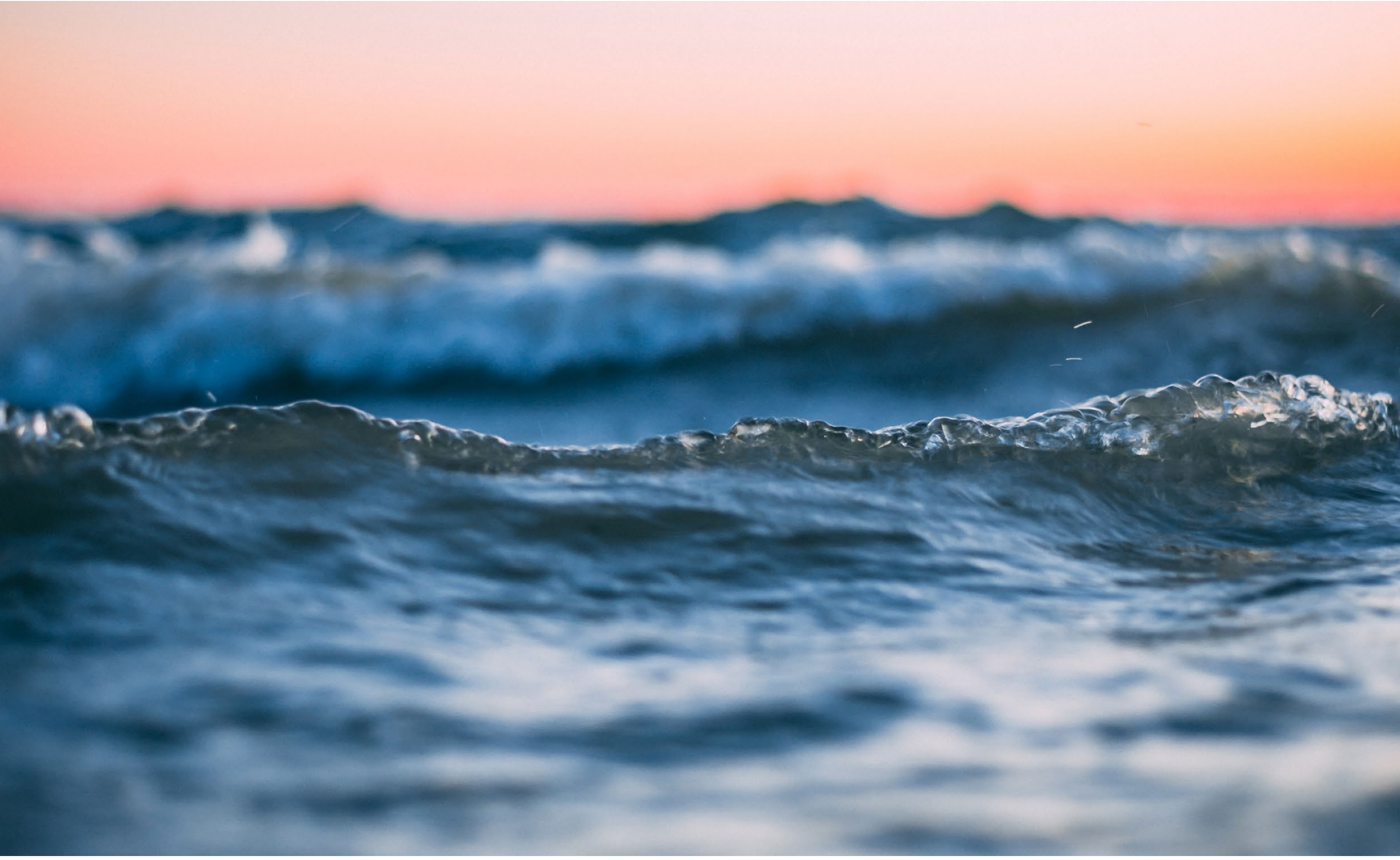
Guidance for Ocean-Based Carbon Dioxide Removal Projects

A PATHWAY TO DEVELOPING A CODE OF CONDUCT

DECEMBER 8, 2021



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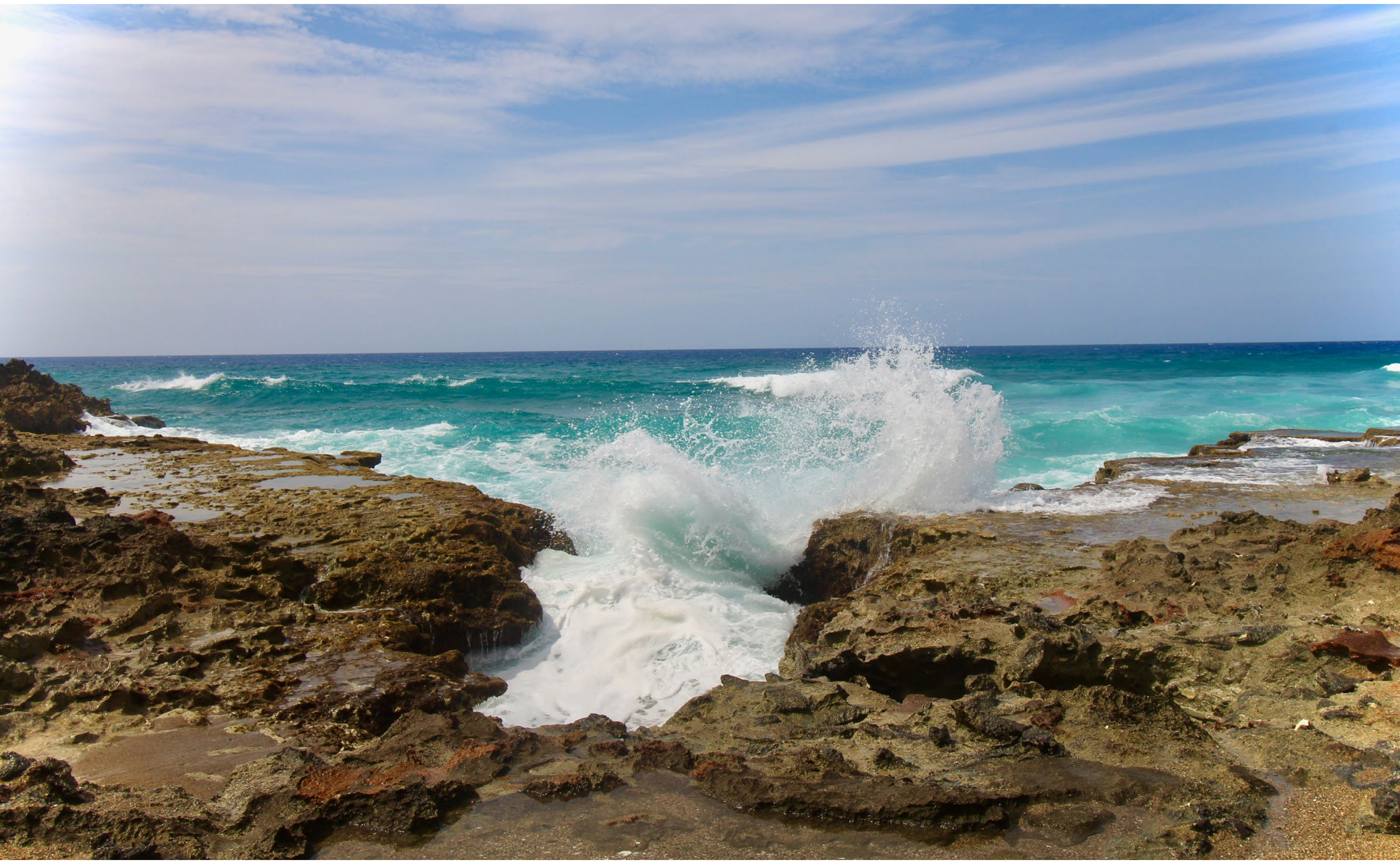
The Aspen Institute Energy and Environment Program is an active and prominent convener of nonpartisan policy dialogue and neutral forums focused on key energy and environmental topics and how to advance environmental sustainability in a technological world. The Program's mission is to take up the enduring questions about nature and society, and to prompt new thinking among diverse participants by deliberately testing assumptions and policies about sustainable water use, clean energy, climate change, and wildlife conservation. The Program promotes values-based dialogue among thought leaders from business, government, nongovernmental organizations (NGOs), and academia to address complex energy and environmental policy challenges in a collegial atmosphere that allows deliberation, creativity, collaboration, and compromise to flourish. Like the Aspen Institute as a whole, the Energy and Environment Program seeks to inspire and explore new ideas and provoke action in the real world.



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FOREWORD

As the world careens toward unprecedented planetary warming and the implications of a changing global climate grow increasingly dire, it is becoming more and more apparent that humanity must consider every possible opportunity to remedy the damage our species has done to our home planet. Even if immediate cessation of all future greenhouse gas emissions was either politically or economically feasible, we would still need to find a way to remove and sequester a significant amount of carbon dioxide (CO_2) from the atmosphere in order to avoid the worst consequences of our historic emissions. Yet, as we pursue emerging methods of doing so, either by accelerating natural processes or engineering new mechanical ones, we must also ensure that we do not cause unintended and potentially irreversible harm to natural systems and coastal communities.

The global ocean, covering more than two-thirds of the surface area of our planet and encompassing over 95 percent of the habitable area by volume, remains the least explored and understood ecosystem known to humankind. In particular, scientists estimate that the deep and remote ocean, much of which exists beyond the political jurisdiction of any single nation, is home to countless undiscovered species, and unknown interactions and phenomena. Many of these ecosystems exist on timescales and with degrees of sensitivity that make them highly susceptible to disruption. From a human perspective, it is also critical that issues of historic inequity be accounted for and rectified in any future actions. Finding the balance between accessing the potential benefits of certain innovative interventions to help meet the existential imperative of combatting runaway climate change while safeguarding biodiversity and intricate natural processes is in itself a challenge of epic proportions.

In an attempt to begin navigating this delicate balancing act, the Aspen Institute, with support from the ClimateWorks Foundation, convened an ocean-based carbon dioxide removal (CDR) Roundtable Discussion Group throughout the summer and fall of 2021, in which 28 individuals joined at least one session (see Appendix A: Discussion Group). These experts represented a diverse array of stakeholder groups, fields of expertise, and geographies to develop guidance and recommendations and begin framing a Code of Conduct for ocean-based CDR practices. This work was carried out concurrent with and independent from an ongoing study by the National Academies of Sciences to develop "A Research Strategy for Ocean Carbon Dioxide Removal and Sequestration," and this report has been timed to be released concurrent with the National Academies' in-depth scientific analysis.

The Aspen Institute's process involved convening a series of five, virtual, multi-hour discussion group sessions and one presentation from a variety of practitioners in the ocean-based CDR space. These meetings were scheduled to accommodate a wide variety of time zones in order to enable participation from contributors across many geographies as well as incorporate trans-disciplinary perspectives, including natural and social scientists, policymakers, non-governmental organization and philanthropic leaders, and representatives from the business and finance communities.

The invited experts provided input on the need for and process to develop an equitable, comprehensive, and scientifically rigorous Code of Conduct for ocean-based CDR research and technology development, with an initial focus on research and development opportunities to vet and assess projects to determine whether and how they should move from laboratory settings to the marine environment. In addition to laying the groundwork for such a Code of Conduct, this work targets practitioners, researchers, policymakers, communities, and others seeking guidance around ocean-based CDR, and also aims to inform media coverage and enhance the uptake and resonance of the forthcoming National Academies of Sciences' report on ocean-based CDR.

The resulting report is issued under the auspices of the Aspen Institute Energy and Environment Program and attempts to capture key themes, ideas, and perspectives raised during the course of the roundtables. This convening, like most hosted by the Energy and Environment Program, was held under the Chatham House Rule, meaning no attribution of specific comments or perspectives would be assigned to individuals or organizations who participated in the dialogues, with the exception of the publication of the names and affiliations of participants at the end of this report. Participants were not asked to agree to the wording of this report and, therefore, participants, speakers, sponsors, discussants, or their organizations are not responsible for the contents. Not all views captured in this report were unanimous and the contents of the report cannot be attributed to any individual or group of individuals in attendance.

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01. INTRODUCTION

The Intergovernmental Panel on Climate Change's (IPCC) Sixth Assessment Working Group I Report has made it clear that strong, rapid, and sustained CO_2 emissions reductions and removal are necessary to remain under or close to the 1.5°C global mean surface temperature warming threshold. Scientists warn that this represents a critical benchmark above which the effects of climate change will be increasingly dire. This grim reality underscores the urgency of not only reducing new greenhouse gas emissions, but also removing significant amounts of existing CO_2 from the atmosphere. Indeed, the report states that both of these elements—reducing greenhouse gas emissions and increasing carbon dioxide removal (CDR) at gigaton-per-year scale—are imperative to meet and address the rapidly unfolding climate crisis. The report goes on to assert that CDR will need to be deployed at this scale well before 2050 to remain consistent with the 1.5°C target but that no CDR option is ready to be deployed at a level commensurate with the challenge. This finding highlights the urgent need for the research and development of myriad CDR approaches, as well as an internationally applicable framework to guide responsible CDR research and development.

The urgent need for climate action suggests a potentially important role for ocean-based CDR—which involves in-ocean or coastal activities that remove and durably store CO_2 from the atmosphere or from seawater—assuming ocean-based CDR is proven to be effective and viable and can be executed responsibly and equitably in the near term. The ocean is already a potent carbon sink, estimated to have absorbed roughly 40% of fossil CO2 emissions since the beginning of the industrial era. Ocean-based CDR could have significant advantages over land-based CDR, including but not limited to greater available space and potentially less competition for human uses. The ocean also offers the possibility of a high degree of permanence of carbon storage. However, ocean-based approaches also involve challenges, such as poorly understood environmental impacts, inadequate governance and uncertain jurisdiction, difficulty of operations in a punishing and unforgiving environment, and verifying the rate and permanence of carbon removal and storage.

Responsible research into and small-scale trials of ocean-based CDR practices could help identify the extent to which these approaches may contribute to the drawdown of historic CO_2 pollution in the atmosphere, serve as a counterbalance for difficult-to-mitigate sources of CO_2 in the short term, alleviate inequities and other negative ramifications of climate change, and provide a range of potential co-benefits. Such research will also be fundamental to understanding, assessing, quantifying, minimizing, mitigating, and where possible, avoiding potential negative consequences, including impacts on the environment (e.g., effects on ecosystems and biodiversity) and communities (e.g., exploitation of communities and inequitable distribution of consequences). Risk assessments of ocean-based CDR approaches must strike an appropriate balance between the risks to ecosystems and communities from such approaches, and the risks to ecosystems and communities from failure to address climate change in a timely manner and at an adequate scale.

Additional thoughtful concerns include the potential for ocean-based CDR deployment to crowd out or de-incentivize climate mitigation tactics and the risk of ocean-based CDR distracting from the research and development of other CDR approaches or adaptation measures. Specifically, if deployment were to lower ambition to reduce emissions, it could have negative consequences for progress towards climate goals. However, given the relatively small amount of attention and funding directed to ocean-based CDR in comparison to land-based CDR, the true risk is likely to be minimal.

Society as a whole will benefit from greater understanding of the extent to which ocean-base. CDR activities may be able to contribute to climate stabilization and restoration, as well as of the associated ramifications for marine ecosystems and communities.

02.
WHAT IS OCEAN-BASED CDR?

In its recent report, the IPCC defines CDR as "anthropogenic activities that deliberately remove CO_2 from the atmosphere and durably store it in geological, terrestrial or ocean reservoirs, or in products. Carbon dioxide is removed from the atmosphere by enhancing biological or geochemical carbon sinks or by direct capture of CO_2 from air" (IPCC AR6 WGI, TS-64). The IPCC report further notes that:

> *CDR approaches could be used to compensate for residual emissions from sectors that are difficult or costly to decarbonize. CDR could also be implemented at a large scale to generate global net negative CO_2 emissions (i.e., anthropogenic CO_2 removals exceeding anthropogenic emissions), which could compensate for earlier emissions as a way to meet long-term climate stabilization goals after a temperature overshoot.*

Land-based CDR can involve direct air capture, reforestation or afforestation, bioenergy with carbon capture and storage, and several other techniques. This document focuses only on ocean-based CDR techniques, which can involve kelp and other marine plant cultivation, coastal weathering of rock and minerals, direct ocean alkalinity enhancement, ocean iron and nutrient fertilization, and many other approaches.

For the purposes of this document, "ocean-based CDR" refers to a range of intervention techniques that: (1) take place primarily in the ocean, including in coastal regions; (2) extract CO_2 directly from the atmosphere, or from seawater leading to additional reduction of atmospheric CO_2; and (3) durably store the extracted CO_2 for a significant period of time.[1] While defining what "significant" means in this context is beyond the scope of our initial work, it will be critical to determining the potential contribution that such activities could make to achieve lasting climate mitigation benefits. A more in-depth treatment of durability should be a central focus of follow-on reports. For example, Siegel et al. assert that "ocean-based CDR strategies that increase upper ocean ecosystem productivity with the goal of exporting more carbon to depth will have mainly a short-term influence on atmospheric CO_2 levels because ~70% will be transported back to the surface ocean within 50 years" and that deeper discharge methods could sequester carbon for decades to centuries and potentially for up to 1.000 years, pointing to the crucial importance of durability in pursuing CDR strategies.

Ocean-based CDR is different from land-based CDR in a number of important ways. The ocean is already the planet's largest long-term sink for anthropogenic carbon. This ability to act as a sink makes the ocean a promising place to explore options to accelerate carbon removal, provided that research is also conducted to ensure accelerating such absorption can be done without over-taxing this carbon absorption function.

Ocean-based CDR also opens up a broader array of options for carbon removal project development, in part because of the ocean's sheer volume, and particularly if such activities are carried out further from shore. Practices that might be less efficient compared to similar land-based practices when measured by the level of carbon-removal impact per unit of area could be

1 There are multiple terms that can be applied to these ocean-based techniques. For example, the National Oceanic and Atmospheric Administration refers to such activities as "marine CDR". The National Academies of Sciences, Engineering, and Medicine refers to them as "ocean carbon dioxide removal and sequestration." This paper uses the term "ocean-based CDR" to encompass the activities under consideration.

viable in the ocean simply because there is more space (e.g., sequestering carbon in plant material via reforestation faces limits on land availability that some ocean-based photosynthesis initiatives may not face). Conversely, human expansion into and demands on the ocean for resources have grown immensely, and the ocean should not be considered void of existing industry or other uses by any means. At the most basic level, the imperative to protect the ocean's many valuable ecosystems and affiliated services from the increasing threats posed by climate change and the potential consequences of ocean-based CDR activity must remain a fundamental principle.

There is also the possibility for multiple uses to be co-located, such as siting ocean-based CDR activities in areas already utilized for fisheries or leveraging shipping traffic for monitoring or even deployment, though any co-location must be carried out in close collaboration with existing user groups and a due measure of precaution.

In addition, ocean-based CDR approaches have the potential for unique, often method-specific, co-benefits, including but not limited to mitigation of ocean acidification at local and global scales (though perhaps only temporarily at the surface and potentially to the detriment of acidifying the deep ocean), co-production of food, and production of biofuels, which will need to be studied and documented.

At the same time, people's perceptions of the ocean and what actions are or are not acceptable in it can be quite different from those on land and can vary widely based

CASE STUDY
Ocean Iron Fertilization

One of the earliest efforts to explore and test some of the scientific principles behind possible large-scale ocean-based CDR practices involved a practice known as ocean iron fertilization (OIF), a methodology that involves dumping dissolved iron in the open ocean to stimulate the growth of phytoplankton that absorb CO_2. This concept rose to prominence in certain scientific circles in the early 1990s and led to at least 13 major OIF experiments that tested whether such actions stimulated phytoplankton growth or drew down CO_2. As these experiments progressed, some began to explore whether such activity could, in principle, contribute to climate stabilization if a substantial amount of the removed organic carbon was effectively transferred to the deep sea. Toxic algal blooms and damage to marine and coastal ecosystems were among some of the early flags raised about the potential negative ramifications of OIF and in 2008 these concerns led the United Nations Convention on the Prevention of Marine Pollution to institute a ban on all large-scale OIF activities for non-scientific purposes until scientists developed a better understanding of potential risks and/or benefits of the approach. Scientific research on OFI was allowed to continue on a case by case basis with external review.

Of the 13 major experiments undergone since 1990, the most controversial OIF experiment took place off the coast of British Columbia in 2012 when the Haida Salmon Restoration Corporation in connection with Russ George, an American entrepreneur, made the case to Haida Gwaii residents that dumping iron sulfate in the open ocean would stimulate a bloom of algae that would boost salmon populations while also sequestering carbon. Part of this case, and the resulting controversy, was the promise of selling carbon credits based on the CO_2 sequestered by the sunken algae. In the aftermath of the 120 tonnes of iron sulfate being deposited into the open ocean, critics were deeply alarmed that this kind of unilateral action with little to no evidence of sequestered carbon or boosted fish populations, could potentially put marine ecosystems at such great risk. The lack of open and transparent scientific monitoring and adequate stakeholder engagement were particularly troubling. The controversial case and resulting backlash contributed to the London Convention on ocean dumping adopting additional rules for regulation in 2013, and have sparked further conversations around the approach itself, as well as other ocean-based CDR techniques that might have negative impacts if ungoverned and not sufficiently researched.

OIF as a case study offers an interesting vantage point into the research and governance around ocean-based CDR, and researchers and practitioners should look to its history as they pursue the promise and seek to avoid potential pitfalls of other methodologies.

on different experiences, cultural values, practices, and priorities. Also, the ocean is vast and interconnected, with currents, upwelling, and downwelling creating mixing effects that may mean the ramifications of ocean-based CDR techniques could affect ecosystems far beyond the local areas where they are carried out. The potential unintended consequences of ocean-based CDR approaches could have global effects that may be difficult to reverse, and monitoring, reporting, and verification of certain approaches are likely to be more challenging and more costly in the ocean than on land.

Although initial small-scale research activities may occur (and are already taking place in some cases) in waters closer to shore within an individual country's Exclusive Economic Zone, for some nascent ocean-based CDR activities, large-scale expansion could involve shifting operations further offshore. This has the potential to create international governance conflicts, including the rise to prominence of transboundary disagreements between neighboring countries, because the ocean has progressively less governance and affiliated legal frameworks for oversight the further one gets from shore. Furthermore, the deep sea remains predominantly unexplored and uncharted with innumerable species that have yet to be discovered, which complicates the potential for science-based decision-making.

These issues become even more acute for activities that take place on the High Seas, outside of the 200 nautical mile Exclusive Economic Zone of each coastal country, and beyond the jurisdiction of any single nation. As a result, this area is subject to governance structures that are spotty and difficult to enforce. Examples include the United Nations Convention on the Law of the Sea, which sets foundational principles for management of the global ocean, and specific treaties such as the Convention on Marine Pollution by Dumping of Wastes and Other Matter. There is significant uncertainty as to whether, when, and how these and other international agreements will apply to different ocean-based CDR techniques, and particularly how they might apply to private actors.

Ongoing efforts to create a United Nations agreement supporting biodiversity beyond national jurisdictions may lead to some restrictions on the use of international waters, but enforcement is likely to be extremely difficult to execute even if this treaty should enter into force in the years to come. Further complicating matters is the reality that it will only apply to nations that are party to the agreement, and it is highly unlikely that all countries will accede to it.

This fragmentation in or absence of governance systems and enforcement mechanisms may make it difficult to ensure responsible ocean-based CDR research and to prevent projects for which the negative externalities (e.g., on ecosystems and communities) outweigh the benefits. It will also complicate the process of determining who should be the appropriate stakeholders or regulators to decide whether, on balance, a project is net-beneficial. The reality of imperfect and inadequate governance is part of the reason why a Code of Conduct for ocean-based CDR activities is needed. At this stage, guidelines for research and development projects can even be considered more appropriate than formal governance structures, to avoid the possibility of creating rigid rules that lead to unintended limitation of innovation in as yet unknown areas.

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03.
GUIDANCE ON OCEAN-BASED CDR RESEARCH AND A CODE OF CONDUCT

While reducing greenhouse gas emissions must remain the top global climate policy priority, the most optimistic scenario in the IPCC's sixth assessment report assumes that billions of tons of CO_2 per year will be drawn out of the atmosphere by 2050. While there is ample reason to believe ocean-based activities are likely to contribute to this effort, the overall lack of scientific understanding of ocean systems and of ocean-based CDR approaches means many uncertainties still exist about whether, how, and to what extent ocean-based CDR techniques will ultimately play a role.

There are societal and ethical questions that are far bigger than any given ocean-based CDR project, which must be addressed before ocean-based CDR can move forward at scale. These questions, the answers to which are mostly beyond the scope of this document, include issues such as:

- What national and international governance structures must be established or adapted to oversee and track sequestration efficiency of ocean-based CDR?

- What requirements are needed for monitoring and characterizing environmental impacts on human safety and livelihoods? How should equivalence metrics be created to ensure that any potential harm to marine ecosystems from ocean-based CDR is weighed against harm from excess atmospheric CO_2 levels and from the impacts of climate change?
- How can knowledge-sharing and technology transfer be promoted and facilitated across governments, and in particular how can research capacities of developing countries be strengthened to ensure a more equitable global ecosystem of research and expertise in the long term?
- What kind of participatory decision-making process(es) should determine whether an ocean-based CDR approach should proceed through multiple stages of technological development to eventual full-scale deployment and implementation? Who or which framework convention will be the arbiter of what negative externalities of ocean-based CDR should be deemed acceptable or will come on line in a timely enough manner to pursue?
- How will co-benefits of any potential activity be accounted for in determining whether and how to allow potential projects to expand?
- What structures, processes, and/or resources should be created or adapted to enable affected stakeholders to help inform initial assessments of project suitability, and to have any grievances aired and addressed should negative consequences arise?
- How will ocean-based CDR address the rights of coastal people worldwide and in particular abide by the United Nations Declaration on Rights of Indigenous People?
- How can ocean-based CDR activities help address existing climate and societal inequities, including the distribution of any benefits and harms of ocean-based CDR? How might the flow of resources from high carbon-emitting per capita nations, including cumulative historical emissions, to less carbon intensive nations be factored into development of ocean-based CDR activities?
- How can the costs and benefits of ocean-based CDR options be evaluated, considered, and weighed against other measures to address climate change? Will ocean-based CDR undermine motivation for other climate mitigation, adaptation, or emissions reductions?
- Should ocean-based CDR projects be able to be used for carbon credits and offsets, including for public sector equivalents such as meeting Nationally Defined Contributions under the Paris Agreement? If so, what additional requirements and issues are raised by that decision and after what stage of research on potential impacts should companies be able to profit from a particular project's associated carbon credits? How should carbon markets based on ocean-based CDR be structured to ensure financial incentives are not allowed to manipulate these markets?
- To what degree, if at all, should the public sector be more directly involved in conducting ocean-based CDR or supporting private sector efforts?

These broad issues are vital to consider and address alongside the urgent need for scalable CDR, and the international community, governments, industry associations, and others must grapple with them. The purpose of this document, however, is decidedly narrower: to provide guidance to researchers and practitioners on how to enable responsible research and development of ocean-based CDR activities that may become deployable at scale in a timely fashion. This document can also be used by policymakers, stakeholders, investors, and others to guide their engagement with ocean-based CDR projects and practitioners.

The pursuit of knowledge regarding ocean-based CDR approaches is already underway in both academia and the private sector, but the parameters for responsible research—particularly as pilot-scale trials move forward in the context of imperfect and inadequate ocean governance—are not yet standardized among the early movers. As scientists and practitioners prepare to advance the body of knowledge about potential ocean-based CDR activities, policymakers must consider the need for expeditious answers that reflect the urgency of the climate crisis and the known, grave consequences of inaction for humanity and many of Earth's critical ecosystems including the ocean. Scientists, practitioners, and policymakers must also balance the need for answers and potential consequences with the need for precaution, care, and thorough oversight to ensure protection of marine ecosystems and biodiversity, allow for consideration of impacts on coastal economies and cultural values and priorities, minimize harm, and avoid or at least allow early detection of and adaptation to other unintended negative consequences. In pursuing ocean-based CDR safely and conscientiously, key questions must first be addressed in the context of small-scale or pilot projects to determine initial viability, but also, to the extent practicable, in the context of potential impacts of large-scale deployment.

Given all the questions about ocean-based CDR and the lack of ocean governance, a Code of Conduct for responsible ocean-based CDR research and development could fill a vital niche. The stakeholders that the Aspen Institute convened, however, were very cognizant of the need for a much broader, more diverse, more inclusive input-gathering process for development of a Code of Conduct than what the Institute could arrange under the time and resource constraints involved.

For example, any Code of Conduct must address the rights and title of coastal peoples and the ocean territory long governed through traditional practices that incorporate responsibility for marine systems. There is significant diversity of understanding, experience, norms, and values in different geographies relating to coastal ecosystems, the ocean, and ocean-based CDR. Among these, certain primarily Western-based knowledge systems are often considered more valid, while non-Western and Indigenous perspectives are largely overlooked. A full treatment of ocean-based CDR as it relates to coastal communities will explore and deliberately differentiate between, for example, the impacts of a large-scale seaweed farm sited along a coast that disrupts local fishing practices and an experiment in the open ocean that might, if developed at scale, contribute to providing global relief from the threat of sea level rise.

All affected communities and other stakeholders need to play a role in determining how to proceed with research on the effectiveness and the potential risks and benefits of ocean-based CDR approaches, including opportunities to contribute to governance and participate in decision-making. This suggests a need for much broader consultation on any Code of Conduct for ocean-based CDR, as well as the importance of gathering input across disciplines (e.g., ecology, geology, biology, sociology, finance) and from nonacademic knowledge communities. It also speaks to the imperative that the questions raised by this document be adopted not just by regulators, but also by investors, philanthropic entities, and government funding agencies whose support will in large part determine the direction of future research and development. Furthermore, because even ocean-based CDR activities that occur in one physical location could have ramifications that extend into other territories or even on a global scale, transparency of data and findings must be paramount.

Accordingly, rather than a final checklist of prescriptive requirements or a fully fleshed-out Code of Conduct, this document sets forth key questions identified by the Aspen Institute stakeholder group that should be considered by researchers and practitioners—as well as policymakers, regulators, investors, communities, and others—related to undertaking limited research to test any particular ocean-based CDR technique. Comprehensive consideration of these issues, concerns, and questions should enable holistic project design for responsible ocean-based CDR research and development, mitigate some of the hurdles posed by imperfect and inadequate governance, and allow multiple stakeholders to hold each other to mutual account.

This work will also help provide an initial foundation upon which future development of a fuller Code of Conduct can proceed.

The key principles and questions identified by the Aspen Institute Discussion Group can be grouped into the following categories. In each case, an independent review body must establish parameters for what constitutes a reasonable and customary scientific standard in order to provide a level playing field for all groups attempting to address these issues and questions:

Define and Verify Carbon Dioxide Removal Potential

The research project must, to a reasonable and customary scientific standard, define and estimate the potential for CO_2 removal and explain the mechanisms to independently verify or directly measure its effectiveness.

Key questions include, but are not limited to:

1. How much carbon will the project remove over and above what would have occurred absent the intervention (referred to as additionality), including the time scale and confidence level of the minimum duration of sequestration? How have such estimates or measurements been developed? This work should include a modelling study to assess uncertainties, including how potential future climate states may affect stored carbon.
2. How will the longevity or permanence of the actual additional CDR occurring be verified, measured, shown, and monitored? Is it feasible or possible to measure and monitor significant durability over time, and if so, for how long? How will the experimental data and methods on CDR perturbations of the ocean, CO_2 removal, and sequestration be shared with the public and stakeholders?
3. What are the CO_2 implications of ending the activities once they have started, including the potential for runaway activities or the possibility of a failure to maintain control over shutting down and ending operations if and when atmospheric carbon levels return to a baseline or target level?
4. What evidence demonstrates proof of concept in a laboratory or other setting, and how has that evidence been independently verified?
5. To what extent, and under what conditions, could the large-scale deployment of the particular ocean-based CDR technique contribute in a timely fashion to realistic and effective pathways for the world to achieve climate neutrality and the goals established in the Paris Agreement? Can this ocean-based CDR technique be researched, developed, and deployed in a timely and economically viable way to be a climatically meaningful solution?
6. What is the result of a full life-cycle accounting of costs and benefits, including the complete carbon footprint of cradle-to-grave operations?
7. Are there flows of total net removals of CO_2 from an activity that initiates in the territory of one nation (or on the High Seas) and concludes in the territory of a different nation? If so, how will emissions and removals from different stages of a project's life cycle be reported, tracked, and regulated in different countries?
8. Are there any problems with or prerequisite conditions needed for the particular ocean-based CDR approach at any stage of the cycle, including upstream sourcing of materials, existence of supportive infrastructure, necessary inputs (e.g., energy use), later-stage scalability, and end-of-life?

Catalogue Potential Environmental Externalities (Negative and Positive)

The research project must, to a reasonable and customary scientific standard, identify and report on potential and certain intended and unintended environmental impacts, both in and beyond the testing area.

Key questions include, but are not limited to:

1. What observational baselines of understanding of ocean systems and current functionality have been established from which any environmental impacts to the test area can be measured?
2. What systems and extant baseline knowledge are in place to monitor other environmental impacts and by what metrics?
3. Is the mitigating activity reversible? That is, can the process be pulled back, and termination shock avoided, if it fails or has serious negative effects? What would be required and has the developer created a plan to do so if necessary?
4. Are there technologies that are relatively more fail safe than others? That is, should they fail, are any consequences minimal when not reversible?
5. What are the anticipated environmental effects? Can the positive and negative environmental impacts be quantified, including their likelihood of occurring, and if so, what are the quantified, cumulative impacts?
6. What systems are in place to minimize negative and maximize positive environmental impacts?
7. Are any assertions regarding potential positive or negative externalities independently verifiable, and if so, have they been verified?
8. What process is in place to conduct an ecological impact assessment, and who will oversee this process to ensure it encompasses the full scope of geographies and ecosystems that could be impacted over time?
9. How are results and data to be communicated, shared, and made fully transparent to best promote research integrity and replicability? Will analyses be created and communicated in a manner such that stakeholders can use them effectively in decision-making, including through peer-review and publication?

Catalogue Potential Societal Externalities (Negative and Positive)

The research project must, to reasonable and customary scientific and ethical standards, identify and report on potential and certain societal impacts, including how such activities will affect less developed countries and underserved populations.

Key questions include, but are not limited to:

1. Who should be considered stakeholders for purposes of this exercise, and who is tasked with making this determination?
2. Have stakeholder engagement and relevant social science expertise been embedded and integrated into the project from the outset of efforts to move beyond the laboratory and towards field trials?
3. Has stakeholder engagement been conducted around both process (including equity and representation) and assessment of outcomes (e.g., as part of any environmental impact analyses)? How will researchers structure the stakeholder engagement process going forward so that engagement is sensitive to both the quality of conversation and the tractability/tangibility of the outcomes proposed?

4. What are the anticipated societal costs and benefits? What analyses of them have been done or are planned?
5. Where do the costs, benefits, and impacts accrue? Which countries, places, and communities will or could bear them? Are they the same as those already bearing disproportionate impacts of the climate crisis or other environmental burdens?
6. What measures are in place to ensure that vulnerable communities are not overburdened with potential negative consequences? How are such communities being engaged in the process?
7. How are results and data to be communicated and shared to best promote research transparency? Will analyses be created and communicated in a manner such that stakeholders can use them effectively in decision-making?

Governance, Funding, and Cessation

As researchers develop pilot projects and begin to move from laboratory settings to in situ testing, they must account for issues related to operations and oversight.

Key questions include, but are not limited to:

1. How are practitioners engaging with regulatory regimes and agencies to ensure adequate compliance with pertinent mandates that can provide oversight from the outset?
2. Are existing local, state, regional, tribal, national, and international governance structures adequate to enable and oversee the project? How does the project plan to ensure responsible conduct in light of any inadequacies of governance and oversight?
3. What resources are available to enable potentially harmed parties to file grievances and seek remuneration and rectification in the case of unintended and unanticipated negative consequences?
4. What is the structure of financing for research, and who stands to benefit financially from approval of the project? What mechanisms can be implemented to ensure any benefits—including financial benefits—are shared with less developed countries and underserved populations that are already feeling the consequences of a climate crisis they did not create?
5. What is the developer's plan for a future in which the project is no longer required or is discovered to impose significant negative consequences? Is there a clear eventual shutdown scenario for the project?
6. What happens to the physical infrastructure deployed (if any) at the project's planned end of life, including in the event of an unplanned shutdown?
7. Is there sufficient funding from the practitioner for all stages of operation (including to remove any equipment and restore any ecosystem damage at the project's conclusion) and for a governing body to conduct oversight and independent verification, in order to ensure the research is carried out in a manner that considers and implements all of the above principles and questions? What are the sources of this funding and what assurances exist that it will continue to be available?

04.
NEXT STEPS

This document is not intended to be merely an academic exercise. Researchers and practitioners are already going ahead with ocean-based CDR research projects, including as part of commercial ventures. It is designed to facilitate responsible research to progress—with caution, methodical review, and an appropriate balance between the urgency of climate action to avoid the most significant negative consequences for communities and natural systems from the harm humanity has already inflicted and with the imperative to avoid inadvertently making the situation worse, even through actions executed with the best intentions. Research activities conducted without clear and explicit reference to these principles are likely to be deemed unacceptable by relevant stakeholders, including the communities hosting these experimental interventions.

Moving forward, the sets of principles and questions described in this document need to be tested, honed, and improved by governance entities, ocean-based CDR researchers, practitioners, and other stakeholders in order to operationalize them. Given the amount of time this will take to develop and the urgency of action to address climate change, ocean-based CDR projects should voluntarily address these questions and principles to the best of their ability, and investors or funders, NGOs, and government should hold developers to account. In addition, resources could be added to provide further guidance to researchers, practitioners, and stakeholders for issues or questions they cannot satisfactorily address.

On a parallel but intertwined track, efforts should proceed toward developing a more comprehensive Code of Conduct for ocean-based CDR, addressing the specific challenges and opportunities presented by each form of ocean-based CDR. The process is intended to be evolutionary and iterative, building on existing Codes in related fields where appropriate (see Appendix B), as well as on other related and relatively novel areas for governance (e.g., deep sea mining and offshore wind). It is also intended to be as inclusive as possible, drawing input from a broad range of affected communities and other stakeholders. In addition, the process and resulting Code must be as nimbly adaptable and amendable as possible. This is especially important in light of the inevitability of mistakes that will be made; improvements that will occur in understanding of the costs, benefits, and externalities of potential activities as they differ for research versus deployment at scale; and potentially dramatic positive or negative ramifications of future developments in the field. All stakeholders should understand that a Code of Conduct for ocean-based CDR must remain dynamic and adaptable—perhaps reviewed and revised on a regular basis—as science and experience discover additional data and the climate crisis itself continues to evolve.

Questions of oversight, compliance, and verification must be addressed for this and future versions of the Code to become practical guides for action. A group of honest brokers or a set of relevant actors and institutions should be identified and empowered to ensure practitioners account for the issues raised in this guidance and in the eventual Code. These entities could provide vetting or check on projects' assertions on these issues, help address gray areas, and provide a line of defense against potential bad actors. (It is possible that the financial community, including investors and insurers, could play a key role in this regard by restricting their funds and services to those that abide by the Code.) Furthermore, it could be interesting to explore the potential for the ocean-based CDR research community to jointly determine key overarching research priorities—similar to the decadal surveys that occur in astronomy and astrophysics and in planetary science and astrobiology—that could further reduce the potential for project competition and bad actors.

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CONCLUSION

While ocean-based CDR techniques are still at a fairly nascent stage of technological development, they could play a vital role in limiting damage from climate change, with some also potentially providing measurable co-benefits for the ocean and ocean communities. Ocean-based CDR approaches, however, also have the potential to create negative consequences for ecosystems and communities around the world, some of which could be irreparable.

As ocean-based CDR research moves forward, all stakeholders would benefit from engagement, dialogue, and learning regarding the suite of issues and concerns, including, but not limited to, questions regarding carbon removal efficacy and durability, positive and negative implications for ecosystems and communities, and governance. These questions posed here can provide much-needed guidance in the near term. However, like ocean-based CDR efforts themselves, the process of crafting a full Code of Conduct for ocean-based CDR has only just begun.

APPENDIX A
DISCUSSION GROUP

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APPENDIX B
OTHER RELEVANT CODES OF CONDUCT

Other relevant Codes of Conduct and guiding documents exist that address broader or adjacent fields. Examples include the following:

- *Principles for Thinking about Carbon Dioxide Removal In Just Climate Policy*, David R. Morrow et al., One Earth (2020), https://doi.org/10.1016/j.oneear.2020.07.015
    - Examines the rising importance of CO_2 removal in the climate-policy agenda and outlines principles to help civil society organizations, funders, and government agencies arrive at informed decisions for fair and effective implementation of CDR as part of a robust, abatement-focused long-term climate strategy.

- *The Oxford Principles for Net Zero Aligned Carbon Offsetting*, Myles Allen et al., University of Oxford (2020), https://www.smithschool.ox.ac.uk/publications/reports/Oxford-Offsetting-Principles-2020.pdf
    - Lays out principles for offsetting strategies that will genuinely move humanity toward a net-zero society and reduce some of the credibility, greenwashing, and other issues that have emerged from a cascade of climate commitments from corporations and other actors buying into carbon offsets without adhering to best practices.

- *Governing Solar Radiation Management*, Netra Chhetri et al., Forum for Climate Engineering Assessment, American University (2018), https://doi.org/10.17606/M6SM17
    - Offers a detailed examination, by a team of global governance experts, of governance needs and options for Solar Radiation Management technologies; focuses on near-term governance, outlining feasible and needed actions that can be taken by approximately 2025, at the national, regional, and international levels and by nonstate actors.

- *Code of Conduct for Responsible Geoengineering Research*, Anna-Maria Hubert (2017), https://www.ce-conference.org/system/files/documents/revised_code_of_conduct_for_geoengineering_research_2017.pdf
    - Interim report by the Geoengineering Research Governance Project (GRGP) lays out the rationale for developing guidance on the conduct of geoengineering research, details a Code of Conduct for Responsible Geoengineering Research that has been developed in the course of the project, and provides ancillary materials exploring issues relating to the Code of Conduct and how it has been developed.
    - *See also: A Code of Conduct for Responsible Geoengineering Research*, Anna-Maria Hubert, Global Policy (2021), https://doi.org/10.1111/1758-5899.12845

- *The Oxford Principles*, Steve Rayner et al., Climatic Change (2013), https://doi.org/10.1007/s10584-012-0675-2
    - Lays out and contextualizes the five high-level Oxford Principles developed by a committee at the Oxford Geoengineering Programme and others to guide legislators on governance of geoengineering research and potential deployment.

- *Good governance for geoengineering*, Phil Macnaghten and Richard Owen, Nature (2011), https://doi.org/10.1038/479293a
  - Reflects on the backlash that resulted from the announcement of the United Kingdom's first climate-engineering project to be given permission to begin field trials, considers lessons learned, and highlights the importance of robust governance and a transparent participatory process.

- *The Asilomar Conference Recommendations on Principles for Research into Climate Engineering Techniques* (2010), http://climate.org/archive/resources/climate-archives/conferences/asilomar/report.html
  - Coming out of the Asilomar Conference (2010), which convened over 165 experts with differing professional expertise from 15 countries, these recommendations develop principles for research into climate engineering techniques; ultimately, the adoption of five principles was recommended.

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