Union (AGU), the Association for the Sciences of Limnology and Oceanography (ASLO) and the European Geophysical Union (EGU). These groups work to support and advance relevant earth science topics for the benefit of society via convenings and products that disseminate science and support collaboration. In addition, they develop policy positions that represent members' perspectives,

helping apply the knowledge created by their membership.

CDR, and OCDR, are being discussed more often at scientific meetings hosted by professional scientific societies. Sessions at AGU 2022 and ASLO 2022 focused on OCDR; AMS 2022 and EGU22 had a handful of abstracts focused on carbon removal.<sup>33</sup> Members of many of these societies have long been engaged in climate intervention research on topics like solar radiation management and atmospheric CO<sub>2</sub> removal. AMS itself produced an issue brief on climate risk reduction and intervention generally in 2014.<sup>34</sup> AGU is leading the development of an ethical framework to guide climate intervention research.<sup>35</sup>

Professional society representatives noted the challenge

<sup>33</sup> <https://annual.ametsoc.org/index.cfm/2023/>; <https://www.egu22.eu/>; <https://www.aslo.org/osm2022/>; <https://www.agu.org/Fall-Meeting>

<sup>34</sup> [https://www2.ametsoc.org/ams/assets/File/Climate\\_Policy\\_Study\\_final.pdf](https://www2.ametsoc.org/ams/assets/File/Climate_Policy_Study_final.pdf)

<sup>35</sup> <https://www.agu.org/Learn-About-AGU/About-AGU/Ethics/Ethical-Framework-for-Climate-Intervention>



of representing not only their memberships' perspectives, but also scientific needs on CDR and OCCR overall. Professional societies represent both academic and industry researchers, who are subject to different requirements about data sharing and different motivating goals; nevertheless, robust and transparent research are ways that OCCR research can be advanced ethically. Moreover, professional science societies focusing on climate intervention tend to have weaker inclusion and links to social science, making many types of public engagement more challenging. Professional society representatives we spoke to noted that the OCCR community will need to consider whether for-profit climate intervention activities can ever lead to ethical implementation where more people benefit from climate intervention than just those who pay for it.

## Research Consortia

Coordinated, multi-institutional research consortia have a long history of advancing oceanographic research. Decades ago, top-down, centrally funded projects such as WOCE (the World Ocean Circulation Experiment, 1988–1998) and JGOFS (the Joint Ocean-Global Flux Study, 1987–2003) transformed ocean circulation and biogeochemistry knowledge. More recently, bottom-up consortia coordinated by the

science community, like the Ocean Observatories Initiative (OOI) and the Argo project, have provided major advances in understanding. The U.N. Decade is another bottom-up activity that seeks to advance ocean understanding and stewardship. Research consortia maximize investments by promoting research coordination and communication, and by helping attract more research funding. Research consortia focused on OCCR are beginning to form in the U.S. and European Union.<sup>36</sup>

The two consortia that have formed to date, ExOIS and OceanNETS, are focused primarily on researching the technical aspects of OCCR, and secondarily on exploring the social considerations (including governance and social acceptance) associated with OCCR research.<sup>37</sup> These consortia do seek global experts as members, but their members and proceedings are still heavily influenced by the U.S. and E.U. Existing consortia are not engaging in policy development or intensive public engagement activities, but they are considering how existing marine policies apply to OCCR and how guiding principles of research concerning responsibility, liability, inclusion, transparency and collective benefit are important to OCCR research. The likely importance of public opinion in future decision making about OCCR<sup>38</sup> suggests that opportunities exist to broaden the scope of these research consortia to

include governance and community engagement in the future.

Research consortium representatives had concerns and information needs similar to researchers and research institutions. In addition to establishing robust collaborations, they were interested in establishing secure long-term funding for OCCR research while not de-emphasizing the need for society-wide decarbonization. Additionally, research consortia representatives expressed concern about the lack of agreement on research priorities within the OCCR research community, the long time from research concept to field trials and the challenge of conducting trials at informative scales.

## Resource Managers

Marine resource managers are minimally, if at all, engaged on OCCR now. However, because their primary focus is the sustainable use of shared marine assets and spaces, OCCR will soon require their attention. Research is just beginning to determine the environmental or social (including economic) outcomes from specific OCCR techniques.<sup>39</sup> Marine resource managers pursue different management targets related to local social and ecological conditions, but how OCCR may interact with management targets is essentially unresearched. Some OCCR activities, including those that distribute terrestrial material and grow biomass,

<sup>36</sup> <https://oceaniron.org/>, <https://www.oceannets.eu/>

<sup>37</sup> <https://www.oceannets.eu/work-package-9-project-management/>; <https://oceaniron.org/our-plan/guiding-principles/>

<sup>38</sup> Cooley SR, et al. 2023. *Annual Review of Marine Science*.

<sup>39</sup> Bermejo R, Buschmann A, Capuzzo E, Cottier-Cook E, et al. 2022. *State of knowledge regarding the potential of macroalgae cultivation in providing climate-related and other ecosystem services*. doi:978-3-944280-28-8. <https://epic.awi.de/id/eprint/56382/>



are likely to be spatially intensive<sup>40</sup> and if they were scaled up, they would need to be fit in among other uses like fishing, shipping, expansion of renewable energy, and submarine cable laying and maintenance.<sup>41</sup> Marine resource management for many types of implemented OCCR would therefore require effective marine spatial planning as well as attention to overall ecosystem function and provision of existing

resources (e.g., fisheries harvests, tourism revenues).

Right now, the intersection of OCCR research and marine resource management is mostly connected to permitting field research.<sup>42</sup> Research is proceeding to determine how existing permits, rules and regulations apply to OCCR and whether any policy adjustments are appropriate to incorporate OCCR into the body of marine policy.<sup>43</sup> If OCCR

techniques reach implementation, marine resource management targets may need to be updated or expanded to accommodate these novel spatial uses and possible environmental perturbations in addition to traditional, cultural, and existing commercial uses.<sup>44</sup> In addition, public decision-making and resource management may eventually need to address OCCR conducted at commercial scale by private entities.<sup>45</sup>

<sup>40</sup> Boyd PW, Bach LT, Hurd CL. et al. 2022. Potential negative effects of ocean afforestation on offshore ecosystems. *Nature Ecology and Evolution* 6, 675–683. <https://doi.org/10.1038/s41559-022-01722-1>.

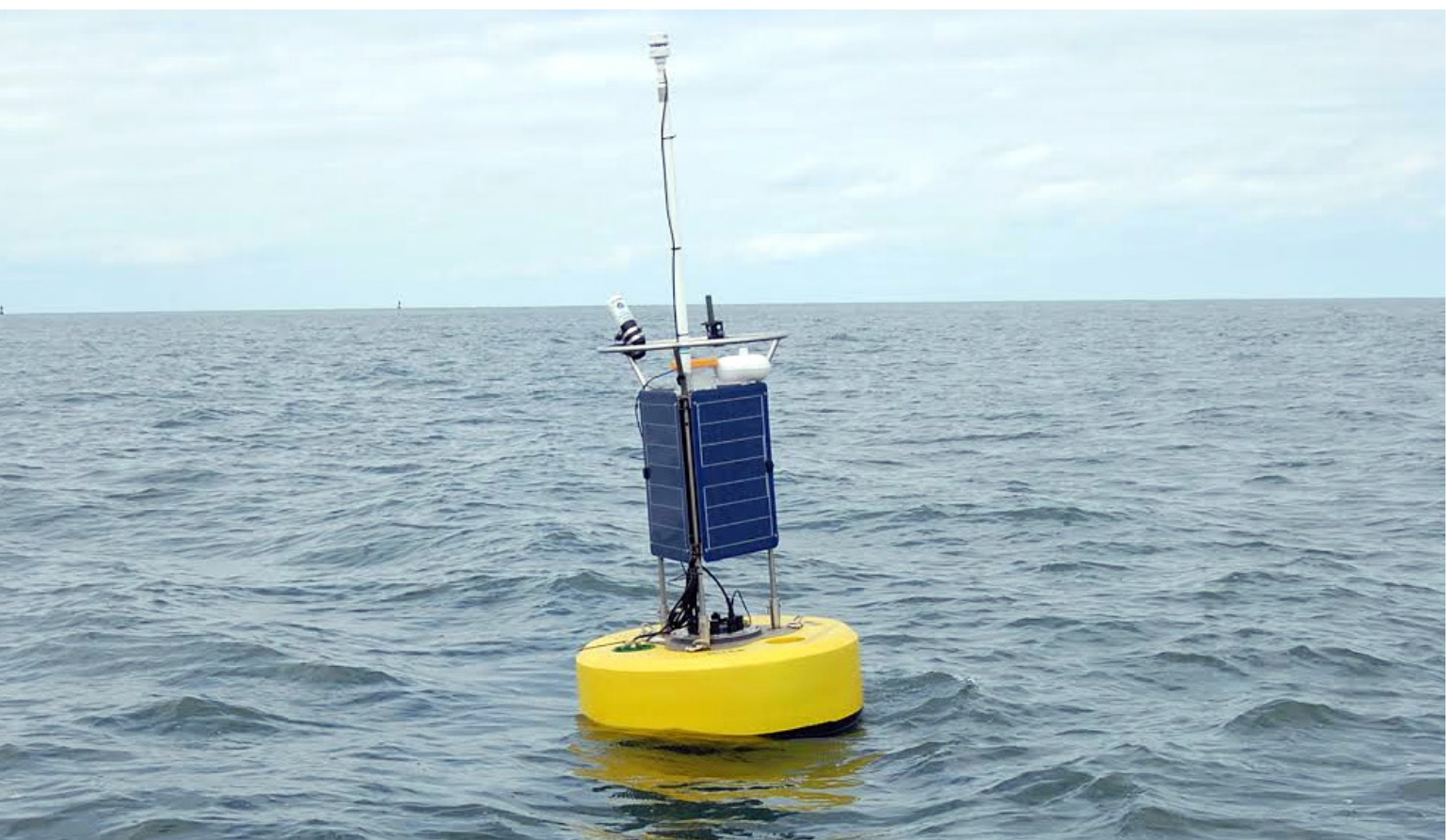
<sup>41</sup> Lezaun J. 2021. Hugging the Shore: Tackling Marine Carbon Dioxide Removal as a Local Governance Problem. *Frontiers in Climate*. 3:684063. doi: 10.3389/fclim.2021.684063.

<sup>42</sup> <https://www.epa.gov/ocean-dumping/ocean-dumping-permits##SRM>

<sup>43</sup> <https://blogs.law.columbia.edu/climatechange/2022/06/15/developing-model-federal-laws-to-facilitate-responsible-ocean-cdr-research/>

<sup>44</sup> <http://globaloceanhealth.org/gearing-up-for-carbon-removal/>

<sup>45</sup> Lezaun, 2021. *Frontiers in Climate*.



## Science Coordination Projects

Science coordination projects, such as the Ocean Carbon and Biogeochemistry Project, SOLAS (Surface Ocean Lower Atmosphere Study), IMBeR (Integrated Marine Biosphere Research), Ocean Visions and the North American Carbon Program (NACP), are beginning to build work programs around OCDR. The National Academies of Sciences, Engineering, and Medicine has also undertaken work on OCDR. Science coordination projects are often the first responders on an emerging topic like OCDR, because they draw together people with a wide variety of applicable expertise to jump-start work and attention. These groups receive funding from some combination of national science agencies and philanthropic funders, and they host convenings, undertake scoping activities and write public-facing reports.

The projects listed above currently count OCDR as one of several areas of focus, and their current efforts largely focus on scientific coordination, collaboration-building, scientific research scoping and knowledge exchange. Projects like these are beginning to synthesize knowledge and facilitate ongoing dialogue among members of the OCDR research community in ways that will support inclusive creation of new knowledge

and expand scientific capacity on the topic. OCDR work by these groups also spans governance and social considerations, providing entry points for social scientists to connect with natural scientists. Several science coordination projects are beginning to address overarching questions that require disparate expertise from many specialties, and a trusting working relationship among experts. Issues include how to verify carbon removal,<sup>46</sup> how to engage the tech industry effectively<sup>47</sup> and how to connect OCDR to environmental management.<sup>48</sup> They are developing information that identifies evolving and necessary research areas.<sup>49</sup> They also are keenly focused on capacity building to support future work on OCDR.

Science coordination project representatives take their role as conveners and facilitators for OCDR research very seriously. One representative described their mission as “co-development of knowledge by co-work.” Frequently hosting bottom-up, community-led initiatives, these science coordination projects carry forward research momentum while bringing in new relevant expertise from diverse scholarly and cultural backgrounds to address knowledge gaps. Science coordination projects sometimes also facilitate dialogue between funders and researchers, helping ensure that top research

needs are prioritized for funding. Science coordination project leaders expressed concerns about ongoing siloing of OCDR research efforts. These programs seek to overcome divisions and bring in new specialties, particularly social science and applied natural science, to support the carbon cycle science research community, but building new interdisciplinary collaborations is perennially challenging due to different research approaches, lack of interaction and/or historical ties among subdisciplines. Representatives of these projects expressed similar concerns to the research community: the traditional one- to five-year funding cycle is not sufficient to support the level of carbon cycle science needed to advance OCDR; there is potential for rogue industry-related experimentation that lacks sufficient consultation and legal review; and transparency and data sharing are necessary to continue to support knowledge development.

## Scientific Researchers

Scientific researchers seek to advance knowledge about OCDR either by leading new research or by leveraging insights from other areas of research. Public and private entities support researchers at academic or similar nonprofit research institutions, whereas public

<sup>46</sup> <https://www.us-ocb.org/marine-co2-removal-workshop/>

<sup>47</sup> <https://oceanvisions.org/our-programs/ocean-based-climate-solutions/advise-and-evaluate-innovators/>

<sup>48</sup> <https://imber.info/imbizo6-workshop-1/>

<sup>49</sup> <https://www2.oceanvisions.org/roadmaps/>, <https://www.nationalacademies.org/our-work/a-research-strategy-for-ocean-carbon-dioxide-removal-and-sequestration>

funds like government grants tend to support researchers at federal scientific agencies and laboratories. Scientific researchers at academic institutions often, but not always, have specialties that align with their institution's mission or research centers. In contrast, researchers at federal laboratories and agencies tend to focus on issues within their agency's mission and scope, but very frequently collaborate with external colleagues. In every case we studied, each researcher is part of a broad network of specialized expertise and perspectives influenced by their institutions, collaborations, and professional communities.

Although OCDR is a relatively new research topic, there are already many researchers worldwide focused on topics relevant to OCDR. A 2018 U.S. National Academies of Science, Engineering, and Medicine (NASEM) report, "Negative Emissions Technologies and Reliable Sequestration,"<sup>50</sup> summarized available information

about carbon dioxide removal via terrestrial and coastal environments (frequently called nature-based carbon storage) or by engineered approaches including direct air capture (DAC), carbon mineralization and geological sequestration. That report laid out a research strategy, but only touched lightly on two major categories of OCDR. The state of knowledge concerning OCDR and immediate research needs were formally evaluated in the 2022 NASEM report,<sup>51</sup> which synthesized hundreds of studies that have established the behavior of the ocean carbon cycle and what is known so far about the ocean carbon cycle's responses to specific human interventions. It also outlined a research strategy to close existing knowledge gaps organized around six major categories of OCDR. In 2021, NASEM published "Reflecting Sunlight: Recommendations for Solar Geoengineering Research and Research Guidance"<sup>52</sup> which considered research governance

topics also applicable to climate interventions other than solar radiation management, including safety, side effects, public engagement and off-ramps.

OCDR scientific research focuses heavily on the carbon storage potential of specific carbon removal techniques and their durability, scalability, cost, and governance.<sup>53</sup> Recent initiatives have broadened the focus to examine co-benefits, governance, technology development, monitoring and modeling.<sup>54</sup> Fewer researchers are involved on the environmental and social outcomes of OCDR techniques,<sup>55</sup> or on determining how these techniques, if proven successful, could fit into comprehensive climate mitigation plans and nationally determined contributions in ways that complement other ocean-based climate actions.<sup>56</sup> There is some research on the economic dimensions of OCDR,<sup>57</sup> and academic institutions and

<sup>50</sup> National Academies of Sciences, Engineering, and Medicine. 2019. *Negative Emissions Technologies and Reliable Sequestration: A Research Agenda*. Washington, DC: The National Academies Press. doi: <https://doi.org/10.17226/25259>.

<sup>51</sup> NASEM 2022. *A Research Strategy*.

<sup>52</sup> National Academies of Sciences, Engineering, and Medicine. 2021. *Reflecting Sunlight: Recommendations for Solar Geoengineering Research and Research Governance*. Washington, DC: The National Academies Press. <https://doi.org/10.17226/25762>.

<sup>53</sup> NASEM 2022. *A Research Strategy*.

<sup>54</sup> For example, DOE/NOAA/Climate Works have put out a cooperative funding opportunity through NOPP: <https://oceanacidification.noaa.gov/WhatsNew/Funding/TabId/3337/ArtMID/15668/ArticleID/15873/Announcing-Funding-Opportunity-in-Marine-Carbon-Dioxide-Removal-mCDR.aspx>. DOE has also funded technology development projects through its ARPA-E program: <https://arpa-e.energy.gov/technologies/exploratory-topics/direct-ocean-capture>

<sup>55</sup> NASEM 2022. *A Research Strategy*, and Cooley SR, et al. 2023. *Annual Review of Marine Science*.

<sup>56</sup> Northrop E, Ruffo S, Taraska G, Schindler Murray L, et al. 2021. *Enhancing Nationally Determined Contributions: Opportunities for Ocean-Based Climate Action*. [https://files.wri.org/d8/s3fs-public/2021-04/enhancing-nationally-determined-contributions-opportunities-ocean-based-climate-action.pdf?VersionId=zEiY0PuwHyP\\_zzc7UGjt.QFF4ooK0Vmu](https://files.wri.org/d8/s3fs-public/2021-04/enhancing-nationally-determined-contributions-opportunities-ocean-based-climate-action.pdf?VersionId=zEiY0PuwHyP_zzc7UGjt.QFF4ooK0Vmu)

<sup>57</sup> E.g., Coleman S, Dewhurst T, Fredriksson DW, St. Gelais AT, et al. 2022. Quantifying baseline costs and cataloging potential optimization strategies for kelp aquaculture carbon dioxide removal. *Frontiers in Marine Science*. 9:966304. doi: 10.3389/fmars.2022.966304.



industry funders are testing several innovative financing mechanisms (see following sections).

Researchers we spoke with usually seek to advance knowledge on the themes identified above through projects that attract funding and operate within existing rules and regulations. However, an increasing number of researchers are beginning to consider how to advance MRV of OCDR techniques as part of a broad coordinated

research and implementation strategy that will likely involve researchers and regulatory agencies. Without a robust universal MRV system for OCDR, several researchers expressed concerns that OCDR's large spatial scales and indirect routes of CO<sub>2</sub> capture could allow the development and exchange of ocean-based CO<sub>2</sub> mitigation credits that were at best, ineffective, and at worst, involved activities that damaged marine

systems. Despite the numerous academic and government researchers collaborating with private industry, many researchers still expressed distrust of private industry. Their concerns centered on industry's motivation to eventually profit from OCDR or its willingness to "cut corners" on monitoring OCDR impacts, consulting local communities, or verifying additionality, in the interest of creating a marketable credit.





# Synthesis

Every interest group wants OCDR research to be transparent and ethical.

Some needs and concerns among OCDR community interest groups seem to be widespread, whereas others are more unique to particular interest groups (Table 1). All of the interest groups are in favor of having more information about OCDR, but each group tempered that point of view with caveats. Frequently, these caveats related to the need to do research in a precautionary way to ensure transparency and ethical behavior, to ensure that research examines environmental and social outcomes, and to ensure that OCDR research is generally socially acceptable. Many people expressed worry that expressing support for researching OCDR might wrongly imply that they, individually or organizationally, were already in favor of implementing OCDR eventually or of attempting other types of climate intervention.

Topics related to the orientation of OCDR in society are foundational concerns for most interest groups (“OCDR Orientation in Society,” Table 1). These concepts include elements such as how their institution’s mission may induce them to work on OCDR, how public opinion may guide their interaction with the topic,

or what sort of engagement poses reputational risks. Because we spoke mostly with groups paying attention to OCDR, their organizations had already engaged similarly in decision-making around needs, missions and risks, and they had identified that there was an opportunity or need to engage institutionally. Social acceptance is also a cross-cutting concern that manifests in different ways—some interest groups seek it, and others question whether or how it should be granted, and by whom—but nearly every interest group identified that as a particularly challenging issue they were following but could not solve at this time. Every interest group, however, stated a need to ensure that OCDR research is done transparently and ethically. Many respondents thought that transparent and ethical research would help grow social acceptance.

All interest groups have needs and concerns related to researching OCDR (“OCDR Research Process,” Table 1). Every knowledge-creating group is focused on developing and facilitating robust multidisciplinary collaborations, either to join or to foster. All types of researchers are perennially focused on securing funding and making the most of

existing assets from previous funding initiatives (e.g., equipment, observing stations, etc.), while still following applicable rules and regulations. Leveraging prior investments and existing infrastructure is also a particular interest of the national government and science agencies. Less commonly articulated by knowledge-creating groups (e.g., researchers, funders) but a priority of knowledge users (e.g., NGOs, resource managers, civil society) was the need to include diverse voices in research development and execution, as well as in making evidence-based decisions. Researchers were also more likely than other interest groups to point to time constraints as drivers of research—either the need to deliver on business or research commitments, or the global urgency of finding climate solutions.

Researchers and groups that support research (e.g., science projects, consortia, etc.) were most clearly focused on contributions back to the OCDR community of practice (“Contributing to the OCDR R&D Community”, [Table 1](#)). Many respondents and interest groups identified capacity building and early career training, common research objectives and trust building as important goals. This suggests that many people in the OCDR community see it as a growing field that will endure, and one which merits support via dedicated community building.

Interest groups more focused on possible future implementation of OCDR (e.g., industry, NGOs, and policymakers) had the most shared concerns related to outcomes of OCDR activities (“Outcomes of OCDR Activities,” [Table 1](#)). NGOs, funders,

resource managers and civil society representatives frequently mentioned needing information on outcomes such as verified carbon removal, environmental and social impacts, and interactions with other ocean uses. Nearly all groups stated a desire to avoid unregulated pilot tests by so-called “rogue actors” (which could be individuals, companies, or nations) for fear of either unintended consequences or loss of social acceptance for further OCDR research. NGOs and people affiliated with the national government wished that OCDR research would be conducted in ways that would inform the U.S.’ approach and ability to deliver on international climate commitments. Currently, only a few groups are thinking as far ahead as decision-making about scaling up any research towards implementation.



**Table 1**

Information needs and concerns expressed by members of OCDR community interest groups (columns) during in-person conversations or in public-facing products. Major themes, discussed in the *Synthesis* section, included overall positioning of OCDR research (“OCDR orientation within society”), the research itself (“OCDR Research Process”), being part of the emerging OCDR community of practice (“Contributing to the OCDR research community”), or what research and other activities related to OCDR may reveal (“Outcomes of OCDR activities”).

	Academic Institutions	Civil society	Industry funders	Industry researchers	National governments & science agencies	NGOs	Philanthropic funders	Professional societies	Research consortia	Resource managers	Science coordination projects	Scientific researchers
<b>OCDR orientation within society</b>												
OCDR relevance to organization’s mission	●		●		●	●	●	●		●	●	●
Funder priorities	●		●	●	●		●	●			●	●
Science needs	●			●	●	●	●	●	●		●	●
Organization’s appetite for risk	●		●				●					
Reputational effect from engaging on OCDR	●		●			●						
Social acceptance of OCDR research	●	●	●	●	●	●		●	●	●		
Conducting research ethically & transparently	●	●	●	●	●	●	●	●	●		●	●
<b>OCDR research process</b>												
Securing and sustaining funding	●			●				●	●			●
Leveraging existing science infrastructure	●				●							●
Following rules and regulations	●	●		●	●	●			●	●		●
Developing/facilitating fruitful, trusting collaborations	●		●	●	●		●	●	●		●	●
Including diverse people with ocean interests		●				●				●		
Formalizing partnerships/legal agreements	●			●								●
Meeting time-bound research/funding goals				●	●				●			
<b>Contributing to the OCDR R&amp;D community</b>												
Educating the next generation of experts	●							●	●		●	●
Setting shared research principles, priorities					●			●	●		●	
Building trust among researchers				●				●	●		●	●
<b>Outcomes of OCDR activities</b>												
Verifying carbon removal		●	●	●	●	●				●		●
Understanding environmental impacts		●	●	●	●	●	●			●		●
Understanding social impacts		●	●	●	●	●	●			●		●
Anticipating interactions with other ocean uses		●			●	●				●		
Avoiding unregulated pilot tests/rogue actors		●		●	●	●			●	●		●
Sharing OCDR benefits & risks		●			●	●		●		●		
Fulfilling Paris Agreement commitments					●	●						
Prioritizing emissions cuts vs. CO <sub>2</sub> removal		●			●	●	●	●				
Scaling decisions (e.g., research → pilot; pilot → implementation)				●			●		●			

# Opportunities

## TRUST BUILDING

There are opportunities to build trust within the OCDR community. Studies have identified steps that build trust in different types of scientific collaborations, such as academic-industry collaborations and evidence-based policy development.<sup>1</sup> Ocean Visions' macroalgae research framework is a recent example of this kind of activity.<sup>2</sup> Furthermore, in pursuit of transparency and demonstrated independence, OCDR activities might require disclosures. The Ocean Carbon and Biogeochemistry Project (see *Science Coordination Projects*, above)<sup>3</sup> set this precedent at their September 2022 workshop, where participants had to disclose all their funding sources. Knowledge generators in the OCDR community (e.g., researchers with any affiliation, science consortia, academic institutions) can also contribute to transparency by adhering to community-wide information sharing standards;

for industry members seeking to develop proprietary products, this may be challenging.

## IMPROVING COORDINATION

OCDR research coordination seems to be a cross-cutting need that may be partly addressed by community-driven activities. Scoping activities, intercomparison projects, or development of best-practices guidelines can help build trust among interest groups as mentioned above, but they can also help begin to engage individual entities (e.g., startups, researchers, institutions, etc.) on both collaborative and solo work to advance knowledge. This work may also start candid conversations about the roles and responsibilities of different entities in governing and scaling OCDR activities. Another development that could improve research coordination would be clear top-down guidance from a leading

federal entity on roles, responsibilities and standards that apply to different subcommunity groups. Central guidance like this would also further build shared national goals and a common approach to ethical and equitable research.

## VERIFYING CARBON REMOVAL

Developing a system for MRV of OCDR techniques is also critically needed. Researchers, science consortia, academic institutions and science coordinating programs are beginning to consider MRV of OCDR, and this is leading to in-depth community conversations about earth observing, technology development and communitywide collaboration. Interest groups like NGOs, federal policymakers, resource managers and civil society are keenly interested in MRV development to ensure that any OCDR technique proposed

<sup>1</sup> Oliver AL, Montgomery K, and Barda S. 2020. The multi-level process of trust and learning in university–industry innovation collaborations. *Journal of Technology Transfer* 45:758–779. <https://doi.org/10.1007/s10961-019-09721-4>, and Cvitanovic C, Shellock RJ, Mackay M, van Putten EI, et al. 2021. Strategies for building and managing 'trust' to enable knowledge exchange at the interface of environmental science and policy, *Environmental Science & Policy*, 123:179-189, <https://doi.org/10.1016/j.envsci.2021.05.020>

<sup>2</sup> <https://oceanvisions.org/our-programs/macroalgaeresearchframework/>

<sup>3</sup> <https://www.us-ocb.org/>



for implementation will achieve what it promises. This information will support public decision-making that incorporates evidence about risks and rewards of OCDR implementation. Because of the indirect nature of carbon removal using most OCDR techniques, developing MRV will require a wide network of experts, observations and models, and sustained support via funding, science coordination and engagement by many interest groups. Federal agencies may be required to set standards around MRV. Here too, the lack of clarity on federal engagement poses an obstacle to progress on MRV development for OCDR.

## EMBEDDING EQUITY

If OCDR techniques do provide verifiable carbon removal with minimal ecosystem impacts, it is essential to determine how OCDR could be implemented equitably. The proliferation of private companies and the use of prizes or AMCs to accelerate innovation poses a risk to equitable climate action. In these situations, wealthier entities have a better chance of developing winning

ideas and receiving compensation. This could move OCDR, which relies on the largest common space on the planet, increasingly into private hands. These private entities are overwhelmingly led by people with significant privilege whose values may not align with ocean users globally.<sup>4</sup> Maintaining mostly private control of OCDR will not allow equitable distribution of benefits or risks. For example, successful technology may not be transferred to low-income communities or nations who might benefit from it. An unsolved ethical issue highlighted during one interview is whether for-profit climate interventions can ever lead to truly just climate intervention that benefits more people than the wealthy who paid for it.

Even less frequently discussed by the OCDR community is liability. This topic came up in conversations with experts working on broader climate action portfolios, and generally not in conversations with experts working mainly on OCDR. Although all OCDR governance research is at an early stage, the community must now consider how liability for harmful outcomes from OCDR (and other climate interventions) should be addressed. There is a large body of

knowledge on environmental liability and environmental risk minimization in many industrial fields (e.g., natural resource extraction seems most analogous), and solar radiation management researchers have also begun to consider liability.<sup>5</sup> Given the many historical failures in holding private companies liable for environmental harm they have caused, liability concerning OCDR (for both large-scale research and implementation) needs to be considered before the field grows further.

## FINAL THOUGHTS

Because OCDR is still “on the drawing board,” research and development can be set up in ways that incorporate lessons from the past. This report indicates that there are many opportunities to help build the OCDR community, from facilitating collaboration among different interest groups to beginning research that will help the benefit of the global public. At every scale, there are opportunities to build the community in ways that will contribute to the knowledge needed by different groups to make informed decisions about OCDR research and outcomes.

<sup>4</sup> Cooley et al., 2023, *Annual Review of Marine Science*.

<sup>5</sup> e.g., Horton JB, Parker A, and Keith D, 2014. Liability for solar geoengineering: historical precedents, contemporary innovations, and governance possibilities. *NYU Environmental Law Journal*, 22:225.

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# Appendix

Sarah Cooley conducted all interviews via videocall, and she typically met with one person at a time. Twice, interviews included two interviewees who were co-workers at the same organization who collaborated closely on this topic. Conversations lasted 35–55 minutes and were guided by the below questions.

1. What decisions are you and your organization are making, or will need to make, about OCCR research?
2. What decisions are on your mind about OCCR research collaboration?
3. How are rules and regulations and ethical considerations entering your decision-making, or your planning, about OCCR research?
4. How do funding and intellectual property considerations intersect with your decision-making about OCCR research?
5. How do you see overlaps between OCCR and other issues affecting your decision-making, now or in the future?
6. [Optional, as time permits] How might any of the things we discussed change upon scaled-up implementation?
7. Is there anything else I should know?

**We are deeply grateful to the following interviewees for sharing their institutional and personal perspectives on OCCR during these semi-structured interviews:**

- **Brad Ack**, Chief Executive Officer, Ocean Visions
- **M. Grace Andrews**, Vice President and Head of Science, Project Vesta
- **Heather Benway**, Executive Officer, Ocean Carbon and Biogeochemistry Project Office
- **Ken Buesseler**, Senior Scientist, Woods Hole Oceanographic Institution
- **Will Burt**, Senior Marine Chemist, Planetary Technologies
- **Hayley Carter**, formerly Senior Science Officer, California Ocean Science Trust
- **Peter de Menocal**, President and Director, Woods Hole Oceanographic Institution
- **Zeke Hausfather**, Climate Research Lead, Stripe
- **Whitney Johnston**, Director of Ocean Sustainability, Salesforce
- **Rachel Licker**, Principal Climate Scientist, Union of Concerned Scientists
- **Shuchi Talati**, Senior Visiting Scholar, Carbon180
- **Kevin Travis** (Science Officer), California Ocean Science Trust
- **Frances Wang** (Associate Director, Carbon Dioxide Removal), ClimateWorks Foundation
- **Billy Williams** (Vice President, Ethics, Diversity, and Inclusion), American Geophysical Union
- **Jamila Yamani** (Senior Manager, Climate Research & Innovation), Salesforce

Ocean Conservancy is working with you to protect the ocean from today's greatest global challenges. Together, we create evidence-based solutions for a healthy ocean and the wildlife and communities that depend on it.

Cooley, et al. Ocean Conservancy. 2023. *The Ocean Carbon Dioxide Removal Decision-Making Landscape*.  
<https://oceanconservancy.org/cdr-landscape-analysis>

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