UNIVERSITY OF DELAWARE
EARTH, OCEAN & ENVIRONMENT

Developing Best Practices for Community Engagement in Marine Carbon Dioxide Removal (mCDR) Research

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Executive Summary

The Intergovernmental Panel on Climate Change lists removing atmospheric carbon dioxide as a key technique to limit global warming to 1.5°C above pre-industrial levels (Rogelj et al., 2018). Marine Carbon Dioxide Removal (mCDR) is an emerging strategy that builds on the oceans natural ability to absorb carbon as the planet's largest carbon sink. Since 1850, the ocean has taken in about a quarter of natural fossil fuel emissions, making it an important tool for reaching net zero goals (Boettcher et al, 2023). However, new techniques come with unknown risks to coastal communities and ecosystems. Without community acceptance, projects risk facing opposition and regulatory hurdles that can cause costly project delays, cancellations, and relocations (Alexandersson & Logadóttir, 2024; Boettcher et al., 2023; Brunsting et al., 2010). To mitigate these risks, we have developed a prototype database to guide mCDR project managers and users through best practices for community engagement. This prototype database filters recommended practices using project-specific inputs and evaluates them based on community benefits, potential risks, and principles of inclusivity and equity. These community engagement practices aim to foster inclusive, equitable, and informed relationships between communities and mCDR practitioners to develop mutually beneficial mCDR projects.

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Introduction

Determining ways to remove atmospheric CO_2, in addition to mitigating CO_2 emissions, continues to be a pressing issue as global temperatures rise, with 2024 being the warmest year on record (World Meteorological Organization, 2025). CO_2 removal techniques include human-induced natural and geoengineered processes, both terrestrial and marine (e.g., photosynthesis, sequestration) (Mulligan et al., 2023). With oceans making up 71% of the Earth's surface, Marine Carbon Dioxide Removal (mCDR) is emerging as a potential strategy. However, mCDR techniques are nascent in the United States as the government determines how to efficiently scale up research while minimizing adverse impacts to communities and ecosystems (Fast Track Action Committee on Marine Carbon Dioxide Removal, 2024).

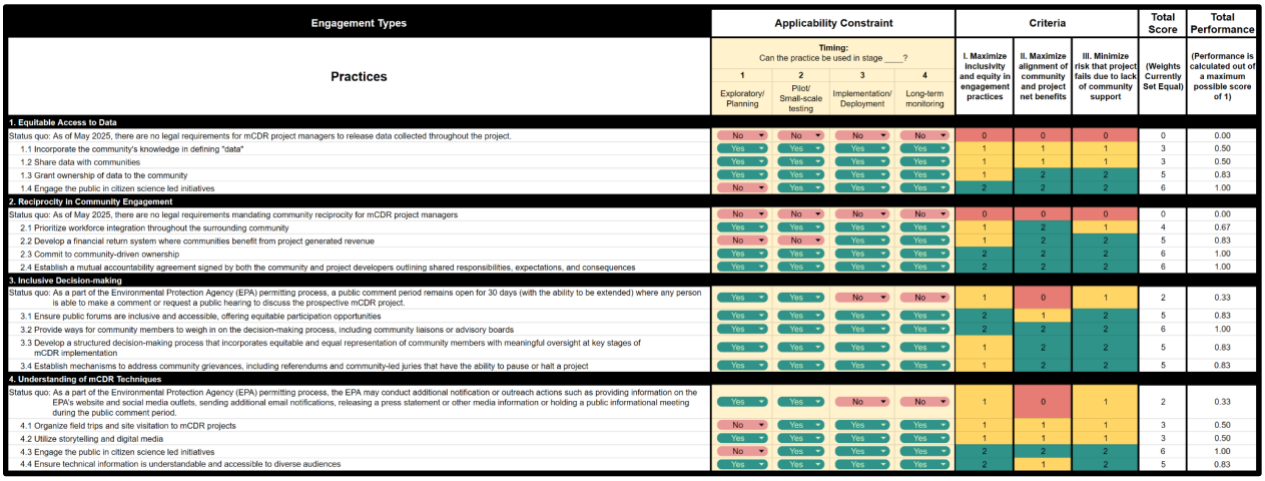
The uncertain ecological impacts of mCDR raise concerns for coastal communities that have economic, cultural, and historical relationships with the marine environment. Differing opinions of mCDR in local communities can further complicate the governance needs and public acceptance of mCDR (Boettcher et al., 2023). The environmental justice movement has expressed opposition toward carbon capture technologies due to their tendency to perpetuate pollution in already overburdened communities. As noted by Earthjustice, carbon capture and sequestration are often used to justify continued operation of fossil fuel facilities rather than eliminating emissions at their source. The approach poses safety risks, lacks transparency, and is frequently implemented without meaningful input from affected communities. This further deepens distrust and diverts resources away from clean energy investments, ultimately threatening to reinforce existing environmental and social injustices (Earthjustice, 2023). Finally, the historical overexploitation of natural resources or environments owned or inhabited by underrepresented groups (i.e., minorities and Indigenous tribes), where little to no form of reciprocity was provided, has created a lasting distrust between some communities and external groups (Bullard et al., 2008; Robyn, 2002).

Without early and meaningful community[3] engagement, mCDR projects risk facing opposition, regulatory hurdles, and may ultimately fail to launch (Boettcher et al., 2023; Brunsting et al., 2010). To address this, we developed an open-access database of best practices[7] for community engagement. This database is intended to help the user (i.e., mCDR project managers) plan community engagement efforts that prioritize inclusivity, transparency, and environmental justice.

Database Structure

This prototype database (Figure 1) is designed to help users incorporate project-specific information to identify the best approach for engaging with prospective communities. The database has three primary components: community engagement practices organized by type, applicability[1] constraints[2] that determine which practices are accessible to a specific project, and criteria[4] for evaluating the effectiveness for each

practice. The design of this database was guided by three key reports: the National Oceanic and Atmospheric Administration's (NOAA) National Marine Carbon Dioxide Removal Research Strategy (Fast Track Action Committee on Marine Carbon Dioxide Removal, 2024), the Aspen Institute's Code of Conduct for Carbon Dioxide Removal Research (Boettcher et al., 2023), and the American Geophysical Union's Ethical Framework Principles for Climate Intervention Research (2024). Our goal is to lay the groundwork for a user-friendly tool for guiding effective and meaningful community engagement. As a prototype, it is designed for community engagement experts to edit and build upon.



Engagement Types	Applicability Constraint				Criteria			Total Score	Total Performance
Practices	Timing: Can the practice be used in stage ____?				I. Maximize inclusivity and equity in engagement practices	II. Maximize alignment of community and project net benefits	III. Minimize risk that project fails due to lack of community support	(Weights Currently Set Equal)	(Performance is calculated out of a maximum possible score of 1)
	1 Exploratory/ Planning	2 Pilot/ Small-scale testing	3 Implementation/ Deployment	4 Long-term monitoring					
1. Equitable Access to Data									
Status quo: As of May 2025, there are no legal requirements for mCDR project managers to release data collected throughout the project.	No	No	No	No	0	0	0	0	0.00
1.1 Incorporate the community's knowledge in defining "data"	Yes	Yes	Yes	Yes	1	1	1	3	0.50
1.2 Share data with communities	Yes	Yes	Yes	Yes	1	1	1	3	0.50
1.3 Grant ownership of data to the community	Yes	Yes	Yes	Yes	1	2	2	5	0.83
1.4 Engage the public in citizen science led initiatives	No	Yes	Yes	Yes	2	2	2	6	1.00
2. Reciprocity in Community Engagement									
Status quo: As of May 2025, there are no legal requirements mandating community reciprocity for mCDR project managers	No	No	No	No	0	0	0	0	0.00
2.1 Prioritize workforce integration throughout the surrounding community	Yes	Yes	Yes	Yes	1	2	1	4	0.67
2.2 Develop a financial return system where communities benefit from project generated revenue	No	No	Yes	Yes	1	2	2	5	0.83
2.3 Commit to community-driven ownership	Yes	Yes	Yes	Yes	2	2	2	6	1.00
2.4 Establish a mutual accountability agreement signed by both the community and project developers outlining shared responsibilities, expectations, and consequences	Yes	Yes	Yes	Yes	2	2	2	6	1.00
3. Inclusive Decision-making									
Status quo: As a part of the Environmental Protection Agency (EPA) permitting process, a public comment period remains open for 30 days (with the ability to be extended) where any person is able to make a comment or request a public hearing to discuss the prospective mCDR project.	Yes	Yes	No	No	1	0	1	2	0.33
3.1 Ensure public forums are inclusive and accessible, offering equitable participation opportunities	Yes	Yes	Yes	Yes	2	1	2	5	0.83
3.2 Provide ways for community members to weigh in on the decision-making process, including community liaisons or advisory boards	Yes	Yes	Yes	Yes	2	2	2	6	1.00
3.3 Develop a structured decision-making process that incorporates equitable and equal representation of community members with meaningful oversight at key stages of mCDR implementation	Yes	Yes	Yes	Yes	1	2	2	5	0.83
3.4 Establish mechanisms to address community grievances, including referendums and community-led juries that have the ability to pause or halt a project	Yes	Yes	Yes	Yes	1	2	2	5	0.83
4. Understanding of mCDR Techniques									
Status quo: As a part of the Environmental Protection Agency (EPA) permitting process, the EPA may conduct additional notification or outreach actions such as providing information on the EPA's website and social media outlets, sending additional email notifications, releasing a press statement or other media information or holding a public informational meeting during the public comment period.	Yes	Yes	No	No	1	0	1	2	0.33
4.1 Organize field trips and site visitation to mCDR projects	No	Yes	Yes	Yes	1	1	1	3	0.50
4.2 Utilize storytelling and digital media	Yes	Yes	Yes	Yes	1	1	1	3	0.50
4.3 Engage the public in citizen science led initiatives	No	Yes	Yes	Yes	2	2	2	6	1.00
4.4 Ensure technical information is understandable and accessible to diverse audiences	Yes	Yes	Yes	Yes	2	1	2	5	0.83

Figure 1. The Prototype Database. An enlarged version of the database is currently located in a Google sheet, organized in a chronological order so the user can start on the left and move to the right, working through the other sections. It starts with Engagement Types & Practices on the left, followed by the Applicability Constraint, and Criteria scoring sections to finish with a final Total Performance score per practice. Enlarged sections of the database are in Figures 2-4.

Community Engagement Types & Practices

For the database to apply to a wide range of scenarios and audiences, our proposed practices are separated into four engagement types[5]: 1. Equitable[6] Access to Data, 2. Reciprocity in Community Engagement, 3. Inclusive Decision-Making, and 4. Understanding of mCDR Technologies (Figure 2). Under each engagement type, we list the status quo[9] practice. As of May 2025, there are minimal policies and regulations specifically geared towards mCDR projects. The current status quos for each engagement type are primarily pulled from Environmental Protection Agency (EPA) permitting requirements that either engage with the communities directly or require project managers to implement various forms of public participation themselves in order to receive the permit to implement the chosen mCDR technique (Environmental Protection Agency, 2013; Environmental Protection Agency, 2020; Environmental Protection Agency Marine Protection Permitting Program, 2024). The two main permits, as of May 2025, applicable to mCDR techniques involving the deposition of material into ocean waters, are the Clean Water Act (CWA) and

Marine Protection, Research, and Sanctuaries Act (MPRSA) (Environmental Protection Agency, 2024). Below the status quo, we sub-number (e.g., 1.1) engagement practices drawn from the literature on inclusivity, transparency, and environmental justice throughout community engagement efforts (David-Chavez & Gavin, 2018). Each practice draws from literature on past failures, recommendations for improvement, and proven successes. We included literature and case studies on community engagement in marine and environmental sectors, environmental justice, and partnerships between communities and researchers.

Engagement Types
Practices
1. Equitable Access to Data
Status quo: As of May 2025, there are no legal requirements for mCDR project managers to release data collected throughout the project.
1.1 Incorporate the community's knowledge in defining "data"
1.2 Share data with communities
1.3 Grant ownership of data to the community
1.4 Engage the public in citizen science led initiatives
2. Reciprocity in Community Engagement
Status quo: As of May 2025, there are no legal requirements mandating community reciprocity for mCDR project managers
2.1 Prioritize workforce integration throughout the surrounding community
2.2 Develop a financial return system where communities benefit from project generated revenue
2.3 Commit to community-driven ownership
2.4 Establish a mutual accountability agreement signed by both the community and project developers outlining shared responsibilities, expectations, and consequences
3. Inclusive Decision-making
Status quo: As a part of the Environmental Protection Agency (EPA) permitting process, a public comment period remains open for 30 days (with the ability to be extended) where any person is able to make a comment or request a public hearing to discuss the prospective mCDR project.
3.1 Ensure public forums are inclusive and accessible, offering equitable participation opportunities
3.2 Provide ways for community members to weigh in on the decision-making process, including community liaisons or advisory boards
3.3 Develop a structured decision-making process that incorporates equitable and equal representation of community members with meaningful oversight at key stages of mCDR implementation
3.4 Establish mechanisms to address community grievances, including referendums and community-led juries that have the ability to pause or halt a project
4. Understanding of mCDR Techniques
Status quo: As a part of the Environmental Protection Agency (EPA) permitting process, the EPA may conduct additional notification or outreach actions such as providing information on the EPA's website and social media outlets, sending additional email notifications, releasing a press statement or other media information or holding a public informational meeting during the public comment period.
4.1 Organize field trips and site visitation to mCDR projects
4.2 Utilize storytelling and digital media
4.3 Engage the public in citizen science led initiatives
4.4 Ensure technical information is understandable and accessible to diverse audiences

Figure 2. Community Engagement Types and Practices. The "Engagement Types" are in the black rows, while the "Practices" suggested within each Engagement Type, including the status quos (as of May 2025), are in the white rows as they appear in the database. The practices are not listed in any specific order.

1. <u>Equitable Access to Data</u>

Promoting equitable access to data involves defining what is considered to be data and who will have ownership of that information. As of May 2025, there appears to be no status quo regarding public access to data, as there are no legal requirements for mCDR project managers to release data collected throughout the project. Access to data is

currently promoted and encouraged through best practices and guidelines for responsible mCDR research (National Academies of Sciences, Engineering, and Medicine, 2022). In addition, during the permitting process, the EPA is responsible for making a tentative permitting determination and initiating a public comment period. The public notice includes details on how to access the data the EPA relied on for tentative determination and how to submit comments, granting the public access to the information underlying the mCDR project's approval (Environmental Protection Agency, 2024; Environmental Protection Agency Marine Protection Permitting Program, 2024).

Practice 1.1 is to incorporate the community's knowledge in defining the data, before collection, to promote collaboration (Druckenmiller, 2022). Thompson et al. (2020) emphasizes how the leveraging of Indigenous and local knowledge with scientific knowledge has the potential to lead to synergies, enhancing the information gained during environmental monitoring. Practice 1.2 is to share the data obtained throughout the entire project duration with the community to promote transparency and equitable access to knowledge (David-Chavez & Gavin, 2018; U.S. Interagency Arctic Research Policy Committee, 2018). Data dissemination enhances mutual understanding, increasing collaboration and the community's involvement (Mosavel et al., 2019). Practice 1.3 is to grant ownership of the data to the community to ensure inclusivity and equity. This practice supports a fair exchange of knowledge that benefits the community (Harding et al., 2011; Singh & Vipra, 2019; The Rising Voices Working Group on Community Resettlement and Site Expansion, 2024). Practice 1.4 involves citizen science-led initiatives to provide opportunities for the public to engage with mCDR research (David-Chavez & Gavin, 2018; Ramaswami, 2025; Riesch et al., 2013). Public citizen science-led initiatives foster inclusivity through empowering the community to collect, share, and manage data (Riesch et al., 2013; Tengö et al., 2021). Overall, the goal of this engagement type is to promote transparent, and inclusive collaboration between the project manager and the community, establishing a mutual understanding of the data obtained throughout an mCDR project.

All practices within Engagement Type 1 will require intentional and thorough public collaboration between local and Indigenous knowledge and project managers. For example, Klain et al. (2015) emphasize that both parties need to be willing to learn from each other to agree on how data is defined (Practice 1.1). When working with Indigenous communities, Practice 1.3 needs to take in account the Indigenous community's concerns regarding their intellectual property rights (David-Chavez & Gavin, 2018).

2. <u>Reciprocity in Community Engagement</u>

Reciprocity highlights the ethical responsibility to engage with communities through ongoing, trust-based interactions that include sharing knowledge, responding to input, and ensuring that research processes and outcomes provide tangible value in return. It emphasizes mutual exchange, transparency, and responsiveness, fostering relationships grounded in respect and accountability (Boettcher et al. 2023; Diver et al. 2019; Nawaz &

Lezaun, 2024). As a part of the EPA permitting process, the EPA requires project managers to provide appropriate information on the environmental assessment of potential impacts to the marine environment and other uses of the ocean, including information the EPA would use to facilitate coordination or consultation with tribal, federal, state or other relevant entities (Environmental Protection Agency, 2013; Environmental Protection Agency Marine Protection Permitting Program, 2024). However, as of May 2025, there are no status quo legal requirements mandating community reciprocity—such as benefit-sharing, job creation, compensation, or co-management—for project managers implementing marine mCDR techniques.

Practice 2.1 aims to prioritize workforce integration throughout the surrounding community to maintain prosperity within the immediate community(ies) being impacted by the mCDR project. Workforce integration throughout the community in which the project is set to take place can be both cost-effective and increase the economic development of the area (Figueroa et al., 2011). Practice 2.2 aims to develop a financial return system to provide communities with ongoing revenue generated from the project. Offering a form of compensation to the surrounding community can help address and avoid historical inequity trends (Boettcher et al., 2023). Practice 2.3 is to commit to community-driven ownership to leave the benefits with the individuals bearing the cost. This would be a new source of capital for communities, potentially increasing public acceptance, fostering stronger support and implementation of an mCDR project (Bolinger, 2001; Klain et al., 2015). Practice 2.4 aims to establish a mutual accountability agreement signed by both the community and project developers outlining shared responsibilities, expectations, and consequences (Boettcher et al., 2023; Southwest Network for Environmental and Economic Justice, 1991). This agreement can benefit both the community and the user by creating a more comfortable, equity driven dynamic between both parties (i.e., Indigenous Peoples Council on Biocolonialism, n.d.) (Harding et al., 2011). A 2023 capstone report from the Columbia Climate School and the Clean Air Task Force provides examples of existing community benefit agreements (CBAs) used in infrastructure and energy projects, offering additional perspective on how formal agreements can be structured to meet community needs (Lavine et al., 2023). This engagement type considers ways for project managers to give back to the community to repay them for any losses resulting from the mCDR project.

When considering practices from Engagement Type 2, it is important to consider each community's specific needs to determine appropriate forms of reciprocity for a given situation. For example, the success and feasibility of Practice 2.1 relies heavily on the capacity of and available training opportunities for the surrounding community (Boettcher et al., 2023; Gutterman, 2023). To prevent the continuation of systemic discrimination and historical overexploitation of underrepresented groups, Practice 2.2 could be accompanied by some form of Community Benefit Agreement (Lebling & Riedl, 2023).

3. Inclusive Decision-making

To prevent repeating historical patterns where harm falls on those with little voice in decisions, this engagement type emphasizes empowered community representation. Community participation in decision-making ensures that the process takes into account the interests of the people who bear its risks as well as its benefits (Boettcher et al., 2023; Burns & Flegal, 2015). As a part of the EPA permitting process, the status quo is a public comment period that remains open for 30 days (with the ability to be extended) where any person is able to make a comment or request a public hearing to discuss the prospective mCDR project (Environmental Protection Agency, 2013; Environmental Protection Agency Marine Protection Permitting Program, 2024). The EPA conducts intergovernmental and interagency coordination (tribal, state, federal, etc.) after a permit has been submitted.

Practice 3.1 aims to ensure that public forums are inclusive and accessible, offering equitable participation opportunities (Boettcher et al., 2023). This practice acknowledges the various hurdles (e.g., physical disability, schedule conflicts, lack of transportation) the public could face in making their views or concerns on the project heard. Practice 3.2 aims to provide ways for community members to weigh in on the decision-making process, including community liaisons or advisory boards (David-Chavez & Gavin, 2018; Head, 2008; Turnhout et al., 2019). These mechanisms increase communication and transparency between project managers and the community, helping to prevent inadvertent consequences such as the spread of misinformation, misaligned expectations, or loss of trust (Romero-Lankao et al., 2023). Practice 3.3 aims to develop a structured decision-making process that incorporates equitable and equal representation of community members with meaningful oversight at key stages of mCDR implementation (Boettcher et al., 2023; Thornton & Scheer, 2012). This practice gives more weight to community voices and minimizes the risk of a majority ruling that could bypass the community's objective (Southwest Network for Environmental and Economic Justice, 1991). Practice 3.4 aims to establish mechanisms to address community grievances, including referendums and community-led juries that have the power to pause or halt a project (The Rising Voices Working Group on Community Resettlement and Site Expansion, 2024). This authority helps prevent the perpetuation of injustices rooted in colonial and extractive histories and promotes recognition justice by valuing the social, cultural, and spiritual connections these communities have with their environment (Bacchiocchi et al., 2022).

All practices within Engagement Type 3 require intentional public collaboration and coordination to ensure all community members can participate effectively. The level of effectiveness of Practice 3.1 depends on whether decision-makers (i.e., project managers) act on community input rather than just collecting feedback. Practice 3.2 needs to be carried out carefully to avoid the risk of community engagement being perceived as superficial or insincere. If mishandled, it could lead to distrust and skepticism between the user and the community (Burns & Flegal, 2015; Southwest Network for Environmental and Economic Justice, 1996). The governance structure proposed in Practice 3.3 is

unprecedented to the US, especially in mCDR projects, and requires further development and research (Lebling & Riedl, 2023).

4. Understanding of mCDR Techniques

Establishing a baseline knowledge of mCDR allows community members to accurately assess and describe their concerns and highlight potential local impacts on the community (Klain et al., 2015). Interactive and experiential learning can offer community members a deeper understanding of mCDR techniques by experiencing things first-hand. Under the status quo, the EPA may conduct additional notification or outreach actions, such as providing information on the EPA's website and social media outlets, sending additional email notifications, releasing a press statement or other media information, or holding a public informational meeting during the public comment period. The public notice may also include information about any public engagement opportunities, such as informational meetings (Environmental Protection Agency Marine Protection Permitting Program, 2024).

To increase the community's engagement with mCDR techniques, Practice 4.1 is to organize field trips and site visitation to mCDR projects (Brown, 2023; Miller & Wyborn, 2023; National Science Foundation, n.d.). Developing a better understanding of the public's perception of and increasing their engagement with the mCDR techniques can mitigate the knowledge gap and lead to innovative mCDR approaches (Aziz et al., 2024). Practice 4.2 is to the utilization of storytelling and digital media as a tool for spreading information on mCDR techniques (Wang et al., 2018). The utilization of storytelling and digital media can reach many audiences of varying ages, broadening the scope of who can be involved with mCDR techniques (Cisneros et al., 2023). Practice 4.3 is like Practice 1.4 in suggesting the use of citizen science-led initiatives to increase the community's involvement in research to increase the understanding of the project's mCDR technique (David-Chavez & Gavin, 2018). Practice 4.4 is to ensure technical information is understandable and accessible to diverse audiences. Science communication is crucial to clearly translate complex scientific concepts to those with minimal prior background knowledge on the matter (Cross et al., 2023).

The proposed practices in Engagement Type 4 will rely heavily on thoughtful and meaningful execution. Practices 4.1 and 4.3 specifically require significant planning and organization for the proposed activities to run smoothly, be effective, and mitigate the chances of misinterpretation (Behrendt & Franklin, 2014). Practice 4.4 also needs significant planning and research to ensure the information is as translatable as possible to a wide array of audiences (Abraham, 2020).

Applicability Constraint

To ensure that each engagement practice is feasible in the context for which it is being considered, the database includes an "Applicability Constraint" section. This section filters practices based on project characteristics, called applicability constraints, that may affect whether a practice can be implemented. Figure 3 shows how the applicability

constraint section is set up in the database. The constraint (i.e., timing) is labeled in the second row, the different stages/ time in which the project is currently in is then split into 4 separate columns, and each row below features a dropdown menu with "Yes" in green, and "No" in red, indicating whether the practice is appropriate for that project stage. The colors utilized were chosen to be visually accessible for those who may be color-blind. This standardized format allows users to quickly identify which practices align with the current phase of their respective mCDR project.

Engagement Types	Applicability Constraint			
Practices	Timing: Can the practice be used in stage ____?			
	1	2	3	4
	Exploratory/ Planning	Pilot/ Small-scale testing	Implementation/ Deployment	Long-term monitoring
1. Equitable Access to Data				
Status quo	No	No	No	No
1.1	Yes	Yes	Yes	Yes
1.2	Yes	Yes	Yes	Yes
1.3	Yes	Yes	Yes	Yes
1.4	No	Yes	Yes	Yes
2. Reciprocity in Community Engagement				
Status quo	No	No	No	No
2.1	Yes	Yes	Yes	Yes
2.2	No	No	Yes	Yes
2.3	Yes	Yes	Yes	Yes
2.4	Yes	Yes	Yes	Yes
3. Inclusive Decision-making				
Status quo	Yes	Yes	No	No
3.1	Yes	Yes	Yes	Yes
3.2	Yes	Yes	Yes	Yes
3.3	Yes	Yes	Yes	Yes
3.4	Yes	Yes	Yes	Yes
4. Understanding of mCDR Techniques				
Status quo	Yes	Yes	No	No
4.1	No	Yes	Yes	Yes
4.2	Yes	Yes	Yes	Yes
4.3	No	Yes	Yes	Yes
4.4	Yes	Yes	Yes	Yes

Figure 3. Practice Applicability Constraint. The "Engagement Types & Practices" are located on the left while the "Applicability Constraint" of timing is on the right-hand side. The "Yes, No" selection was based on whether the database user can implement said practice, given the stage at which their mCDR project is currently in.

Timing

The current constraint, Timing, identifies the stages of the project life cycle at which each practice is generally feasible. The database distinguishes four stages: Exploratory/Planning, Pilot/Small-Scale Testing, Implementation/Deployment, and Long-Term Monitoring. A designation of "Yes" means the practice can be realistically carried out during that project phase. A "No" means the practice is not appropriate or actionable

during that phase, often because the necessary conditions or activities have not occurred yet. For example, Practice 2.3, which involves committing to community-driven ownership mechanisms, is feasible during all phases of the project, including the Exploratory/Planning phase. By contrast, strategies such as Practice 4.3, which focuses on engaging the public in citizen science initiatives, is not feasible during the Exploratory/Planning phase because science is not being conducted yet. However, a practice cannot be effectively implemented unless it is considered and planned for during the Exploratory/Planning phase, regardless of when it is carried out. Early planning of a practice is critical to ensure that the necessary logistical, legal, and relational groundwork is in place, which supports smoother implementation and builds community trust. The timing constraint helps users determine when a practice could be applied to maximize its effectiveness.

A relevant example that supports the importance of aligning practices with timing is the LOC-NESS Wilkinson Basin Study, an ocean alkalinity enhancement research project conducted by the Woods Hole National Oceanographic Institute off the coast of Massachusetts. The study demonstrates a phased structure that reflects the database's first two stages in the applicability constraint. The project has involved extensive planning, including laboratory and modeling analyses as well as stakeholder outreach conducted through multiple events and interest group sessions. These activities align with the Exploratory/Planning phase within our database. The project then proceeded to a one-time pilot field trial involving the release of sodium hydroxide over approximately four to twelve hours within a designated offshore site, which fits the Pilot/Small-Scale Testing phase. During the deployment, activities were tightly regulated. The permit required releases to occur only during daylight hours, limited vessel speeds, and established thresholds for pH levels and seawater dilution rates to ensure safety and efficacy. Following release, monitoring activities were extended for at least 72 hours and included chemical, biological, and physical measurements. Some tracking, including autonomous glider deployment, was permitted for up to 40 days (Environmental Protection Agency, 2025).

This phase-based rollout supports the use of the "Yes" and "No" drop-down system in the database. When assigning "Yes" or "No" values in the database, we made decisions based on whether a practice is realistically possible during a given phase, not based on what we assume a project manager might choose to do. Although the EPA did not use this exact structure in the LOC-NESS Wilkinson Basin Study, their project followed a similar idea. For example, the EPA stated their intentions of making the data obtained through the pilot studies publicly available. This is like Practice 1.2 in the database, which focuses on sharing data with the community and is marked "Yes" for the Pilot/ Small-scale testing phase. On the other hand, also during the LOC-NESS Pilot/ Small-scale testing, no team member had any financial stake in the results of their research. Thus, Practice 2.2, which focuses on developing a financial return system, would not be relevant in this stage of the project and is marked as a "No". Organizing these timing-based decisions into a simple

format helps users easily understand which actions are feasible to implement during each part of a project. This approach ensures the timing filter reflects actual feasibility, not just typical behavior. Organizing these timing-based decisions into a simple format helps users easily understand which practices would be plausible to implement during the current stage of their mCDR project (Environmental Protection Agency, 2025).

Criteria

This section introduces an evaluation framework for assessing mCDR community engagement practices, based on three criteria: to maximize inclusivity and equity in engagement practices, to maximize alignment of community and project net benefits, and to minimize the risk that the project fails due to a lack of community support (Figure 4). The framework draws from literature on environmental justice, community engagement practices from related sectors such as offshore wind and terrestrial carbon capture, as well as insights from emerging marine carbon removal efforts and relevant case studies. Each criterion is accompanied by a rationale, illustrative examples, and guidance on how it is scored using a qualitative matrix.

Engagement Types	Criteria			Total Score	Total Performance
Practices	I. Maximize inclusivity and equity in engagement practices	II. Maximize alignment of community and project net benefits	III. Minimize risk that project fails due to lack of community support	(Weights Currently Set Equal)	(Performance is calculated out of a maximum possible score of 1)
1. Equitable Access to Data					
Status quo	0	0	0	0	0.00
1.1	1	1	1	3	0.50
1.2	1	1	1	3	0.50
1.3	1	2	2	5	0.83
1.4	2	2	2	6	1.00
2. Reciprocity in Community Engagement					
Status quo	0	0	0	0	0.00
2.1	1	2	1	4	0.67
2.2	1	2	2	5	0.83
2.3	2	2	2	6	1.00
2.4	2	2	2	6	1.00
3. Inclusive Decision-making					
Status quo	1	0	1	2	0.33
3.1	2	1	2	5	0.83
3.2	2	2	2	6	1.00
3.3	1	2	2	5	0.83
3.4	1	2	2	5	0.83
4. Understanding of mCDR Techniques					
Status quo	1	0	1	2	0.33
4.1	1	1	1	3	0.50
4.2	1	1	1	3	0.50
4.3	2	2	2	6	1.00
4.4	2	1	2	5	0.83

Figure 4. Criteria. This table presents a qualitative evaluation of different mCDR community engagement practices across three core criteria. Each practice is assessed on a scale of 0 to 2 for each criterion, where higher scores indicate stronger alignment with the criterion. The status quo

practice is included for each engagement type to represent a baseline or typical existing approach. Total scores are calculated as the sum of the three criteria scores (with equal weighting), and performance is expressed as a proportion of the maximum possible score (1.0).

Criterion I: Maximize Inclusivity and Equity in Engagement Practices

Inclusive and equitable engagement is essential for environmental justice and successful mCDR implementation in the ocean, a shared public resource. Due to the ocean being a public resource, all activities that occur within the ocean or affect it should consider the effects and impacts to those who use it. Maximizing inclusivity and equity in engagement practices ensures those most affected by ocean-based carbon removal are both informed and empowered. For this criterion, engagement efforts that empower those most affected to help guide decisions rather than simply being informed will score higher.

Providing resources, such as financial support, technical assistance, and access to expertise can foster more genuine partnerships through equitable distribution of resources which increases engagement sustainability throughout the project lifecycle. In the absence of maximizing inclusivity and equity, these partnerships may not be as strong. Arnstein (1969) notes that community leaders need resources to shape outcomes and act independently, make decisions on behalf of their constituencies, and build trust. Removing barriers to participation allows for more meaningful input and stronger outcomes, particularly when efforts are grounded in equity, meaning a commitment to fair distribution of resources based on community needs, and shaped by the lived experiences of coastal and Indigenous communities (National Academies of Sciences, Engineering, and Medicine, 2022). By maximizing inclusivity and equity, less barriers to participation allows for meaningful engagement informed by a broader array of communities. Redistribution of power to include marginalized and excluded groups, such as Indigenous communities, avoids superficial engagement lacking influence mechanisms and follow-through. Engagement that fails to reach and include all sectors of the community can undermine the project's effectiveness and risks reinforcing existing inequities (Arnstein, 1969). Maximizing inclusivity and equity promotes receiving project feedback from these marginalized and excluded communities.

Criterion II: Maximize Alignment of Community and Project Net Benefits

Community engagement is not only beneficial for communities but also critical for project managers and implementers. Meaningful engagement fosters local trust, reduces conflict, and improves the quality and relevance of project outcomes. It also provides early insights into potential challenges, supports adaptive management, and enhances project legitimacy in the eyes of the public and decision-makers. Practices that intentionally invest in community capacity, such as training, knowledge sharing, and equitable access to resources, help build the foundations for meaningful participation, trust, and adaptive learning. This kind of reciprocal investment strengthens the ability of communities to co-manage resources and contribute valuable local and traditional knowledge (Thornton &

Scheer, 2012). Importantly, as Turnhout et al. (2019) highlight in cases of co-production, the ability of elites to step back is central to renegotiating roles and responsibilities, allowing community members to redefine project goals and priorities and empowering traditionally marginalized voices within decision-making. When engagement efforts are designed to benefit only the project rather than fostering shared leadership and mutual benefit, they risk alienating local communities and undermining long-term support.

Some approaches go beyond inclusion and seek to manage the unequal power dynamics that can marginalize local voices. As Reed et al. (2017) emphasize, professional facilitation and mediation can help resolve conflict and ensure all participants have equal opportunity to contribute meaningfully. Effective community engagement should prioritize not only who is at the table but how voices are heard and decisions are shaped. Engagement includes working with community liaisons and integrating local residents into every stage of a project, from research design to data interpretation and reporting. This inclusive approach supports equity, accountability, and long-term collaboration (U.S. Interagency Arctic Research Policy Committee, 2018).

Note: While this criterion implicitly includes considerations of cost, feasibility, and effort, we do not score these elements separately. Instead, net benefits are interpreted qualitatively as the balance between community value and implementation practicality. We do not specifically consider net benefits in a strict economic sense, due to variability in project scopes and other particulars.

Criterion III: Minimize Risk of Project Failure Due to Lack of Community Support

Minimizing the risk of failure due to lack of community support requires more than just outreach; it requires trust, transparency, and early, continuous involvement. While community engagement can be time-consuming and resource-intensive, project delays, cancellations, and relocations are also costly, both financially and socially. According to the U.S. Government Accountability Office (2022), several terrestrial carbon capture and storage projects in the United States, such as those proposed in Jamestown, NY; Carson, CA; and Greenville, OH, were canceled or relocated due in part to community opposition stemming from poor or delayed engagement. Concerns included increased electricity costs, environmental justice, and distrust of government and industry. By contrast, the project in Decatur, IL faced little resistance due to its comprehensive, proactive engagement plan that built community trust from the outset. As shown in Table 1, projects that lacked early and substantive community engagement often faced strong opposition, resulting in cancellation or relocation (U.S. Government Accountability Office, 2022).

Table 12: Use of community engagement practices by select carbon capture and storage projects

Community	Jamestown, NY	Carson, CA	Greenville, OH	Wallula, WA	Decatur, IL
Status	Cancelled	Cancelled	Cancelled	Moved	Completed injection
Conducted early engagement	✓	✓	x	x	✓
Communicated through public presentations	✓	✓	✓	✓	✓
Tailored outreach materials to different audiences	–	✓	x	x	✓
Gained local political support	✓	✓	x	x	✓
Effectively characterized local opinions before project development	x	x	x	x	✓
Involved the community in initial project planning	x	x	x	x	✓
Addressed key community concerns	x	x	–	–	✓

Legend: ✓ = yes, **X** = no, — = unknown

Source: GAO analysis of studies, reports, and public meeting minutes. | GAO-22-105274

Table 1. Case Studies Examples. Five case studies conducted across the U.S. that link lack of community engagement to project failures. Use of community engagement practices by terrestrial carbon capture and storage projects. This table is sourced directly from Table 12 in the U.S. Government Accountability Office (2022).

These outcomes underscore the importance of grounding community engagement in mutual respect, responsiveness, and shared decision-making (Klain et al., 2015). Carbon removal projects like mCDR are particularly vulnerable to failure without meaningful community inclusion. Building a social license to operate depends on honest, sustained collaboration, not treating engagement as an afterthought (U.S. Government Accountability Office, 2022).

Note: This criterion may be adapted in the future to more explicitly align with environmental justice principles. While minimizing risk is important, it is not the sole or ultimate goal. Efforts should go beyond securing trust merely to ensure project approval. If misapplied, this criterion could be misconstrued as instrumentalizing engagement rather than centering community self-determination, justice, and long-term empowerment.

Scoring Matrix

Criteria	0 Points	1 Point	2 Points
I. Maximize inclusivity and equity in engagement practices	**Fails to consider** inclusion or equity	**Minimally considers** diverse perspectives; limited in scope or depth	**Thoroughly considers** inclusion; prioritizes underrepresented voices
II. Maximize alignment of community and project net benefits	**One-sided benefits**; serves project interests	**Some shared value**; partial alignment between community and project goals	**Mutually beneficial**; strong alignment and consideration of feasibility
III. Minimize risk that project fails due to lack of community support	**Does not engage** community perspectives	**Minimal reduction** in risk; insufficient engagement	**Significant reduction** in risk through meaningful, ongoing engagement and trust-building

Table 2. The Scoring Matrix. The scoring matrix is utilized to weigh the effectiveness of each practice across each criterion. This table is adapted from Table 1 in Bressane et al. (2024).

This scoring matrix is designed to help users assess and compare mCDR community engagement practices based on three core criteria described above. These criteria reflect key principles of environmental justice, inclusivity, and long-term project success. Rather than offering definitive judgments about individual practices, the matrix is intended to support strategic reflection and informed decision-making.

Importantly, poor or superficial engagement can cause real harm by eroding trust, reinforcing disparities, and producing ineffective or even counterproductive outcomes (Williamson, 2022). This underscores the need for thoughtful, intentional approaches that center community voices from the outset.

The scoring matrix was adapted from Bressane et al. (2024). Each practice is scored on a scale from 0 to 2 under each criterion:

- **0**: Minimal or no consideration of the criterion
- **1**: Partial or limited consideration
- **2**: Full and intentional integration

To help interpret these scores, we suggest a traffic light analogy that also uses green for accessibility:

- **Red (0)**: Stop and reconsider — This practice may pose equity risks or lack sufficient community value.
- **Yellow (1)**: Proceed with caution — There may be useful elements, but revision or supplementation is likely needed.
- **Green (2)**: Ready to proceed — This practice aligns with best practices and principles of equitable engagement, though it should still be implemented alongside other efforts.

The total score in Figure 4 is calculated as the sum of the points earned for each criterion. With our current scoring matrix, the maximum total score that a practice can receive is six points. Total performance divides the total score by six to determine a practice's potential effectiveness on a scale from 0 to 1.

These scores are meant to guide improvement, not enforce a one-size-fits-all approach. Practices are often most effective when combined and adapted to local conditions. Some may not be feasible for every project depending on factors such as timing, capacity, or community readiness. For example, a project may not be positioned to implement community-driven decision-making but could still prioritize workforce integration or transparent communication.

The intent is to promote flexible, justice-oriented engagement that builds trust and long-term viability. Many of the practices in the database are designed to complement one another, rather than serve as isolated interventions. While it is not always possible or appropriate to "do everything," the scoring matrix, total score, and performance score assist in determining the effectiveness of each status quo and practice in the context of the criteria specified. While the scores provide general guidance, it is not prescriptive. Some practices that receive lower scores may still offer outsized benefits depending on the specific mCDR project context, community priorities, or cultural preferences. For instance, a practice rated lower overall may be particularly effective if it aligns with a community's preferred mode of participation or reflects a locally trusted tradition of engagement. This underscores the importance of contextual judgment in applying the matrix as a reflective tool, rather than a rigid framework.

Running Tide Case Study

Running Tide, a now-defunct company headquartered in Portland, Maine that aimed to implement ocean-based carbon removal through kelp farming and ocean alkalinity enhancement in Akranes, Iceland, in the surrounding North Atlantic, serves as a cautionary example of what can go wrong without meaningful community engagement or oversight A privately funded startup, Running Tide sought to quickly scale mCDR solutions to sell to

companies seeking to offset their carbon emissions. When its initial plan to sequester carbon by growing kelp in the ocean faltered, it pivoted to dumping vast amounts of wood chips into the sea. This triggered Iceland's Environmental Agency to require them to get a dumping permit. The company appealed this decision on the merits of research and won, leaving the Environmental Agency with no legal basis for supervision despite serious concerns that it was damaging the marine ecosystem (Alexandersson & Logadóttir, 2024).

Throughout the project, Running Tide refused to answer questions from regulators or share information with public agencies, even requesting that "provision be included that all results that Running Tide considers to be trade secrets will not be shared with government agencies or the public." Over time, scrutiny from the scientific community and news organizations called into question many of the company's claims, and in 2024 the company shut down and laid off all its employees (Alexandersson & Logadóttir, 2024).

Had funders or Iceland required more robust stakeholder engagement and oversight practices, the damage could have been minimized. For example, if users wanted to maximize inclusivity & equity (Criterion I), our database would have recommended Practice 4.4 (ensuring technical information is accessible and understandable) and Practice 3.3 (developing equal representation of stakeholders and oversight in decision-making processes). This would have created a second mechanism, beyond permitting, for transparency and oversight. Similarly, to maximize alignment of benefits (Criterion II), our database would have recommended Practice 2.4 (establishing a mutual accountability agreement) and might have created more legal avenues for accountability. Lastly, if the user wanted to minimize risk that a project fails (Criterion III), our database would have recommended Practice 1.3 (granting real-time access and ownership of data) and Practice 3.4 (establishing mechanisms for grievances, such as referendums or the ability to pause or halt a project). This could have given Iceland's Environmental Agency legal access to the data it needed and provided more opportunities to halt the project sooner, reducing financial and ecological harm.

Though no specific practice would have prevented the project's failure, the incorporation of these engagement practices could have played a key role in reducing its impact and ensuring that project risks were addressed in a timely and responsible manner. The project had many issues beyond engagement, ranging from reliance on unproven science and failure to adhere to expertise from oceanographers, to not meeting monitoring, reporting, and verification standards for carbon credits. While these challenges were significant, stronger community engagement and oversight might have helped mitigate some of the risks and highlighted the project's flaws earlier (Alexandersson & Logadóttir, 2024).

Considerations, Recommendations, and Next Steps

The database provides a preliminary structural framework to assist in determining community engagement for mCDR projects. It is important to note that other potential

practices, features, and areas of consideration exist and are not presently covered in the current database due to time and resource constraints. Our recommendations primarily focus on expanding the prototype database further to encompass a broader and more diverse range of community engagement practices. Expanding the database in future iterations can offer users more flexibility and a wider range of available practices. Expanding on applicability constraints in future iterations can give users greater control over identifying potential project limitations and restrictions that may affect the community engagement practices they implement. Our current applicability constraint, timing, should be expanded upon to account for complexities in project stages and as emerging practices are incorporated and filtered through this constraint. The criteria section can include additional criteria with beneficial community engagement goals and inclusive, equitable environmental justice values.

Our prototype database incorporates concepts and values of environmental justice. There remain significant concerns among climate mitigation groups, the energy policy sector, and the environmental justice movement regarding mCDR and its efficacy and potential impacts on the environment. For example, environmental justice advocates argue that carbon capture is often used as a false climate solution that prolongs fossil fuel dependency and burdens frontline communities (Earthjustice, 2023; Nawaz & Lezaun, 2024). Due to the complexity of this situation and the scope of our framework, these concerns may not always be directly addressable within the structure of the database. However, future iterations should strive to acknowledge and incorporate them where possible.

We considered the potential impacts a project's scope may have on community engagement. There are several dimensions of project scope, such as the project's physical geographic scale, the extent of an mCDR facility's goals, and how much carbon dioxide it aims to remove from the environment. Complex situations across multiple communities are possible and may scale with scope, such as a project's geographical extent intersecting with different jurisdictions and communities, complicating the allocation of benefits and engagement (Head, 2008; Reed et al., 2017). E.g., a utility-scale offshore wind project may have diffuse benefits that exempt it from local community benefit requirements in the state where it's located (Sotolongo, 2024). Larger projects could also create conflicts between different communities or stakeholders. While the prototype database does not include practices to resolve conflicts, future iterations could incorporate lessons from success stories such as the California's Marine Life Protection Act (MLPA) Initiative. Planners established an inclusive decision-making process to balance ecological design standards, jurisdictional boundaries, and a wide range of stakeholder interests (Yaffee, 2020; Kirlin et al., 2013). Smaller projects, on the other hand, could have fewer resources or less capacity to implement some of these community engagement practices. Future iterations of the database should examine and incorporate the impacts of a project's scope on community engagement as well as identify federal and local resources.

Furthermore, the database should be used as an assistive tool rather than an absolute determination. It is intended to guide community engagement but may need to be adapted to fit unique circumstances. Indigenous communities should also be considered while expanding the database. There are vast differences among Indigenous communities, some of which do not have federal recognition, and these complexities warrant further examination. An expanded database should examine and highlight potential practices and ideals related to community engagement with Indigenous communities to ensure inclusive and equitable engagement across varying cultures.

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Glossary

Number	Term	Definition
1	Applicability	Project-specific constraints that influence which practices are relevant.
2	Constraint	Factor that influences whether a practice is appropriate.
3	Community*	Groups or individuals, particularly those impacted by marine carbon dioxide removal (mCDR), who hold local knowledge, cultural values, or lived experience, and who should be treated not merely as stakeholders but as ethical partners in research and decision-making, deserving of transparency, consent, inclusion, and equity throughout the engagement process (American Geophysical Union, 2024; Boettcher et al., 2023).
4	Criteria	The overarching goal that a user may be aiming to obtain from utilizing the database.

5	Engagement Types	A structured group of approaches to ensuring just, transparent, and inclusive engagement.
6	Equity	Distributing resources fairly based on individual needs to ensure equal outcomes.
7	Practice	A specific action or method used to implement an engagement type.
8	Reciprocity*	The ethical responsibility to engage with communities through ongoing, trust-based interactions that include sharing knowledge, responding to input, and ensuring that research processes and outcomes provide tangible value in return. It emphasizes mutual exchange, transparency, and responsiveness, fostering relationships grounded in respect and accountability (Boettcher et al. 2023; Diver et al. 2019; Nawaz & Lezaun, 2024).
9	Status quo	The current standard approach to engagement, which we aim to improve on.

Acronyms	Definition
EPA	Environmental Protection Agency
CWA	Clean Water Act
mCDR	Marine Carbon Dioxide Removal
MPRSA	Marine Protection, Research, and Sanctuaries Act
NOAA	National Oceanic and Atmospheric Administration

***Note:** Definitions of community and reciprocity may differ across different locations, regions, cultures, and populations. For more ambiguous words, we provide literature to support their definitions and offer additional context on how we define them.