Depending on the Ocean

Research and Policy Priorities for Responsible Ocean Carbon Removal

WHITE PAPER | MAY 2023

The ocean is the largest carbon sink on the planet and contains almost 50 times[1] more carbon dioxide than is currently in the atmosphere. The ocean's ability to remove and store CO_2 can be enhanced through a suite of approaches known collectively as ocean carbon dioxide removal (CDR).

Given the vast scale of the ocean and its natural role in the carbon cycle, governments, researchers, and entrepreneurs are recognizing its potential to remove legacy emissions and address the impacts of climate change.

AUTHOR
Sifang Chen, PhD

REVIEWERS (Alphabetical)
Brad Ack
Alayna Chuney, Esq.
Anu Khan
Ugbaad Kosar
Katie Lebling
Charlotte Levy, PhD
Sarah Mastroni
Sara Nawaz, PhD
Delaney Pues
Vanessa Suarez
Romany Webb

EDITOR
Emily Reich

DESIGNER
Eliot Reali

1. Friedlingstein, P., Sullivan, M. O., Jones, M. W., Liu, Y., Gregor, L., Hauck, J., Quéré, C. L., Van Der Laan-Luijkx, I. T., Olsen, A., Peters, G. P., Peters, W., Pongratz, J., Schwingshackl, C., Sitch, S., Canadell, J. G., Ciais, P., Jackson, R. B., Alin, S. R., Alkama, R., . . . Zheng, B. (2022). Global carbon budget 2022. *Earth System Science Data*, 14(11), 4811–4900. https://doi.org/10.5194/essd-14-4811-2022

Carbon180

While ocean CDR pathways could meaningfully contribute to CO_2 drawdown and may even have significant non-climate benefits, many steps remain before ocean CDR is ready for deployment. First, we must answer critical research questions about potential ecosystem impacts and removal and storage efficacy, develop the technologies and protocols to monitor project outcomes, and build the capacity of coastal communities to determine if and how nearby projects are carried out.

Further, the ocean is a global commons and a critical part of our planet's biosphere. The effects of altering ocean biogeochemistry can travel beyond national borders and reverberate into future generations, raising important questions around governance and the long-term benefits and risks of ocean carbon removal. The ocean represents over 95% of the Earth's biosphere[2] and is home to 78% of animals on the planet.[3] Billions of people live in coastal regions, and millions depend on the ocean for their livelihood.[4] Yet, in many ways, the ocean is still full of unknowns: To date, more than 80% of the ocean remains unmapped and unexplored[5] and 91% of marine species remain unclassified.[6] Scientists are still trying to understand marine species interactions, the effects of climate change on ocean chemistry, and how human activities and contaminants affect ocean biodiversity. Ocean carbon removal will complicate these unknowns by introducing additional disturbances to the marine ecosystem.

While today there may be uncertainties surrounding ocean carbon removal, the risks of not achieving climate targets are unequivocal. Therefore, it is important to improve society's understanding of ocean CDR so that we can make better-informed decisions regarding the development of ocean carbon removal as a potential piece of our holistic approach to addressing climate change. Because of existing knowledge gaps, Carbon180 currently doesn't endorse or oppose ocean carbon removal. However, in order to build capacity for if and when ocean CDR deployment is needed in the future, efforts aimed at filling current knowledge gaps must start today.

This paper explores how policy can help lower existing uncertainties around ocean carbon removal and offers specific recommendations aimed at clarifying efficacy, ecosystem impacts, and necessary regulations and governance. First, we explore the various ocean carbon removal pathways and their benefits and risks. Next, we discuss the challenges ocean CDR faces today and, using imagined scenarios, illustrate two possible, diverging futures for a world where ocean CDR is deployed at scale. Finally, we put forth policy recommendations that would set us on a path towards responsible development of ocean carbon removal.

2. The Secretariat of the Convention on Biological Diversity (2018, November 26). *Oceans contain a wealth of biodiversity*. Convention on Biological Diversity. https://www.cbd.int/article/biodiversityforwater-1
3. Ritchie, H. (2019, November 26). *Oceans, land and deep subsurface: How is life distributed across environments?* (2019, April 26). Our World in Data. https://ourworldindata.org/life-by-environment
4. Food and Agriculture Organization of the United Nations. *The state of world fisheries and aquaculture 2022: Towards blue transformation.* (2022). https://doi.org/10.4060/cc0461en
5. National Oceanic and Atmospheric Administration. *How much of the ocean have we explored?* (2023, January 20). National Ocean Service. https://oceanservice.noaa.gov/facts/exploration.html
6. Mora, C., Tittensor, D. P., Adl, S., Simpson, A. G. B., & Worm, B. (2011). How many species are there on Earth and in the ocean? *PLoS Biology*, 9(8), e1001127. https://doi.org/10.1371/journal.pbio.1001127

SECTION 1:

Background

Ocean Carbon Removal Methods

In this paper, we use the term "ocean carbon removal" to refer to technological approaches that enhance the uptake of carbon dioxide by the ocean. These approaches can broadly be categorized as biological or chemical depending on the mechanism of removal. Both biological and chemical ocean carbon removal pathways remove CO_2 from the surface ocean and lock it away in ocean sediments or other stable forms of carbon in the deep ocean. By reducing the amount of CO_2 in seawater, the ocean can in turn absorb more CO_2 from the atmosphere.

In biological ocean carbon removal pathways, CO_2 in the ocean is first taken up via photosynthesis by microalgae (i.e., phytoplankton) and macroalgae (i.e., seaweed) in the surface ocean, after which it sinks to the deep ocean where a portion of it is sequestered. Biological ocean CDR pathways include ocean fertilization, macroalgae cultivation, and artificial upwelling and downwelling. Chemical ocean CDR pathways store CO_2 as dissolved inorganic carbon or remove CO_2 from seawater through chemical reactions and include ocean alkalinity enhancement and direct ocean capture.

GLOSSARY

Surface ocean
The top layer of the ocean, roughly 0–200 meters down, where seawater most actively absorbs CO_2 from the atmosphere.

Deep ocean
Below the surface ocean. At around 200 meters depth light dwindles, plants can no longer photosynthesize, and the ocean isn't exchanging CO_2 with the atmosphere. At 1000 meters, CO_2 can be most durably stored.

Dissolved inorganic carbon (DIC)
Forms of carbon in the ocean that are not directly derived from living organisms. DIC such as carbonate and bicarbonate ions are an important repository for long-term carbon sequestration.

METHODS DEFINED

Ocean fertilization
The addition of nutrients to surface ocean waters to increase photosynthesis and CO_2 uptake by marine phytoplankton. Removed carbon is sequestered by the sinking of phytoplankton biomass to the deep ocean.

Macroalgae cultivation
Large-scale seaweed farming that aims to remove CO_2 from the atmosphere by sinking seaweed to the deep ocean where carbon can be sequestered.

Artificial upwelling*
Using pipes or other methods to transport cold, CO_2-rich, and nutrient-dense deep seawater to the surface to promote the growth of algae. Carbon is removed and sequestered via extra biomass sinking to the deep ocean.

Artificial downwelling*
Using pipes or other methods to transport CO_2-rich surface waters to the deep ocean to store carbon.

Ocean alkalinity enhancement (OAE)
Increasing ocean alkalinity and, therefore, the ocean's capacity to remove CO_2 from the atmosphere through methods such as distributing alkaline minerals in the ocean or adding alkalinity via electrochemical reactions.

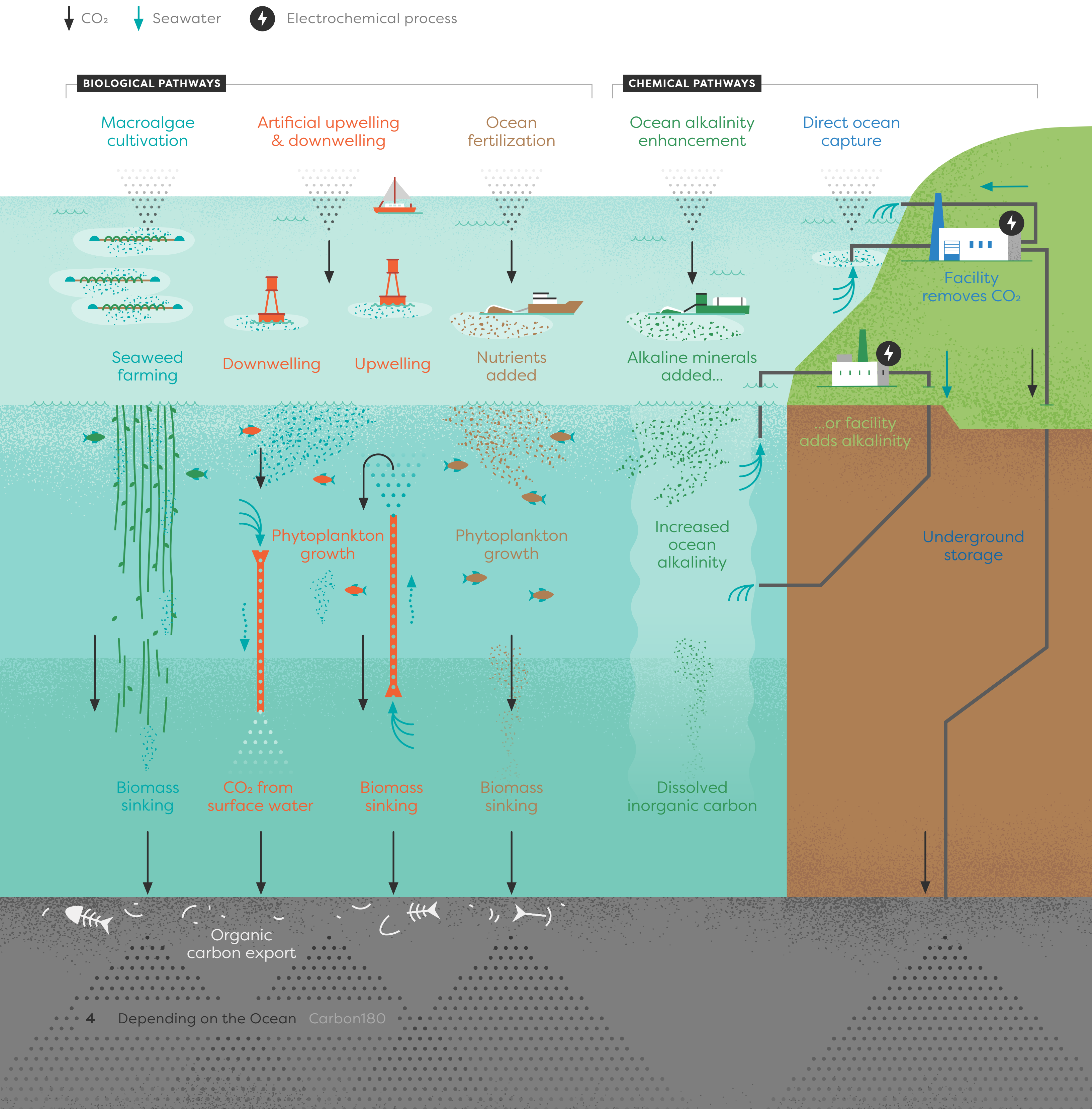
Direct ocean capture
Direct removal of CO_2 from seawater using electrochemical approaches to "swing" seawater towards producing CO_2, which is removed and stored. CO_2-lean seawater is reintroduced to the ocean to increase the ocean's capacity to remove CO_2 from the atmosphere.

*Due to conservation of mass and the incompressibility of water, where there is upwelling there is also a corresponding mass of water that is downwelled, and vice versa.

FIGURE 1

Ocean carbon removal

Ocean carbon removal refers to a variety of pathways, both biological and chemical, that enhance the ocean's uptake of carbon dioxide. By removing CO_2 from seawater, these approaches cause the ocean to soak up more CO_2 from the atmosphere. Biological pathways use photosynthesizing organisms in the surface ocean, including seaweed and phytoplankton, to convert CO_2 into biomass. When some of this biomass sinks to the deep ocean, the CO_2 is locked away. Chemical pathways increase the ocean's alkalinity, causing the ocean to absorb more CO_2, or directly extract CO_2 from the ocean for storage on land.



Ocean carbon removal pathways vary in their mechanisms of removal, technology readiness, cost, and climate and non-climate risks and benefits.[7,8] Biological ocean CDR pathways can have impacts on marine ecosystems, and it's important to consider how growing algae can affect light, oxygen levels, pH values, and available nutrients. Chemical pathways can have impacts on marine and terrestrial environments, including air pollution from mining and transporting minerals, introduction of trace toxins contained in alkaline minerals, and potential risks to marine life from localized and abrupt changes to ocean biogeochemistry.

Some ocean CDR pathways have the potential to provide environmental and social co-benefits, such as ocean deacidification, job creation, and new economic opportunities for the aquaculture sector.

Ocean Deacidification as a Potential Co-Benefit of Ocean Carbon Removal

Just deployment of carbon removal should aim to redress past harms while generating new benefits. Ocean carbon removal has the potential to deacidify the ocean, a clear opportunity to begin mitigating past injustices.

A NOTE ON BLUE CARBON

Blue carbon, which refers to the practice of increasing carbon stock through the restoration of coastal and marine ecosystems, is not included in this paper, because it has fundamentally different opportunities and challenges. Compared to ocean carbon removal pathways, blue carbon is more widely practiced and accepted, may face fewer governance and regulatory hurdles, and faces fewer technical challenges. Though there are still areas of blue carbon that necessitate further research, it's clear that conserving, restoring, and sustainably managing marine ecosystems can provide substantial environmental and social benefits. Today, a number of coastal blue carbon projects are already underway in different parts of the world.[9]

Despite these benefits, blue carbon projects do still face a range of challenges related to land use and management, durability of sequestered carbon, and project accountability. In fact, there are many parallels between blue carbon and other land-based carbon removal pathways (e.g., soil carbon sequestration). As such, blue carbon should be considered separately from ocean carbon removal.

7. National Academies of Sciences, Engineering, and Medicine. (2022). *A research strategy for ocean-based carbon dioxide removal and sequestration*. The National Academies Press. https://doi.org/10.17226/26278

8. Lebling, K., Northrop, E., McCormick, C., & Bridgwater, E. (2022). *Toward responsible and informed ocean-based carbon dioxide removal: Research and governance priorities*. World Resources Institute. https://doi.org/10.46830/wrirpt.21.00090

9. Francis, E., Beeston, M., Wilkman, A. (2023). *Blue carbon project location map*. Fair Carbon. https://faircarbon.org/content/fc/projectmap

A 2021 Proceedings of the National Academy of Sciences article identifies ocean acidification as one of three drivers (the other two being ocean warming and deoxygenation) pushing the ocean towards "high-probability, high-impact" tipping points[10] — critical thresholds at which the ocean system changes from one stable state to another stable state, often irreversibly.[11] As a result of anthropogenic climate change, the level of acidification observed in the present ocean is unprecedented for the last 65 million years. Moreover, ocean acidification and changes to marine chemistry due to climate change will persist long after carbon emissions have reached zero.

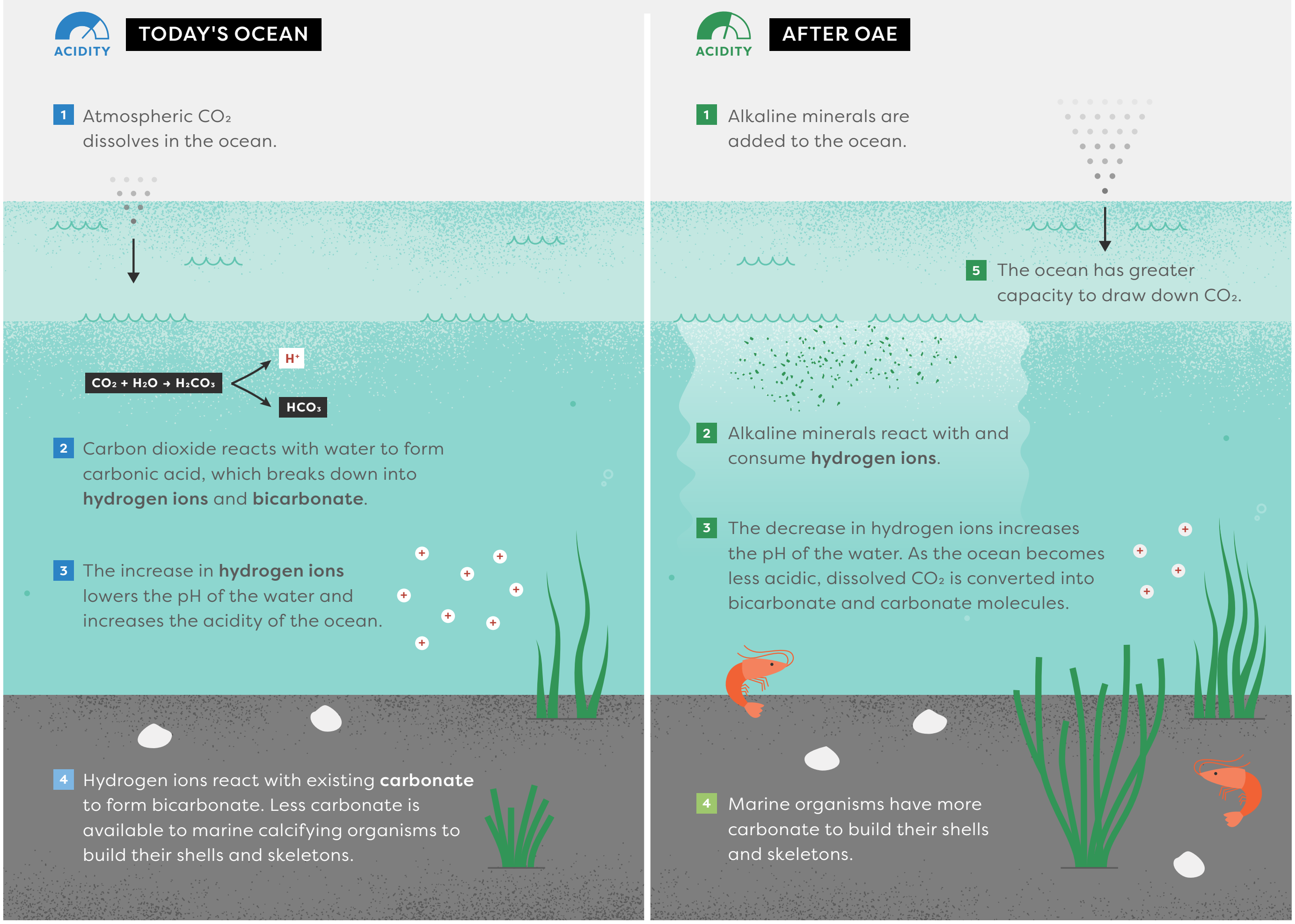
10. Heinze, C., Blenckner, T., Martins, H., Rusiecka, D., Döscher, R., Gehlen, M., Gruber, N., Holland, E., Hov, Ø., Joos, F., Matthews, J. B. R., Rødven, R., & Wilson, S. (2021). The quiet crossing of ocean tipping points. *Proceedings of the National Academy of Sciences*, 118(9). https://doi.org/10.1073/pnas.2008478118

11. Intergovernmental Panel on Climate Change. *Special Report on the Ocean and Cryosphere in a Changing Climate.* (2019). Cambridge University Press. https://doi.org/10.1017/9781009157964

FIGURE 2

Ocean alkalinity enhancement

Raising ocean alkalinity deacidifies seawater, supports healthy ecosystems, and allows more atmospheric CO_2 to be absorbed.



According to the National Oceanic and Atmospheric Administration (NOAA), "ocean acidification is a threat to food security, economies, and culture because of its potential impacts on marine ecosystem services."[12] Yet there are currently no meaningful ways to counteract ocean acidification at scale. Ocean carbon removal has the potential to mitigate ocean acidification by removing CO_2 from seawater and/or raising ocean alkalinity (see figure 2 above). This potential should be seriously considered and explored.

Given the harms inflicted by ocean acidification on ecosystems and communities, pathways with the potential to redress past injustices, mitigate environmental damages, and offer co-benefits should be prioritized. Today, this might mean starting trials that target areas of the ocean most impacted by acidification or cultivating macroalgae near coastlines that are prone to erosion from rising sea levels.

12. NOAA Ocean Acidification Program. Human Connections. Retrieved April 5, 2023 from https://oceanacidification.noaa.gov/WhatWeDo/HumanConnections.aspx

SECTION 2:

Ocean Carbon Removal's Challenges and Possible Futures

As discussed above, there are compelling reasons to explore ocean carbon removal both as a means to draw down CO_2 and to mitigate ocean acidification. At the same time, research and development of ocean carbon removal must proceed with care.

Today, ocean carbon removal faces four major challenges:[13] insufficient governance, a small knowledge base, underdeveloped monitoring and verification processes, and uncertain environmental and social impacts (figure 3). These four interrelated challenges must be addressed in tandem to lower uncertainties around ocean carbon removal and unlock shared opportunities.

On the next page are two imagined scenarios for the future of ocean carbon removal, one in which guardrails and policy support are put in place to address these challenges responsibly and another where policy support is lacking. These scenarios illustrate in broad strokes some possible outcomes for ocean carbon removal. Of course, these futures are neither exhaustive nor definitive. A good future could be better or a bad future worse than we can predict now, with infinite shades of possibilities in between.

13. National Academies of Sciences, Engineering, and Medicine. (2022). *A research strategy for ocean-based carbon dioxide removal and sequestration*. The National Academies Press. https://doi.org/10.17226/26278

GLOSSARY

Monitoring, reporting, and verification (MRV)
Keeps track of the effectiveness and impacts of carbon removal projects. To ensure accountability, projects should regularly collect data (monitoring), share those data with stakeholders (reporting), and ensure the reported data is independently reviewed (verification).

FIGURE 3

Key challenges for ocean carbon removal

Four interrrelated challenges hamper ocean CDR's development. Solving them in tandem will unlock shared opportunities.

Governance
Insufficient regulatory clarity and governance

Knowledge base
Poor understanding of CDR efficacy and durability

MRV
Underdeveloped tools for oversight and accountability

Public benefits
Uncertain impacts on ecosystems and communities

OPPORTUNITIES WHEN SOLVED TOGETHER

GOVERNANCE & PUBLIC BENEFITS
Safeguard the environment and communities

PUBLIC BENEFITS & KNOWLEDGE BASE
Improve understanding of environmental and community impacts

GOVERNANCE & KNOWLEDGE BASE
Enable research projects to take place

PUBLIC BENEFITS & MRV
Increase public trust in CDR

GOVERNANCE & MRV
Inform regulators on governance frameworks

KNOWLEDGE BASE & MRV
Enable development of MRV tools and protocols

A responsible future
for ocean carbon removal

- Clear permitting processes allow a range of field tests of various ocean carbon removal methods to take place, enabling the identification of pathways with high removal and storage efficacy, low ecological impact, and clear co-benefits, including ocean deacidification.
- There are governance structures in place to ensure research projects are conducted in safe and responsible ways that minimize risks to the environment and nearby communities, including mechanisms to promptly shut down projects that have adverse impacts.
- Coastal communities can access information from research projects and have the capacity and resources to identify desired benefits and opportunities from ocean carbon removal, such as jobs, economic growth, ecological benefits, etc. Communities are empowered to make decisions to select and deploy projects that can provide these benefits.
- Because of active public engagement in the research process and transparent data sharing of research progress, public awareness and perception of ocean carbon removal improves. With increased support, large-scale ocean carbon removal projects are granted social license to operate.
- There are appropriate monitoring, reporting, and verification (MRV) tools and protocols in place to keep projects and developers accountable. We can measure with certainty how much carbon is being sequestered and assess ecological impacts.
- Project development and MRV provide new job opportunities and other socioeconomic benefits that align with the wants and needs of coastal communities, especially those that are historically disadvantaged. Ocean carbon removal projects deliver ecological benefits including improvements to ocean health, local reduction of ocean acidity, and increased biodiversity.

An irresponsible future
for ocean carbon removal

- Controlled field tests do not take place due to a lack of clear and/or streamlined permitting processes, and funding for research on ocean carbon removal remains low. A lack of research data impedes our understanding of ocean carbon removal efficacy and its social and environmental implications.
- Existing marine governance mechanisms and regulations are not updated to provide oversight on ocean carbon removal. However, some companies still proceed with commercial deployments in places with looser regulations, potentially aggravating climate injustices in Black, Indigenous, and people of color (BIPOC), historically disadvantaged, and coastal communities across the globe.
- There is no framework for community engagement, and communities are unequipped to participate in project development. Efforts to align ocean carbon removal projects with community priorities and local climate goals are sidelined in favor of faster deployment. The ocean CDR sector fails to build trust with communities.
- A lack of understanding and transparency around ocean carbon removal makes it difficult to fundraise, pass policy, and garner public support. News of companies taking advantage of loopholes to conduct experiments makes ocean CDR a controversial topic, and the public remains skeptical of or opposes ocean CDR technologies.
- Some companies sell ocean CDR credits, but there is no robust and community-vetted MRV to hold these developers accountable. Ocean carbon removal ends up contributing to low-accountability carbon credit schemes that allow continued pollution in BIPOC and other historically disadvantaged communities.
- A lack of accountability and oversight results in poorly designed and regulated ocean carbon removal projects, which leads to wide-ranging negative ecosystem and community impacts, including damage to fisheries, invasive species, and toxic algae blooms.

To resolve the tension between the need to carry out ocean carbon removal and the need to safeguard the ocean and nearby communities from unintended consequences, ocean CDR should proceed with a phased approach. The first phase should focus on addressing the four key challenges laid out in this paper to systematically lower uncertainties around ocean carbon removal. Only by overcoming these challenges will society be able to make better-informed decisions about the next steps for ocean CDR, identify subsequent development phases, and ultimately set the field on a path to a bright future.

SECTION 3:

Policy Recommendations for Responsibly Developing Ocean Carbon Removal

Robust federal policy support will be crucial to help this fledgling industry overcome existing challenges in order to establish governance and regulatory frameworks, expand the existing knowledge base, advance MRV tools and protocols, and assess and center public benefits. Because ocean carbon removal is a nascent industry, federal policy can have an outsized impact on its future trajectory.

Specifically, policy can enable the timely research and development of ocean CDR to reduce uncertainty around carbon storage permanence, evaluate net negativity, and assess potential impacts on ocean ecosystems and biogeochemistry, with the goal of identifying ocean CDR pathways that maximize climate and ecosystem co-benefits and remove CO_2 from the atmosphere. Policy can also support the development of ocean CDR technologies under a framework of responsible innovation and equitable distribution of benefits. Because ocean carbon removal could lead to far-reaching consequences at local and global scales, it is critically important to ensure ocean CDR is developed responsibly to safeguard our ocean ecosystems and coastal communities. Failing to do so would be detrimental to the environment and to building and maintaining public trust.

With this in mind, we offer the following recommendations for US policymakers.

Establish Governance and Regulatory Frameworks

RECOMMENDATION 1:

Develop appropriate permitting and oversight mechanisms to allow controlled field trials of ocean carbon removal research projects to take place, with guidelines to ensure open, transparent scientific monitoring of project performance.

A lack of adequate permitting structure for conducting controlled research field trials is a major roadblock to advancing our understanding of the efficacy and impacts of ocean carbon removal. Existing permitting procedures were developed with other activities in mind, and there is uncertainty around how well they would apply to ocean CDR research.[14] Further, a lack of regulatory clarity creates room for legal loopholes and gray areas, which could lead to low-accountability projects that take place with little to no oversight.

14. National Academies of Sciences, Engineering, and Medicine. (2022). *A research strategy for ocean-based carbon dioxide removal and sequestration.* The National Academies Press. https://doi.org/10.17226/26278

A. Congress should designate a lead agency to oversee permitting and regulation of ocean CDR research projects in US waters.

B. In issuing permits for ocean carbon removal research projects, the lead agency should extensively consult with NOAA, the Environmental Protection Agency (EPA), the Bureau of Ocean Energy Management (BOEM) at the Department of the Interior, the Coast Guard, and the Army Corps of Engineers, among other relevant agencies, to ensure adherence to environmental regulations and that research projects do not interfere with commercial activities.

C. Congress should identify and/or update current statutes as needed to authorize the lead agency to regulate ocean carbon removal research projects and identify where authority may overlap with other federal agencies. To enable clear and streamlined permitting processes, we recommend the lead agency have exclusive authority to issue ocean CDR research permits. However, the roles of other relevant regulatory agencies in permitting ocean carbon removal research, such as EPA and BOEM, should be clarified.

D. The lead agency should provide opportunities for the public, including state, local, and Tribal governments, to comment and meaningfully engage in permitting decisions and processes. Support from relevant public stakeholders should be an essential criterion for granting permits to conduct ocean CDR research.

E. The lead agency should clearly define the timing, steps, and requirements for project developers to apply for and obtain permits and should create documentation that quickly and clearly disseminates this information.

F. The lead agency should develop guidelines and data management strategies enabling open and transparent access to data related to project performance.

RECOMMENDATION 2:

Improve global governance of ocean carbon removal.

We are all connected through the ocean. Ocean carbon removal activities are inherently transboundary, and regional efforts could result in global ecosystem impacts. Further, to maximize CDR potential, ocean carbon removal will likely have to take place on the high seas. However, existing international legal frameworks are inadequate to govern ocean carbon removal.

A. Increase funding to NOAA's Oceanic and Atmospheric Research International Activities Office to coordinate research efforts with international counterparts (e.g., the EU's OceanNETS project), allowing multilateral collaboration on ocean CDR and increasing the capacity of the office to work with researchers from the Global South.

B. Collaborate with international partners to develop a common framework for the global governance of ocean carbon removal research and update existing governance frameworks, such as the London Protocol.

Expand the Existing Knowledge Base

RECOMMENDATION 3:

Develop and fund targeted research programs to advance scientific understanding and increase the technology readiness levels of ocean carbon removal.

Major gaps exist in our understanding of the efficacy and durability of removing and sequestering carbon from seawater and the atmosphere. Significant research is needed to identify and quantify environmental impacts, risks, and benefits of ocean carbon removal activities for ocean biogeochemistry and biodiversity.[15] There is additional uncertainty around the feasibility of ocean carbon removal due to its overall low technology readiness levels and high costs.[16] As such, basic research programs should be accompanied by applied research programs aimed at advancing enabling technologies to evaluate the energy requirements, materials use, and costs associated with at-scale ocean carbon removal.

A. NOAA is a nexus for US ocean research, with a wealth of knowledge and expertise on ocean biogeochemistry and ocean observation. As such, we recommend Congress create and fund a dedicated office under NOAA to lead on ocean carbon removal research.

B. Within two years, increase funding to relevant basic research programs and offices at NOAA, the National Science Foundation (NSF), and the National Aeronautics and Space Administration (NASA), such as NOAA's Carbon Program at the Pacific Marine Environment Lab, NSF's Division of Ocean Sciences, and NASA's Carbon Monitoring System. Funding should go towards studying the interactions between ocean CDR and ocean ecosystems, the long-term durability of sequestered carbon, the impacts of ocean CDR on local biogeochemistry and biodiversity, the extent to which ocean CDR could mitigate ocean acidification, and other research priorities identified by research roadmaps, including reports from the National Academies,[17] Ocean Visions,[18] and the Energy Futures Initiative.[19] Funding should be provided to NOAA to participate in developing a code of conduct that outlines principles for conducting responsible research into ocean CDR.

15. National Academies of Sciences, Engineering, and Medicine. (2022). *A research strategy for ocean-based carbon dioxide removal and sequestration.* The National Academies Press. https://doi.org/10.17226/26278

16. Energy Futures Initiative. (2020). *Uncharted waters: Expanding the options for carbon dioxide removal in coastal and ocean environments.* https://energyfuturesinitiative.org/reports/uncharted-waters/

17. National Academies of Sciences, Engineering, and Medicine. (2022). *A research strategy for ocean-based carbon dioxide removal and sequestration.* The National Academies Press. https://doi.org/10.17226/26278

18. Ocean Visions. (2021, September 20). *Ocean-based carbon dioxide removal: Road maps.* https://www2.oceanvisions.org/roadmaps/

19. Energy Futures Initiative. (2020). *Uncharted waters: Expanding the options for carbon dioxide removal in coastal and ocean environments.* https://energyfuturesinitiative.org/reports/uncharted-waters/

C. Within two years, increase funding to applied research programs at NOAA, the Advanced Research Projects Agency–Energy (ARPA-E), and the Defense Advanced Research Projects Agency (DARPA) to advance a portfolio of ocean carbon removal pathways, including marine biomass burial, ocean alkalinity enhancement, and direct ocean capture. This could include creating new programs or building on existing ones, such as ARPA-E's MARINER[20] and direct ocean capture programs.[21] These programs should also focus on advancing enabling technologies for ocean CDR, such as platforms for open ocean seaweed cultivation and sinking, efficient electrochemical systems for removing CO_2 from seawater, or converting marine biomass into carbontech products.

Advance MRV

RECOMMENDATION 4:

Fund the development of key enabling technologies for ocean observation and ocean carbon removal MRV.

Advancing sensor technologies and modeling tools will be key for filling knowledge gaps, assessing efficacy and impacts, and enabling robust MRV of ocean CDR.

A. Leverage and expand the capabilities of existing ocean-sensing infrastructure and systems — such as NOAA's Ocean Acidification Program, Global Ocean Monitoring and Observation Program, and Ocean Carbon Network — to monitor and quantify impacts from ocean CDR projects. Some key ocean properties to observe include partial pressure of CO_2, salinity, nutrients, pH, DIC, total alkalinity, and dissolved oxygen.

B. Establish or expand research programs at NOAA, ARPA-E,[22] and DARPA[23] to develop novel approaches to advance MRV for ocean carbon removal, including new technologies and modeling tools to measure and monitor the effects of ocean CDR on the marine carbon cycle and ecosystems.

C. Centralize in situ and remote data on key parameters related to ocean CDR research under a single, publicly accessible portal managed by NOAA. This database could serve as the basis for standards-setting and conducting MRV.

D. NOAA, the National Institute of Standards and Technology, and EPA should coordinate on the development of standardized environmental monitoring and carbon accounting methods for ocean carbon removal.

20. The Advanced Research Projects Agency–Energy. (2017, September 19). *Macroalgae research inspiring novel energy resources.* https://arpa-e.energy.gov/technologies/programs/mariner

21. The Advanced Research Projects Agency–Energy. *Direct removal of carbon dioxide from oceanwater.* https://arpa-e.energy.gov/technologies/exploratory-topics/direct-ocean-capture

22. The Advanced Research Projects Agency–Energy. (2023, February 16). *Sensing exports of anthropogenic carbon through ocean observation.* https://arpa-e.energy.gov/technologies/programs/sea-co2

23. Ocean of Things. (n.d.). *Ocean of things.* The Defense Advanced Research Projects Agency. https://oceanofthings.darpa.mil/

GLOSSARY

Carbontech
A wide variety of commercial products made with removed CO_2 emissions.

Partial pressure of CO_2 (pCO_2)
A measure of the amount of CO_2 that is dissolved in seawater.

In situ data
Data taken by instruments at the place of interest.

Assess and Center Public Benefits

RECOMMENDATION 5:

Establish an interagency group to assess the climate, environmental, and social benefits of ocean carbon removal and align ocean carbon removal with broader climate goals.

Ocean carbon removal should be developed in line with national, state, and local climate action plans and within the context of broader climate mitigation efforts. Given the energy and other resources required by ocean CDR, assessments of potential benefits and resource needs should take place even while deployment is not guaranteed.

A. The National Oceanographic Partnership Program (NOPP) should create an interagency group on ocean CDR with participation from NOAA, EPA, the Department of Energy (DOE), BOEM, and other relevant agencies to create a national strategy for ocean carbon removal. Such a group would mirror several interagency subcommittees of similar scope that already exist within NOPP and advise key decision makers on ocean carbon removal development, such as integrating ocean CDR into the Ocean Climate Action Plan. Alternatively, the Ocean Policy Committee can directly set up an interagency group for this purpose.

B. The interagency group on ocean CDR should coordinate relevant federal agencies to create a framework for cross-sectoral research analyzing the interactions between ocean CDR activities, fisheries and aquaculture, energy and resource use, sustainable development goals, mitigation and adaptation strategies, and other systems, sectors, and industries.

C. The interagency group on ocean CDR should develop strategies for planning and implementing larger and longer-duration ocean CDR research projects, including the use of holistic models that integrate ecological, geochemical, and socioeconomic factors, when assessing potential benefits and risks.

D. Working with the interagency group on ocean CDR, BOEM and DOE should explore the need to develop ocean-based renewable energy sources to power ocean CDR operations, such as co-locating ocean CDR systems with offshore wind power. Additionally, BOEM and DOE should coordinate with NOAA to demonstrate integrating ocean CDR systems with existing climate resilience infrastructure, such as co-locating direct ocean capture facilities with desalination plants.

E. By 2030, using research data obtained from field trials, the interagency group should identify and begin scaling ocean carbon removal pathways with clear climate, environmental, and social benefits, low ecosystem and socioeconomic risks, and the capacity to achieve one gigaton of ocean carbon removal by 2050.

RECOMMENDATION 6:

Create a framework for incorporating environmental and climate justice into ocean carbon removal projects and establish best practices for community engagement and public education.

More than 120 million Americans live in coastal areas, and tens of thousands of Americans work in the aquaculture sector. Ocean carbon removal activities could have far-reaching impacts on these communities. Additionally, public awareness and acceptance of ocean carbon removal is currently low to nonexistent,[24] potentially hindered by past irresponsible tests to fertilize the ocean surface with iron particles.[25] Ocean carbon removal can only scale by gaining and retaining a social license to operate. Ocean CDR projects should only take place when there is strong support from frontline and historically disadvantaged communities.

A. All ocean carbon removal projects should be required to include robust public engagement and community participation strategies, including a schedule for ongoing public engagement after project commencement. To the extent possible, NOAA should coordinate with EPA's Office of Environmental Justice and External Civil Rights to establish expectations and best practices for soliciting community input.

B. Create a dedicated position at NOAA responsible for coordinating and hosting listening sessions and/or public workshops with environmental justice groups, coastal communities, local and Tribal governments, ocean CDR companies, and relevant experts from government and academia. These convenings can be used to identify key stakeholders and issues concerning ocean carbon removal research and solicit extensive stakeholder feedback on if and how ocean CDR can advance equity, high-quality jobs, and environmental protections.

C. Congress should establish a new initiative for NOAA and EPA to educate and engage local communities and other stakeholders on ocean CDR.

D. EPA, BOEM, NOAA, and the United States Geological Survey should coordinate to identify and assess potential environmental harms from ocean CDR–related activities, such as water and air pollution associated with mining minerals for enhanced weathering and ocean alkalinity enhancement.

24. Bertram, C., & Merk, C. (2020). Public Perceptions of ocean-based carbon dioxide removal: The nature-engineering divide? *Frontiers in Climate*, 2. https://doi.org/10.3389/fclim.2020.594194

25. Tollefson, J. (2017, May 24). *Iron-dumping ocean experiment sparks controversy.* Scientific American. https://www.scientificamerican.com/article/iron-dumping-ocean-experiment-sparks-controversy/

Conclusion

Ocean carbon removal presents significant opportunities to mitigate climate change and remove legacy emissions from the atmosphere. However, the ocean is a vast, complex, and delicate system, and many unknowns remain about ocean CDR. In order to avoid damaging the very system we are trying to protect and leverage, it is imperative that we minimize uncertainties around the effectiveness, community and ecosystem impacts, and governance of ocean carbon removal. Only by doing so can we make informed decisions on the next steps for this field. Federal policy support is essential in this effort to minimize uncertainties and chart a course towards responsible development.

To learn more about any of the recommendations in this report, email policy@carbon180.org.