NAVIGATING THE BLUE FRONTIER: EVALUATING THE POTENTIAL OF MARINE CARBON DIOXIDE REMOVAL APPROACHES

JOINT HEARING

BEFORE THE

SUBCOMMITTEE ON ENVIRONMENT
SUBCOMMITTEE ON ENERGY

OF THE

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

OF THE

HOUSE OF REPRESENTATIVES

ONE HUNDRED EIGHTEENTH CONGRESS

SECOND SESSION

SEPTEMBER 19, 2024

Serial No. 118–45

Printed for the use of the Committee on Science, Space, and Technology

Available via the World Wide Web: http://science.house.gov

U.S. GOVERNMENT PUBLISHING OFFICE
56–701PDF WASHINGTON : 2025

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NAVIGATING THE BLUE FRONTIER: EVALUATING THE POTENTIAL OF MARINE CARBON DIOXIDE REMOVAL APPROACHES

THURSDAY, SEPTEMBER 19, 2024

HOUSE OF REPRESENTATIVES, SUBCOMMITTEE ON ENVIRONMENT, JOINT WITH SUBCOMMITTEE ON ENERGY, COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY,
Washington, D.C.

The Subcommittees met, pursuant to notice, at 10:02 a.m., in room 2318 of the Rayburn House Office Building, Hon. Max Miller [Chairman of the Subcommittee on Environment] presiding.

SUBCOMMITTEE ON ENVIRONMENT
AND
SUBCOMMITTEE ON ENERGY

HEARING CHARTER

"Navigating the Blue Frontier:
Evaluating the Potential of Marine Carbon Dioxide Removal Approaches"

Thursday, September 19, 2024
10:00 a.m.
2318 Rayburn House Office Building

Purpose
The purpose of this hearing is to explore the benefits and risks of marine carbon dioxide removal (mCDR) approaches as they relate to carbon capture and sequestration. In addition, this hearing will inform members on research and development of this technology and address scientific gaps and deficiencies facing researchers and scientists today.

Witnesses
- **Mr. Noah Deich,** Senior Advisor, Office of Fossil Energy and Carbon Management, U.S. Department of Energy
- **Dr. Sarah Kapnick,** Chief Scientist, National Oceanic and Atmospheric Administration, U.S. Department of Commerce
- **Mr. Ben Tarbell**, CEO and Co-Founder, Ebb Carbon
- **Dr. Scott Doney,** Joe D. and Helen J. Kington Professor in Environmental Change, The University of Virginia

Overarching Questions
- Where do mCDR techniques stand in terms of technology readiness levels (TRLs)? Are these techniques ready for large-scale, open-system deployment?
- What resources do scientists and researchers need from the Federal government to advance and scale up mCDR?
- What are the environmental benefits and risks of mCDR to the ocean system, marine life, and coastal communities?

- How should federal agencies, the private sector, and academia collaborate in order to most efficiently further research of mCDR? What are each agency's strengths and weaknesses in this field?

Background

The ocean is the Earth's largest carbon sink, holding 42 times the amount of carbon dioxide (CO_2) that is in the atmosphere and absorbing 25% of human-caused carbon dioxide emissions each year. Global atmospheric carbon reduction efforts have led scientists to try to enhance the ocean's natural sequestration abilities by developing mCDR techniques. Leveraging the ocean can help diversify the range of carbon dioxide removal approaches, reducing the pressure on land-based approaches.[1] Marine CDR can also have non-carbon environmental benefits, such as reducing ocean acidification, replenishing ecosystems, and providing jobs. However, most mCDR techniques have not been tested at scale, and a few are at the earliest stages of research. Dedicated resources, including streamlined permitting, to enable research will help clarify the uncertainties associated with mCDR.

Key Marine Carbon Dioxide Removal Techniques

Ocean Fertilization Methods

Ocean fertilization (OF) enhances phytoplankton production in the ocean to accelerate the natural process that moves carbon from the atmosphere to the deep sea. In this process, specific nutrients are added to the ocean's surface to promote phytoplankton growth that then removes atmospheric carbon dioxide through photosynthesis and converts it into biomass.[2]

Ocean Alkalinity Enhancement Methods

Ocean alkalinity enhancement (OAE) can be achieved in a variety of ways, including depositing fine alkaline minerals into seawater, spreading alkaline sand or gravel on beaches or coastal seabeds, and using specialized fuel cells to facilitate the reaction of sea water with alkaline minerals. Adding alkalinity to the ocean removes carbon dioxide from the atmosphere through a series of reactions that convert dissolved CO_2 into stable bicarbonate and carbonate molecules, which in turn causes the ocean to absorb more CO_2 from the air.[3]

Electrochemical Engineering Methods

Electricity can be used to remove carbon dioxide from seawater through chemical reactions that either release CO_2 from the seawater for capture and sequestration or alter seawater's chemical balances to enable it to store more CO_2 than it naturally would.[4] This combination of carbon sequestration and ocean alkalinization requires large quantities of reactants, seawater, and energy. Further, electrochemical engineering has been demonstrated only at the prototype scale due to the amount of energy required.

[1] *Demystifying Ocean Carbon Dioxide Removal*, ENVIRONMENTAL AND ENERGY STUDY INSTITUTE (EESI) AND WORLD RESOURCES INSTITUTE (WRI), Congressional Briefing, Apr. 16, 2024.

[2] *Impacts of Ocean Fertilization*, DEEP-OCEAN STEWARDSHIP INITIATIVE (2021), https://www.dosi-project.org/wp-content/uploads/Ocean-Fertilization-Policy-Brief.pdf.

[3] *Ocean Alkalinization Carbon Removal Fact Sheet*, AMERICAN UNIVERSITY (2020), https://www.american.edu/sis/centers/carbon-removal/upload/icrlp_fact_sheet_ocean_alkalinization_2020_update.pdf.

[4] Taqieddin, A., Sarrouf, S., Ehsan, M.F., et al. *Electrochemical ocean iron fertilization and alkalinity enhancement approach toward CO2 sequestration*. NPJ OCEAN SUSTAIN (2024), https://doi.org/10.1038/s44183-024-00064-8.

Artificial Upwelling and Downwelling Methods
Upwelling involves the transport of cold, nutrient-rich seawater from the deep sea to the surface in order to stimulate phytoplankton activity and increase carbon intake.[5] The inverse process is downwelling, pushing surface water to deeper depths in order to increase the dissolved oxygen concentration in bottom waters and mitigate hypoxia. Since the 1950s, researchers have sought to artificially enhance these physical transport processes to geoengineer localized regions of the ocean.

Key Stakeholders Making Progress on Marine Carbon Dioxide Removal
National Oceanic Atmospheric Administration (NOAA)
The National Oceanic Atmospheric Administration (NOAA) is home to the Ocean Acidification Program (OAP), established to better understand impacts of ocean acidification and adaptation.[6] In May 2023, the program, in collaboration with the Pacific Marine Environmental Laboratory, published their paper *Strategy for NOAA Carbon Dioxide Removal Research: A White Paper documenting a potential NOAA CDR Science Strategy as an element of NOAA's Climate Interventions Portfolio*.[7] In September 2023, OAP announced $23.4 million in funding for public and private research in mCDR, with a focus on understanding uncertainties and filling knowledge gaps for different mCDR approaches.[8] These awards support 17 projects with partners from 47 institutions to further enhance efficiency of marine research and provide NOAA with funding and information sharing opportunities to advance mCDR development.

Of note, on June 5, 2024, NOAA signed a memorandum of agreement (MOA) with the Department of Energy, including the Office of Fossil Energy and Carbon Management, the Office of Science, and the Water Power Technologies Office, to further accelerate progress towards large-scale, efficient mCDR research and development.[9] The MOA also defines four primary mutual responsibilities, summarized below:

- Coordinate and collaborate on efforts relevant to multiple mission areas such as research efforts, technical plans, funding opportunities, and technical viability projects.
- Accelerate the development of research and development infrastructure to enable mCDR testing.
- Engage in the development of standard operating procedures for accountable (e.g., utilizing monitoring, measurement, reporting, and verification) and science-based mCDR to inform permitting and regulation, private investment, and carbon credit markets.
- Enter into additional agreements to implement the purposes of this MOA.

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[5] *Artificial Upwelling and Downwelling*, OCEANVISIONS.ORG, https://oceanvisions.org/artificial-downwelling/ (last visited Jul. 23, 2024).
[6] *NOAA Ocean Acidification Program*, NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION, https://oceanacidification.noaa.gov/ocean-acidification-research/ (last visited Jul. 23, 2024).
[7] Cross, J.N., Sweeney, C., Jewett, E.B., et.al. *Strategy for NOAA Carbon Dioxide Removal Research*, NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION (May 2023), https://sciencecouncil.noaa.gov/wp-content/uploads/2023/06/mCDR-glossy-final.pdf.
[8] National Oceanic and Atmospheric Administration, *Announcing $24.3M Investment Advancing Marine Carbon Dioxide Removal Research*, NOAA.GOV (Sep. 7, 2023), https://oceanacidification.noaa.gov/fy23-nopp-mcdr-awards/.
[9] U.S. Department of Energy and National Oceanic and Atmospheric Administration, *Memorandum of Agreement Between Office of Fossil Energy Carbon Management, the Office of Science, the Water Power Technologies Office, and the National Oceanic and Atmospheric Administration*, NOAA.GOV (Jun. 5, 2024), https://www.noaa.gov/sites/default/files/2024-06/EXEC-2024-003330-Final_NOAA-DOE_MOA_05222024_GR_RS_Signed.pdf.

Department of Energy (DOE)
The Department of Energy (DOE) supports mCDR as a key technology development area. It is a central component of DOE's Carbon Negative Shot — calling for innovation in CDR pathways that can capture CO_2 and store it at gigaton scales for less than $100/net metric ton of CO_2-equivalent.[10]

In October 2023, DOE announced $36 million for 11 projects across 8 states, funneled through the Advanced Research Projects Agency-Energy's (ARPA-E) Sensing Exports of Anthropogenic Carbon through Ocean Observation (SEA-CO2) program, to accelerate the development of mCDR technologies.[11,12] The focus of the projects receiving these funds is to advance sensing and modeling techniques that more accurately measure the impacts of mCDR technologies. Supported projects include development of fiber optic sensor cables, micro-electronic seafloor probes, and ocean carbon flux monitoring. If successful, SEA-CO2 measurement, reporting, and verification technology innovations will ensure that the quantity and quality of emission removals are correctly valued.

Office of Science and Technology Policy (OSTP)
The Office of Science and Technology Policy (OSTP) is the federal government leader in interagency research collaboration, including research across the various disciplines associated with oceans. Recognizing the pivotal role the ocean must play in carbon reduction efforts, OSTP's National Science and Technology Council (NSTC) established a new Fast-Track Action Committee (FTAC) on Marine Carbon Dioxide Removal in September 2023.[13,14] The FTAC includes DOE and NOAA, along with other relevant federal agencies, and is focused on developing an implementation plan to advance mCDR and establish sufficient knowledge that can potentially guide research, development, and deployment decisions. The FTAC is set to sunset in November 2024, at which point a final report of the committee's findings and next steps will be published.

Businesses and Nonprofits
Private companies and nonprofits have been working diligently alongside federal agencies to promote and scale up different mCDR approaches. One of the witnesses at the hearing will represent Ebb Carbon which approaches mCDR with electrochemical OAE.[15] They have partnered with DOE's Pacific Northwest National Laboratory (PNNL) and opened their first site in 2023, which is now able to sequester 100 tons of CO_2 per year.

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[10] U.S. Department of Energy, *Carbon Negative Shot*, ENERGY.GOV, https://www.energy.gov/fecm/carbon-negative-shot (last visited Jul. 23, 2024).
[11] U.S. Department of Energy, *DOE Announces $36 Million to Advance Marine Carbon Dioxide Removal Techniques and Slash Harmful Greenhouse Gas Pollution*, ENERGY.GOV (Oct. 26, 2023), https://www.energy.gov/articles/doe-announces-36-million-advance-marine-carbon-dioxide-removal-techniques-and-slash.
[12] U.S. Department of Energy ARPA-E, *Sensing Exports of Anthropogenic Carbon through Ocean Observation (SEA-CO2)*, ENERGY.GOV, https://arpa-e.energy.gov/technologies/programs/sea-co2 (last visited Jul. 23, 2024).
[13] Scott Doney & Jane Lubchenco, *Marine Carbon Dioxide Removal: Potential Ways to Harness the Ocean to Mitigate Climate Change*, WHITE HOUSE OSTP BLOG (Oct. 6, 2023), www.whitehouse.gov/ostp/news-updates/2023/10/06/marine-carbon-dioxide-removal-potential-ways-to-harness-the-ocean-to-mitigate-climate-change/.
[14] U.S. National Science and Technology Council, *Charter of the Marine Carbon Dioxide Removal Fast Track Action Committee of the Subcommittee on Ocean Science and Technology*, NOAA.GOV (Sep. 15, 2023), https://www.noaa.gov/sites/default/files/2023-10/mCDR_FTAC_charter_2023_09_19_approved.pdf.
[15] Ebb Carbon, *Solution: Electrochemical Ocean Alkalinity Enhancement*, EBBCARBON.COM, https://www.ebbcarbon.com/solution (last visited Jul. 23, 2024).

While companies are engineering a variety of mCDR technologies, some nonprofits have focused their mission on looking deeper into the real-world context and viability of these technologies. One of the witnesses at the hearing will represent Carbon to Sea Initiative, a nonprofit that systematically assesses the conditions under which OAE can safely and permanently remove CO_2, as well as market intelligence to advance sector knowledge.[16]

[16] Carbon to Sea Initiative, *How We Work*, CARBONTOSEA.ORG, https://carbontosea.org/#how-we-work (last visited Jul. 23, 2024).

Chairman MILLER. The joint hearing will come to order.

Without objection, the Chair is authorized to declare recess of the Subcommittees at any time.

Welcome to today's hearing titled "Navigating the Blue Frontier: Evaluating the Potential of Marine Carbon Dioxide Removal Approaches." I recognize myself for 5 minutes for an opening statement.

Good morning, and thank you to our witnesses for being with us here today. Today's hearing is on a topic that stands to increase in relevance as technology develops. Marine carbon dioxide removal, otherwise known as mCDR, it is also a special hearing because I am co-chairing it with my friend Mr. Williams, the Chair of the Energy Subcommittee, as we are conducting this as a joint Environment and Energy Subcommittee hearing.

The field of mCDR presents a unique opportunity, not only because of its immense potential benefits, but also because it builds off existing knowledge and research for land-based carbon removal that is already delivering results. Yet, at this very early stage of research, it is important to encourage involvement from a blend of Federal agencies, private sector companies, and academia.

In order for the field to grow, we must ensure that public-private partnerships work together to prevent duplicative efforts. In a step toward that, the Department of Energy (DOE) and NOAA (National Oceanic and Atmospheric Administration) signed a memorandum of agreement that will establish a joint effort to enhance coordination, research, and technology development to advance the state of mCDR science. This is crucial to combating wasteful government spending.

Combining NOAA's ocean science expertise with DOE's research and infrastructure will allow the Federal Government to operate efficiently and have the greatest possible impact. We cannot rely solely on Federal agencies. However, as a robust private sector exploring all different types of removal techniques, it is critical to practical advancements.

One of our witnesses today is representing Ebb Carbon, a private company that is pioneering one of the largest-scale and lowest-cost approaches to carbon removal by accelerating the ocean's natural ability to capture and store carbon. As a native Ohioan representing the 7th District of the Buckeye State, I recognize the potential of mCDR holds to the State's economy.

The Great Lakes are the largest freshwater system on Earth, holding 95 percent of the United States' freshwater supply. They are some of the largest carbon sinks in the world, second only to the oceans. NOAA has established a constant presence in the Great Lakes with their acidification research and the Great Lakes Restoration Initiative. This work has been crucial to ensuring a successful future for significant fisheries and recreational tourism that create income and jobs for the region. It is my belief that studying how to remove and sequester that carbon will also prove critical to the long-term viability of the Great Lakes region.

As we continue to innovate, it is important that the investments that we are making have the best path to commercialization. By having the Federal and commercial sector utilize the research academia is producing, we will lay the groundwork for successful implementation of it. Through conservations like today's—excuse me, conservation—through conversations like today, as we're talking about conservation, we can ensure that everyone is moving in the right direction together. I look forward to working with Chairman Williams and Members of the Committee to establish a commonsense legislation that will create a well-rounded approach into this underutilized market.

I want to thank all of our witnesses for being here today, and I look forward to each of your testimonies.

[The prepared statement of Chairman Miller follows:]

Good morning and thank you to our witnesses for being with us today. Today's hearing is on a topic that stands to increase in relevance as technology develops: marine carbon dioxide removal, otherwise known as mCDR. It is also a special hearing because I am co-chairing it with my friend, Mr. Williams, the chair of the Energy Subcommittee, as we are conducting this as a joint Environment and Energy Subcommittee hearing.

The field of mCDR presents a unique opportunity not only because of its immense potential benefits, but also because it builds off existing knowledge and research for land-based carbon removal that is already delivering results.

Yet, at this very early stage of research, it is important to encourage involvement from a blend of federal agencies, private sector companies, and academia. In order for the field to grow, we must ensure that public-private partnerships work together to prevent duplicative efforts.

In a step towards that, the Department of Energy and NOAA signed a memorandum of agreement that will establish a joint effort to enhance coordination, research, and technology development to advance the state of mCDR science. This is crucial to combatting wasteful government spending. Combining NOAA's ocean science expertise with DOE's research and infrastructure will allow the federal government to operate efficiently and have the greatest possible impact.

We cannot rely solely on federal agencies, however, as a robust private sector exploring all different types of removal techniques is critical to practical advancements.

One of our witnesses today is representing Ebb Carbon, a private company that is pioneering one of the largest scale and lowest cost approaches to carbon removal by accelerating the ocean's natural ability to capture and store carbon.

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As we continue to innovate, it is important that the investments we are making have the best path to commercialization. By having the federal and commercial sector utilize the research academia is producing, we will lay the groundwork for successful implementation.

Through conversations like today's, we can ensure that everyone is moving in the right direction, together.

I look forward to working with Chairman Williams and members of the committee to establish common sense legislation that will create a well-rounded approach into this under-utilized market. I want to thank all our witnesses for being here today, and I look forward to each of your testimonies.

Chairman MILLER. I ask for unanimous consent to enter into the record a letter from the mCDR community in support of this hearing and future legislation, as well as a letter with additional background material from Dr. Julie Pullen of the Carbon to Sea Initiative. Without objection, so ordered.

I now recognize the Ranking Member, the gentlewoman from North Carolina, for an opening statement.

Ms. ROSS. Thank you, Chairman Miller—and Chairman Williams when he joins us—for holding this important hearing on an emerging field of science that could help mitigate the ongoing climate crisis. And thank you to our expert witnesses, some of whom I've met, for sharing your testimony and insights on this topic.

Global—the global climate is changing at an alarming and unprecedented rate due to ever-increasing atmospheric concentrations of greenhouse gases. This year alone, the United States has experienced the earliest category 5 Atlantic hurricane on record, massive tornado outbreaks, torrential floods, some of which we saw in my home State of North Carolina just this week, widespread wildfires, severe heat waves, and more. Around the world, extreme weather has become more frequent and more dangerous, and it's only expected to worsen. The longer we wait to aggressively combat climate change, the more we can expect devastating impacts to humans and the environment.

The ocean is a natural sink of atmospheric carbon. In fact, in the more than 200 years since the Industrial Revolution, scientists estimate that the ocean has taken up one-quarter of the carbon dioxide that humans have emitted into the atmosphere. Marine carbon dioxide, or mCDR, aims to enhance the ocean's natural ability to absorb carbon from the atmosphere. This developing field holds great promise as a strategy to reverse some of the harm caused by a century of greenhouse gas emissions.

However, there are still many uncertainties surrounding mCDR, including its effectiveness and some of its environmental impacts. By design, mCDR has the potential to significantly alter the marine environment. While we hope to use this to our advantage and sequester carbon dioxide, we must ensure that mCDR does not create yet another stressor for marine ecosystems and the human communities that are reliant on them, including along the coast of my home State of North Carolina.

Dedicated and responsible research is necessary to grapple with these uncertainties and ensure that the field develops ethically and effectively. This research must be carried out in collaboration with communities that may be impacted, while leveraging partnerships across levels of government and with the academic and private sectors. In North Carolina, a form of mCDR using coastal olivine weathering is being explored by the company Vesta, and I look forward to seeing how the results of that work can inform the path forward.

The potential for meaningful climate change mitigation through mCDR is exciting, but we must recognize the value of the ocean as a cultural and economic resource and do our best to ensure that mCDR approaches do not jeopardize our treasured coastline and marine environments. In today's hearing, we will explore the state of the science and discuss a responsible path forward.

While mCDR and other emerging climate solutions may be critical to our endeavor to mitigate climate change, we must remember that the most straightforward path to keeping carbon dioxide out of the atmosphere is to reduce emissions. Carbon dioxide removal can be viewed just as one tool in our toolbox to combat climate change but should not be relied upon as an excuse to avoid acting right now. We can and should act to decarbonize our economy today and as quickly as we can and look to novel and innovative climate solutions, including mCDR, to help us remove legacy carbon emissions in the future.

I look forward to hearing from our expert witnesses about the status of mCDR science and what Congress can do to support its responsible advancement.

Thank you, Mr. Chairman, and I yield back.

[The prepared statement of Ms. Ross follows:]

Thank you, Chairman Miller and Chairman Williams, for holding this important hearing on an emerging field of science that could help mitigate the ongoing climate crisis. And thank you to our expert witnesses for sharing your testimony and insights on this topic. Global climate is changing at an alarming and unprecedented rate due to ever-increasing atmospheric concentrations of greenhouse gases.

This year alone, the U.S. has experienced the earliest Category 5 Atlantic hurricane on record, massive tornado outbreaks, torrential floods, widespread wildfires, severe heatwaves, and more. Around the world, extreme weather has become more frequent and more dangerous, and is only expected to worsen. The longer we wait to aggressively combat climate change, the more we can expect devastating impacts to humans and the environment.

The ocean is a natural sink of atmospheric carbon. In fact, in the more than 200 years since the Industrial Revolution, scientists estimate that the ocean has taken up one-quarter of the carbon dioxide that humans have emitted into the atmosphere. Marine carbon dioxide removal—or mCDR—aims to enhance the ocean's natural ability to absorb carbon from the atmosphere. This developing field holds great promise as a strategy to reverse some of the harm caused by centuries of greenhouse gas emissions.

However, there are still many uncertainties surrounding mCDR—including its effectiveness and environmental impacts. By design, mCDR has the potential to significantly alter the marine environment. While we hope to use this to our advantage and sequester carbon dioxide, we must ensure that mCDR does not create yet another stressor for marine ecosystems and the human communities that are reliant on them, including along the coast in my home state of North Carolina.

Dedicated and responsible research is necessary to grapple with these uncertainties and ensure the field develops ethically and effectively. This research must be carried out in collaboration with the communities that may be impacted, while leveraging partnerships across levels of government and with the academic and private sectors.

In North Carolina, a form of mCDR using coastal olivine weathering is being explored by the company Vesta—and I look forward to seeing how the results of that work can inform the path forward. The potential for meaningful climate change mitigation through mCDR is exciting—but we must recognize the value of the ocean as a cultural and economic resource and do our best to ensure that mCDR approaches do not jeopardize our treasured coastal and marine environments.

In today's hearing, we will explore the state of the science and discuss a responsible path forward for mCDR. While mCDR and other emerging climate solutions may be critical to our endeavor to mitigate climate change, we must remember that the most straightforward path to keeping carbon dioxide out of the atmosphere is to reduce emissions.

Carbon dioxide removal can be viewed as just one tool in our toolbox to combat climate change—but should not be relied upon as an excuse to avoid acting in the present. We can and should act to decarbonize our economy today—as quickly as we can—and look to novel and innovative climate solutions including mCDR to help us remove legacy carbon emissions in the future.

I look forward to hearing from our expert witnesses about the status of mCDR science and what Congress can do to support its responsible advancement.

Thank you, Mr. Chairman, and I yield back.

Chairman MILLER. Thank you, Ms. Ross.

I now recognize the Chairman of the Energy Subcommittee, the gentleman from New York, for an opening statement.

Mr. WILLIAMS. Thank you, Mr. Chairman, and thank you to our witnesses for being here.

There's an extraordinary amount of innovation happening and, at the same time, an extraordinary amount of research happening to discover and measure the effect of the oceans on our climate and particularly around carbon dioxide and carbon storage. And so that's what the focus of today is. The Marine—as has been said, these—the mCDR is an up and coming solution, and we're here to talk about it today.

We've seen development and progress in direct air capture technologies, certainly around—the oil and gas industry have embraced these. People might overlook the fact that the ocean has the potential to hold up as much as 50 times more carbon dioxide than the atmosphere, and this potential could provide another avenue to regain United States' energy independence, while also being conscious stewards of the environment.

Like most early stage science topics, the Federal research ecosystem is critically important and has started to build an understanding of the nuances associated with mCDR. Last year, the Department of Energy Advanced Research Project Agency, or ARPA, funded 11 high-risk, high-reward projects to support novel efforts to measure, report, and validate mCDR and identify cost-effective and energy-effective carbon removal solutions. This is the excellent work that the DOE ARPA program does.

And in June of this year, NOAA announced a memorandum of agreement with the Department of Energy to ensure that ocean science expertise is combined with and utilized by Department of Energy research efforts. Separate from these public sector efforts, the private industry has been and will continue to be a crucial partner in facilitating the commercialization of these approaches and creating valuable byproducts that can thrive in the free market.

Academia has also conducted crucial research that provides the foundation for advancement in the public and private sectors. In order for mCDR technologies to compete—sorry, to complete the path to commercialization, public-private partnerships synchronizing all of these efforts will be paramount.

So thank you to our witnesses today. They are well suited to discuss this and to bring this not only to the attention of Congress, but also to the attention of the public. We're going to cover such exciting topics as nutrient fertilization, ocean alkalinity enhancement, and direct ocean capture. I feel like I'm back in nuclear power school.

All right. The approaches vary in the amount of carbon dioxide they can sequester, as well as the duration of storage. Different approaches are at different readiness levels in terms of their technology and different stages of commercialization. All of these are fraught with risk, and I'm very happy that the Department of Energy is derisking some of these strategies so that we can move on.

Therefore, I hope today's hearing is a chance for us to learn how we in Congress can enable and accelerate the most promising innovations associated with mCDR. And, as the Chairman of the Energy Subcommittee, I want to ensure that the Department of Energy's world-leading resources serve as productive counterparts to NOAA's expertise in ocean science. And that is what government can do best, is to use our incredible investments in science and partner across agencies to keep the United States as a leader in these important endeavors.

So thank you. I look forward to our conversation. And, Mr. Chairman, I yield back.

[The prepared statement of Mr. Williams follows:]

Good morning and thank you to all our witnesses for taking the time to join us. Today, the Environment and Energy Subcommittees will jointly examine the status of marine carbon dioxide removal approaches, the costs and benefits they provide for reducing emissions, and potential legislative efforts to support this fledgling industry.

Marine carbon dioxide removal, or mCDR for short, is an up-and-coming solution for long-term carbon dioxide storage.

While we have seen progress in the development of direct air capture technologies over the last two decades, people might overlook the fact that the ocean has the potential to hold up to 50 times more carbon dioxide than the atmosphere. This potential could provide another avenue to regain United States energy independence while also being conscious stewards of the environment.

Like most early-stage science topics, the federal research ecosystem has started to build an understanding of the nuances associated with mCDR. Last year, the Department of Energy's Advanced Research Project Agency funded 11 high-risk, high-reward projects to support novel efforts to measure, report, and validate mCDR and identify cost-effective and energy efficient carbon removal solutions.

And in June of this year, the National Oceanic and Atmospheric Administration announced a memorandum of agreement with DOE to ensure their ocean science expertise is combined with and utilized by DOE's research efforts.

Separate from these public sector efforts, private industry has been and will be crucial to facilitating the commercialization of these approaches and creating valuable by-products that can thrive in the free market. Academia has also conducted crucial research that provides the foundation for advancements in the public and private sectors.

In order for mCDR technologies to complete the path to commercialization, public-private partnerships synchronizing all of these efforts will be paramount.

Our witnesses today are well suited to discuss this, as they represent a diverse range of expertise and sectors. Our panel will discuss several different types of mCDR approaches, such as nutrient fertilization, ocean alkalinity enhancement, or direct ocean capture.

These approaches vary in the amount of carbon dioxide they can sequester, as well as the duration of storage. Different approaches are at different technology readiness levels and different stages of commercialization. But there is one commonality amongst them: collectively, they have the potential to mitigate and remove hundreds of millions of tons of carbon dioxide emissions.

Therefore, I hope today's hearing is a chance for us to learn how we in Congress can enable and accelerate the most promising innovations associated with mCDR. As the Chairman of the Energy Subcommittee, I want to ensure that the Department of Energy's world-leading resources serve as a productive counterpart to NOAA's expertise in ocean science. Together with the private sector, these advancements can usher in a new era of United States energy dominance and a clean environment.

With that, I look forward to our conversation, and I yield back.

Chairman MILLER. Thank you, Mr. Williams.

I now recognize the Ranking Member of the Energy Subcommittee, the gentleman from New York, for an opening statement.

Mr. BOWMAN. Good morning, and thank you, Chairman Williams and Chairman Miller, for convening this hearing today. And thank you to our panel of witnesses for appearing before the Committee to discuss the importance of conducting well-coordinated research into marine carbon dioxide removal.

My name is Congressman Jamaal Bowman, by the way. The Chairman didn't mention that, so I want to mention it.

This research is critical not only to advancing technologies and methods that may significantly reduce greenhouse gases in our atmosphere, but also to inform us of any risk and potential unintended impacts of these approaches early on so that we can ensure that they have proper guardrails and to better determine if any of these methods should ever be deployed at all.

First, let's talk about why this is important. If we look back to DOE's 2023 carbon management liftoff report, DOE's modeling study suggests that reaching our energy transition goals could require capturing and permanently storing 400 to 1,800 million tons of carbon dioxide annually by 2050. Marine carbon dioxide removal seeks to enhance the already large role that the ocean plays as a naturally large carbon sink, and several of these approaches have a substantial potential to help our planet meet these targets.

However, many of these emerging technologies and methods are far from ready to be deployed, and some may pose risks that are greater than we should be willing to accept. These technologies continue to require extensive research to understand their efficacy in storing carbon and any ecological impacts they may have.

We all understand the vast importance of the ocean to our ecosystem and communities, so we want to make sure that Congress and the Federal Government have all the data they need to make informed decisions on these technologies before they are used on the widespread basis. That is why this Committee is developing legislation to better coordinate our research and develop (R&D) efforts between the Department of Energy and the National Oceanic and Atmospheric Administration. Coupling DOE's incredible network of national labs and research infrastructure with NOAA's world-class expertise in ocean science will ensure that our academic institutions, local communities, industry, and ultimately U.S. policymakers have all the tools needed to fully understand the benefits and risks associated with this carbon removal pathway.

With that, I want to thank our excellent panel of witnesses for being here today, and I look forward to hearing your testimony. I yield back.

[The prepared statement of Mr. Bowman follows:]

Good morning and thank you, Chairman Williams and Chairman Miller, for convening this hearing today. And thank you to our panel of witnesses for appearing before the Committee to discuss the importance of conducting well-coordinated research into marine carbon dioxide removal. This research is critical not only to advancing technologies and methods that may significantly reduce greenhouse gases in our atmosphere, but also to informing us of any risks and potential unintended impacts of these approaches early on so that we can ensure that they have proper guardrails. And to better determine if any of these methods should ever be deployed at all.

First let's talk about why this is important. If we look back to DOE's 2023 Carbon Management Liftoff report, DOE's modeling studies suggest that reaching our energy transition goals could require capturing and permanently storing 400 to 1,800 million tons of carbon dioxide annually by 2050. Marine carbon dioxide removal seeks to enhance the already large role that the ocean plays as a naturally large carbon sink, and several of these approaches have a substantial potential to help our planet meet these targets.

However, many of these emerging technologies and methods are far from ready to be deployed. They continue to require extensive research to understand their efficacy in storing carbon and any ecological impacts they may have. We all understand the vast importance of the ocean to our ecosystem and communities, so we want to make sure that Congress and the federal government have all the data they need to make informed decisions on these technologies before they are used on a widespread basis.

That is why this Committee is developing legislation to better coordinate our research and development efforts between the Department of Energy and the National Oceanic and Atmospheric Administration. Coupling DOE's incredible network of national labs and research infrastructure with NOAA's world-class expertise in ocean science will ensure that our academic institutions, local communities, industry, and ultimately us policymakers have all the tools needed to fully understand the benefits and risks associated with this carbon removal pathway.

With that, I want to again thank our excellent panel of witnesses for being here today, and I look forward to hearing your testimony. I yield back.

Chairman MILLER. Thank you, Mr. Bowman.

Let me now introduce our witnesses. Our first witness today is Mr. Noah—I'm going to struggle—Deich. Is that correct? All right. Thank you both. Noah Deich, Senior Advisor at the Office of Fossil Energy and Carbon Management of the United States Department of Energy. Our next witness is Dr. Sarah Kapnick, Chief Scientist of the National Oceanic and Atmospheric Administration. Next, we have Mr. Ben Tarbell, CEO (Chief Executive Officer) and co-founder of Ebb Carbon. Finally, we have Mr. Scott Doney, the Joe D. and Helen J. Kington Professor in Environmental Change at the University of Virginia.

With that, I now recognize Mr. Noah Deich for 5 minutes to present his testimony. Deich, my apologies again.

TESTIMONY OF MR. NOAH DEICH, SENIOR ADVISOR, OFFICE OF FOSSIL ENERGY AND CARBON MANAGEMENT, U.S. DEPARTMENT OF ENERGY

Mr. DEICH. No, thank you, Chairmen Williams and Miller, for welcoming me here. Thank you, Ranking Member Bowman and Ross and all the Members of the Subcommittee. I'm very grateful to be able to testify here today and to speak about the Department of Energy's work on marine carbon removal.

I also want to acknowledge the Committee's long-standing work on carbon removal overall. Some of the hearings over a decade in this Committee helped inform me about the potential and the need for carbon removal. And I co-founded a nonprofit dedicated to carbon removal back in 2015. Most of the time when I talked about CDR, nobody had any clue what those three letters stood for back then, but this Committee and the staff were always incredibly knowledgeable and leaders on this topic, and I'm very grateful for the continued support.

We've also seen the carbon removal conversation mature massively in the past decade, and marine CDR, I think, is one of the maybe late starters, but very important pieces of that equation. Academic studies and independent engineering assessments have shown just immense potential for this suite of solutions, not just to tackle the climate crisis, but to create jobs for coastal communities and to protect our vital marine resources.

Yet many challenges remain, as have been noted already, from understanding how ocean biogeochemistry responds to various marine CDR interventions, to developing the nascent policies and markets needed to bring solutions to scale in a responsible manner. That's why I'm really proud to work on the Department of Energy's Carbon Negative Shot initiative. This is one of the Department's many innovation moonshots. The Carbon Negative Shot specifically is focused on a broad range of carbon removal solutions. It's an all-hands-on-deck call for innovation to bring the cost of carbon removal down below $100 a ton, inclusive of really robust measurement, reporting, and verification.

And marine CDR is one of the core pillars of this work. DOE is leveraging its deep expertise in novel technology innovation and commercialization to help the mCDR portfolio flourish as part of the Carbon Negative Shot. We have funded modeling work, sensor development, small pilots, and research on ecosystem impacts and community benefits to make sure that the mCDR field can catch up and be a key piece of this Carbon Negative Shot ecosystem that we see as critical for all of our climate and economic work going forward.

I also want to recognize that DOE alone won't be able to achieve the Carbon Negative Shot goals. Only by collaborating across agencies, including our highly impactful collaboration with our colleague NOAA. Despite the occasional confusion of Noah the person versus NOAA the agency, it's been very impactful, and we're very grateful for our partners across the U.S. Government and with industry and civil society to really chart a path forward in this space that we all see as incredibly important, but still facing many uncertainties that we all must tackle. Congressional support for these efforts is clearly critical, and we're very grateful for you all convening this hearing and for us to be able to participate.

So with that, I will say thank you and look forward to your questions.

[The prepared statement of Mr. Deich follows:]

TESTIMONY OF MR. NOAH DEICH
SENIOR ADVISOR
OFFICE OF FOSSIL ENERGY AND CARBON MANAGEMENT
U.S. DEPARTMENT OF ENERGY
BEFORE THE
HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
SUBCOMMITTEE ON ENERGY ON
MARINE CARBON DIOXIDE REMOVAL RESEARCH AND DEVELOPMENT
September 19, 2024

Thank you, Chairman Williams and Chairman Miller, Ranking Member Bowman and Ranking Member Ross and distinguished members of the Committee. Thank you for the opportunity to testify today on marine carbon dioxide removal research and development.

1. INTRODUCTION

The Intergovernmental Panel on Climate Change is clear that if we are to limit average global temperature increase to 1.5°C, we not only must drastically reduce greenhouse gas emissions, but also must actively remove carbon dioxide from the atmosphere..[1] In line with this scientific consensus, the Department of Energy (DOE) is investing billions of dollars in carbon management and carbon dioxide removal solutions as part of the Biden-Harris Administration's commitment to building a net-zero economy by 2050. The Office of Fossil Energy and Carbon Management plays a central role in funding science and innovation related to a broad portfolio of carbon removal solutions, including marine carbon dioxide removal (mCDR), and we are honored to participate in this hearing on such an important and rapidly advancing field.

Marine Carbon Dioxide Removal, as defined by the White House Ocean Climate Action Plan[2], refers to deliberate efforts to increase the amount of atmospheric carbon dioxide stored by the ocean, including seawater, marine life, and marine sediments. mCDR is one of the six primary pathways that DOE has prioritized for funding as part of its broader programming for carbon dioxide removal, as directed within the Consolidated Appropriations Act, 2021[3] and coordinated through DOE's Carbon Negative Shot™[4], as one of several Energy Earthshots[5]. The Carbon Negative Shot™ initiative has developed a target for a comprehensive portfolio of CDR

[1] IPCC, 2023: Sections. In: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland, pp. 35-115, doi: 10.59327/IPCC/AR6-9789291691647

[2] Ocean Policy Committee. (March 2023). "Ocean Climate Action Plan." The White House. Washington, DC. https://www.whitehouse.gov/wp-content/uploads/2023/03/Ocean-Climate-Action-Plan_Final.pdf

[3] Consolidated Appropriations Act, 2021, Pub. L. No. 116-260 (2020). https://www.congress.gov/bill/116th-congress/house-bill/133

[4] Office of Fossil energy and Carbon Management. (January 4, 2024). Carbon Negative Shot. Department of Energy. Washington, DC. https://www.energy.gov/fecm/carbon-negative-shot

[5] Department of Energy. (2024). "Energy Earthshot Initiative." U.S. Department of Energy. Washington, DC. https://www.energy.gov/energy-earthshots-initiative

approaches to deliver billion-tonne per year net removal capacity at less than $100 per net tonne of carbon dioxide equivalent removed from the atmosphere. The Carbon Negative Shot™ initiative also prioritizes efforts aimed at increasing the duration of carbon storage and improving measurement, monitoring, reporting, and verification (MMRV) to enable CDR solutions to be compared in an apples-to-apples manner across different pathways.

For mCDR to contribute meaningfully to the Carbon Negative Shot™ goals, significant research and development will be necessary to assess and inform the viability and efficacy of different mCDR pathways.

2. THE DEPARTMENT OF ENERGY'S CURRENT ROLE IN MARINE CARBON DIOXIDE REMOVAL EFFORTS

DOE seeks to build on its core strengths as a science and innovation funding agency to support promising mCDR concepts to move from lab research to field testing to potential commercial scale operations. The DOE at present is a leader in carbon management research, development, and demonstration, and aims to further integrate mCDR into our largely terrestrial-based portfolio, applying our experience and lessons learned from industries like direct air capture and marine energy to expansion of the mCDR field. DOE also has significant analytic capabilities that it plans to leverage to assess the cost and performance of promising mCDR solutions as they mature to successively higher technology readiness levels, to help inform where future public- and private-sector investment would be most valuable and how mCDR can advance in as responsible a manner as possible. Lastly, DOE is investing in the ongoing creation and development of measurement, monitoring, reporting, and verification (MMRV) technologies and methodologies. MMRV tools developed by DOE include a suite of hardware, modeling, and computational approaches to accurately and reliably quantify the comprehensive greenhouse gas benefit of a CDR approach. Strong MMRV is of national security and economic interest, both to ensure that the international community is carrying out mCDR in a responsible manner, and to ensure that mCDR pathways can participate in carbon markets in an effective way.

Specifically, DOE is supporting safe and responsible research and potential commercialization of advancing a range of mCDR approaches through:

(1) foundational research and development,

(2) lab-scale design and prototype,

(3) analysis and community engagement,

(4) field pilot and validation, and

(5) CDR credit market development.

Foundational research and development:

Foundational research and development are necessary to inform decisions regarding the progression of applied mCDR research to technology development, and if appropriate, the potential scaling of these mCDR techniques..[6] The goal of DOE's mCDR research and development portfolio is to identify, assess, and validate innovative approaches, consistent with the best available science.

To achieve that goal, DOE is collaborating with the National Oceanic and Atmospheric Administration (NOAA), through our involvement in the NOAA-managed National Oceanographic Partnership Program (NOPP) in fiscal years 2022 and 2023 to support several mCDR projects. In FY22, this effort supported DOE's Pacific Northwest National Laboratory (PNNL) to collaborate with NOAA's Pacific Marine Environmental Lab, and Ebb Carbon, Inc., an industry partner, to advance Ebb Carbon's ocean alkalinity enhancement method..[7] In FY23, this partnership provided funding for two projects focused on ocean alkalinity enhancement. The Office of Energy Efficiency and Renewable Energy's (EERE) Water Power Technologies Office (WPTO) is funding additional work at PNNL with Ebb Carbon, specifically on investigating potential uses for the acidic product stream from the Ebb Carbon system, in an effort to lower the costs and carbon footprint of the overall process.[8].

Lab-scale design and prototype:

The goal of DOE's lab-scale design and prototyping work is to understand whether mCDR systems can operate effectively on a path to climatically relevant and cost-effective scale.

To achieve this goal, FECM issued a funding solicitation for mCDR projects,.[9] and awarded eight projects to carry out conceptual design studies on abiotic direct ocean capture (DOC) systems.

In addition, DOE's Advanced Research Projects Agency (ARPA-E) is funding a $36 million portfolio of projects focused on improving mCDR MMRV through their Sensing Exports of Anthropogenic Carbon through Ocean Observations (SEA-CO2) program..[10] This program is funding eleven projects across eight states that focus on researching and developing novel efforts for mCDR MMRV in order to identify cost-effective and energy efficient carbon dioxide removal solutions. The knowledge gained from these projects will play a critical role in creating new and appropriately scaled sensors and models that will quantify the effectiveness and impacts of mCDR techniques.

Analysis and Engagement:

[6] National Academies of Sciences, Engineering, and Medicine. (2022). "A Research Strategy for Ocean Carbon Dioxide Removal and Sequestration." National Academies Press. Washington, DC. https://www.nationalacademies.org/our-work/a-research-strategy-for-ocean-carbon-dioxide-removal-and-sequestration

[7] Water Power Technologies Office. (March 14, 2024). "First-of-its-Kind Marine Carbon Dioxide Removal Device Deployed in Washington State." Department of Energy. Washington, DC. https://www.energy.gov/eere/water/articles/first-its-kind-marine-carbon-dioxide-removal-device-deployed-washington-state

[8] Ibid

[9] Office of Fossil Energy and Carbon Management (2024). "Project Selections for FOA 2614: Carbon Management (Round 2)." Department of Energy. Washington, DC. https://www.energy.gov/fecm/project-selections-foa-2614-carbon-management-round-2

[10] Advanced Research Projects Agency - Energy. (2023). "DOE Announces $36 Million To Advance Marine Carbon Dioxide Removal Techniques and Slash Harmful Greenhouse Gas Pollution." Department of Energy. Washington, DC. https://www.energy.gov/articles/doe-announces-36-million-advance-marine-carbon-dioxide-removal-techniques-and-slash

It is imperative for the success of mCDR efforts that research, scaling, and potential implementation occur in a responsible manner that stewards taxpayer funding effectively, minimizes harm, and provides benefits to ecosystems, local communities, and others that rely on the ocean economically and culturally.

To ensure investment flows to the projects with the greatest potential, DOE is leveraging its analytic capabilities to assess the cost and performance of mCDR pathways.

To align with Administration priorities like the Justice40 initiative,.[11] and to maximize the effectiveness and efficiency of its carbon management activities, the FECM recently released the Responsible Carbon Management Initiative (RCMI) Principles.[12] to encourage project developers, researchers, and others in the carbon management industry to pursue the highest levels of safety, environmental stewardship, accountability, workforce development and quality jobs, community engagement, and societal benefits in carbon management projects. Through the RCMI process, FECM is engaging with the broader community around key guardrails and guidance for responsible research, development, and demonstration of carbon management technologies and will leverage the principles laid out within this effort to guide our future mCDR activities. DOE is, and will continue to be, a leader in ensuring that carbon management practices mitigate risks and provide global climate benefits alongside local and regional community benefits and economic development opportunities.

Field pilot and validation:

The goal of DOE's field validation and pilot-scale work is to leverage our expertise in technoeconomic, environmental health and safety, and life cycle assessment to identify and demonstrate the mCDR approaches that are most likely to perform efficiently, cost-effectively, verifiably, and safely in field environments. Field research activities will require permits issued under the appropriate regulatory authorities of the *Marine Protection, Research and Sanctuaries Act, Clean Water Act*, and other relevant laws.

To achieve this goal, FECM will select two projects from a funding opportunity announcement to carry out pilot project field validation, with expected DOE cost-share up to $4 million per project to develop and test direct ocean capture technologies in representative environments..[13] Ongoing projects selected for Phase 2 participation will test their technology in an integrated system and field conditions to accelerate ocean processes that remove carbon dioxide from the atmosphere. Projects supported under this program should develop techno-economic analyses that demonstrate

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[11]Office of Energy Justice and Equity. (2024). "Justice40 Initiative." Department of Energy. Washington DC. https://www.energy.gov/justice/justice40-initiative

[12] Office of Fossil Energy and Carbon Management. (August 6, 2024). "Responsible Carbon Management Principles Resources." Department of Energy. Washington, DC. https://www.energy.gov/fecm/responsible-carbon-management-principles-resources

[13] Ibid.

meaningful progress towards achieving DOE's Carbon Negative Shot ™ target of less than $100 per net tonne of carbon dioxide equivalent removed.

CDR Credit Market Development:

The Department of Energy recognizes that if carbon dioxide removal efforts are to be implemented at the scale necessary to achieve a net-zero economy and remove legacy emissions from the atmosphere, a strong and science-driven market for carbon credits may be necessary. FECM's CDR Purchase Pilot Prize is supporting a range of CDR projects, including three mCDR companies in the semifinalist stage of this Prize..[14] DOE recognizes that the Prize is insufficient to drive mCDR projects to scale alone, and so has designed the Prize to crowd in additional voluntary private sector support through identifying projects that have demonstrated the potential for effective field-scale validation and testing, in a way that catalyzes innovation in the field and incorporates rigorous MMRV. These efforts are in pursuit of the Biden-Harris Administration priority to drive forward a high-quality carbon credit market, as outlined in the Principles for Responsible Participation in Voluntary Carbon Markets policy statement, co-signed by the Energy Secretary Jennifer Granholm and Treasury Secretary Janet Yellen, among others..[15] Specifically, the CDR Purchase Pilot Prize is designed to support the broader CDR field as it navigates the challenges of this emerging market to identify and develop high-quality credits. The inclusion of mCDR approaches as semifinalists within the CDR Purchase Pilot Prize provides an opportunity to leverage the research performed and expertise available across the U.S government to rigorously assess the quality, efficacy, and safety of these pathways and their corresponding CDR credits, within the context of voluntary markets.

3. THE DEPARTMENT OF ENERGY'S ROLE IN ADVANCING MARINE CARBON DIOXIDE REMOVAL INTO THE FUTURE

Looking to the future, to maximize complementary capacities and minimize duplication of efforts, we have embarked on a formal collaboration with NOAA, the Agency that leads U.S. efforts in oceanography, atmospheric composition, and ocean observations. A five-year Memorandum of Agreement (MOA) was signed in June 2024 by DOE's Under Secretary for Science and Innovation, Dr. Geraldine Richmond, and NOAA's Under Secretary of Commerce for Oceans and Atmosphere, Dr. Richard Spinrad..[16] This interagency partnership on mCDR formalizes engagement between NOAA and DOE's FECM, EERE, and Office of Science. Activities under

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[14] Office of Fossil Energy and Carbon Management. (May 28, 2024). "Carbon Dioxide Removal Purchase Pilot Prize Phase 1 Semifinalists." Department of Energy. Washington, DC. https://www.energy.gov/fecm/carbon-dioxide-removal-purchase-pilot-prize-phase-1-semifinalists

[15] U.S. Department of the Treasury. (2024). "Voluntary Carbon Markets Joint Policy Statement and Principles." Department of the Treasury. Washington, DC. https://home.treasury.gov/system/files/136/VCM-Joint-Policy-Statement-and-Principles.pdf

[16] Office of Fossil Energy and Carbon Management. (2024). "NOAA, DOE Sign Agreement to Advance Marine Carbon Dioxide Removal." Department of Energy. Washington, DC. https://www.energy.gov/fecm/articles/noaa-doe-sign-agreement-advance-marine-carbon-dioxide-removal

the MOA will advance four key responsibilities: (1) coordination and collaboration, (2) acceleration of research and development infrastructure, including facilities, data management, and feasibility studies, (3) development of protocols for accountable and science-based mCDR for ecosystem safety, social benefit, and economic viability, and (4) the potential for future additional collaboration between both agencies. Activities carried out under this partnership will be in line with recommendations that will be included in an interagency Research Strategy that will be put forth by the White House Fast Track Action Committee on Marine Carbon Dioxide Removal (MCDR-FTAC),.[17] of which DOE is a member. Together, NOAA and DOE will build on our strengths to advance mCDR technology that can contribute meaningfully to climate goals while protecting communities that rely on the ocean, ecosystems, and U.S. national security and economic interests. DOE houses extensive expertise, capabilities, and facilities that have direct applications to the transfer of mCDR efforts from foundational and fundamental research into the prototype and pilot phases, and as appropriate, potential large-scale demonstration. The collaborations and programs summarized above indicate DOE's strong potential to advance research and development of mCDR approaches and technologies. Our Department supports pilot projects, provides leadership on principles regarding social governance and community benefits, improves MMRV hardware and software development to enable research through large scale implementation, and is actively assessing the potential role of market mechanisms to enable a responsible net-zero emissions economy. We aim to support the mCDR field as technologies and research expand in scale and scope.

Additionally, DOE has a number of programs and expertise that can offer lessons applicable to the expansion of the mCDR field. Through FECM's direct air capture programs,.[18] we have rapidly expanded carbon dioxide removal efforts in the United States, building capacity in bringing cutting edge climate solutions from modeling and lab-based studies, into pilot projects and commercial-scale operation. Through these efforts, FECM has established rigorous technical and community engagement standards for demonstrations including appropriate permitting and environmental assessment, engineering studies, life cycle analyses, and techno-economic assessments. We look forward to applying this expertise to the mCDR field, as science and interagency coordination lead our programming.

Separately, through efforts advanced by WPTO, DOE is the leader in marine energy research and development. WPTO's Testing Expertise and Access for Marine Energy Research (TEAMER).[19]

[17] Scott Doney. (2023). "Marine Carbon Dioxide Removal: Potential Ways to Harness the Ocean to Mitigate Climate Change." The White House. https://www.whitehouse.gov/ostp/news-updates/2023/10/06/marine-carbon-dioxide-removal-potential-ways-to-harness-the-ocean-to-mitigate-climate-change/

[18] DOE is currently implementing multiple programs on direct air capture technologies supported through the Infrastructure Investment and Jobs Act, including the Regional Direct Air Capture (DAC) Hubs Program, the Commercial DAC Prize, and the Precommercial DAC Prize.

[19] Water Power Technologies Office. (2024). "The U.S. Testing Expertise and Access to Marine Energy Research Program (TEAMER)." Office of Energy Efficiency and Renewable Energy. Washington, DC. https://www.energy.gov/eere/water/us-testing-expertise-and-access-marine-energy-research-program-teamer

program and PacWave.[20] program facilitate marine and wave energy research and development through government-supported testbeds. The mCDR research community has expressed that a lack of mCDR testing infrastructure creates time and financial burden on individual projects that are already financially constrained. The government-supported establishment of mCDR testbeds would greatly support mCDR research and development in this critical stage of the field, when all efforts to scale climate solutions must be safe, responsible, and expeditious. Complementary to the applied offices, the Office of Science conducts large scale climate and environmental modeling that includes marine environments and biogeochemistry throughout the earth system. These capabilities have not yet been applied to mCDR, but could be augmented to do so, allowing simulation and projection of carbon removal in the ocean and carbon fluxes across the earth system as well as study of impacts on ocean dynamics and ecosystems. WPTO's in-house expertise on marine-based research hubs, Office of Science's climate and environmental modeling capabilities, and FECM's expertise on building world-class carbon management testing centers and pilot projects, could collectively be applied to advance the mCDR field into the next stage of necessary testing and development.

4. CONCLUSION

The Department of Energy recognizes that mCDR research and development is a critical part of the current carbon dioxide removal research landscape and demonstrates potential to scale to be a significant part of overall United States carbon dioxide removal efforts. We are not only actively funding areas of research and development in this field but also look forward to leveraging our relevant knowledge as active participants in the field, in our partnership with NOAA, and a whole of government approach in the future.

We thank the Committee for the opportunity to testify on this important topic.

[20] Water Power Technologies Office. (2024). "PacWave: Offshore Wave Energy Test Site." Office of Energy Efficiency and Renewable Energy. Washington, DC. https://www.energy.gov/eere/water/pacwave-offshore-wave-energy-test-site

Noah Deich, Senior Advisor, Office of Fossil Energy and Carbon Management

Mr. Noah Deich is the Senior Advisor for Carbon Management in the Office of Fossil Energy and Carbon Management (FECM). In this role, he supports CO_2 capture, transportation, conversion, storage, and removal innovation projects, including hydrogen production with carbon management. Prior to this, Mr. Deich served as the Deputy Assistant Secretary, Office of Carbon Management in FECM.

Mr. Deich joined FECM from Carbon180, which he co-founded to catalyze the development of a portfolio of carbon removal solutions. Prior to that, he was an economic and management consultant with Accenture and ICF international, and received his Master of Business Administration from the Haas School of Business at UC Berkeley and his Bachelor of Arts degree from the University of Virginia.

Chairman MILLER. Thank you very much.
I now recognize Dr. Sarah Kapnick for 5 minutes to present her testimony.

TESTIMONY OF DR. SARAH KAPNICK, CHIEF SCIENTIST, NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION, U.S. DEPARTMENT OF COMMERCE

Dr. KAPNICK. Chairmen Miller and Williams, Ranking Members Bowman and Ross, and Members of the Subcommittees, thank you for the opportunity to testify today regarding NOAA's work on marine carbon dioxide removal and providing comments regarding the Committee's draft marine carbon dioxide removal legislation. I am Dr. Sarah Kapnick, the Chief Scientist of NOAA. I appreciate the Committee's interest in learning more about this critical emerging field and NOAA's position as the lead agency in the Federal Government on mCDR foundational research.

As the leader in the ocean observations and modeling with an emphasis on long-term monitoring and research, NOAA is ideally suited to analyze the potential of mCDR efforts. mCDR is projected to be a major economic sector with the Earth system impacts that transcend national borders. NOAA views mCDR engagement with the mCDR field as necessary to ensure safe, accountable development of potential future deployment, as well as continued U.S. leadership of the field.

mCDR approaches enhanced natural ocean processes that draw down carbon dioxide from the atmosphere. NOAA stands at the forefront of supporting this foundational research that is a critical tool for decisionmakers to assess if, how, and when this industry can safely upscale. The field has tremendous potential to make a positive climate impact and spur economic growth. However, fundamental questions remain about the safety, efficacy, and sustainability of mCDR pathways. We cannot afford to remain on the sidelines of the field of research for the climate, for economic potential of the sector, and for our national security. Due to growing interest in the voluntary carbon market, some companies are already pursuing small-scale mCDR pilot studies, both in the United States and abroad.

As a Department of Commerce agency, NOAA recognizes the importance of enabling markets while minimizing risk to our ocean communities and ecosystems. To ensure accountable growth in this fast-paced sector, NOAA must improve our mCDR knowledge base and global observing capabilities, while continuing to ramp up our efforts to engage invested communities.

NOAA has four main functions in the Federal approach to mCDR. One, providing foundational ocean and atmospheric research and leading research in the efficacy of and potential ecological responses to mCDR pathways. Two, coordinating Federal, academic, and nongovernmental mCDR research to inform decisions about potential future deployment. Three, addressing ecological considerations through regulatory authority and by providing guidance and research to inform the mCDR permitting process in Federal waters, in collaboration with the EPA (Environmental Protection Agency) and U.S. Army Corps. Four, managing mCDR research data archives to ensure the data are publicly findable, accessible, interoperable, and reusable.

NOAA's 2023 strategy for mCDR research lays out our vision for how the agency can work with its partners to act in these roles. Over the past year, NOAA, as a co-chair of the interagency Fast Track Action Committee on mCDR, together with OSTP (Office of Science and Technology Policy), also led the development of a Federal mCDR research strategy, a process which included multiple listening sessions to gather public comment for consideration. The strategy, expected to be released imminently, outlines research, permitting, and partnerships needed to inform decisionmaking about the potential future mCDR scaling.

NOAA's mCDR research is anchored by the investments in leveraging the National Oceanographic Partnership Program, or NOPP, and funding from the *Inflation Reduction Act.* In 2023, the NOAA-led NOPP portfolio funded the first large-scale public multipartner research specifically focused on mCDR approaches. These projects required applicants to provide education and outreach plans to ensure that the researchers open a dialog with the invested communities. The initiative is primarily made possible by funding provided by Congress through the *Inflation Reduction Act.*

NOAA is building the knowledge necessary to understand the effectiveness and ecosystem responses to mCDR and to keep the United States positioned as a responsible leader in the field and in climate mitigation more broadly. NOAA cannot do this alone. Partnerships within and outside of government, such as our highly successful collaboration with DOE, enables a comprehensive response to the scientific, technical, and economic questions and opportunities raised by mCDR. Support for this work will greatly advance the Federal Government's ability to meet these challenges and threats to our national security.

NOAA appreciates the Committee's dedication work on this legislation to guide marine carbon dioxide removal work, although we note the bill is not—does not provide additional appropriations, which would require NOAA to reduce other activities to fund additional mCDR work. We look forward to continuing the work with the Committee and are happy to provide technical drafting assistance to the Committee as they further consider this bill.

Thank you, Chairmen and Ranking Members and Members of the Subcommittees, and I look forward to answering any questions you may have.

[The prepared statement of Dr. Kapnick follows:]

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
WRITTEN TESTIMONY OF
DR. SARAH KAPNICK
CHIEF SCIENTIST, NATIONAL OCEANIC & ATMOSPHERIC ADMINISTRATION

LEGISLATIVE HEARING
ON
Discussion Draft of H.R. XX, Marine Carbon Dioxide Removal Research and Development Act of 2024

BEFORE THE
HOUSE COMMITTEE ON SCIENCE, SPACE AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES

SEPTEMBER 19, 2024

1. INTRODUCTION

Chairman Lucas, Ranking Member Lofgren, and Members of the Committee, thank you for the opportunity to testify today regarding NOAA's work on marine carbon dioxide removal (also known as ocean carbon dioxide removal) and to provide comments regarding the Discussion Draft of H.R. XX, Marine Carbon Dioxide Removal Research and Development Act of 2024.

The United States and the world face a profound climate crisis. We have a narrow opportunity to pursue action at home and abroad to reduce the concentration of greenhouse gases in the atmosphere to avoid the most catastrophic impacts of that crisis, while also adapting to changes already underway and those to come – and doing so equitably. The Biden-Harris Administration, thanks to major investments provided by Congress, is acting decisively to reduce emissions, increase resilience, advance environmental justice, and achieve energy security. However, the Intergovernmental Panel on Climate Change (IPCC) is clear that in addition to deep, rapid, and sustained emission reductions, limiting warming to 1.5 degrees Celsius with no or limited overshoot requires removing legacy carbon dioxide emissions from the atmosphere. Some of these potential solutions would remove carbon dioxide from the atmosphere with the assistance of ocean-based processes. Companies and governments around the world have begun to recognize this reality, and are beginning to develop and test the technologies necessary to conduct marine carbon dioxide removal. This is a potentially major new economic sector with Earth-system impacts that transcend national borders. NOAA therefore views engagement with the field of marine carbon dioxide removal as necessary to ensure safe, accountable development and potential future deployment, as well as continued U.S. scientific leadership.

Marine carbon dioxide removal processes accelerate or augment ocean processes (biological and otherwise) that draw down carbon dioxide from the atmosphere. Non-biological approaches include ocean alkalinity enhancement and electrochemical methods. Alkalinity enhancement makes the ocean more basic, and therefore more able to take up carbon dioxide without accelerating ocean acidification, by introduction of liquid or solid alkaline material. Electrochemical approaches directly remove carbon dioxide from the water via electrical current or membranes, allowing the ocean to take up more carbon dioxide as it reestablishes equilibrium. These two methods are sometimes paired. Biological marine carbon dioxide removal (mCDR) processes alter or enhance the ocean's ability to convert carbon dioxide into biomass that can be stored away at depth from the atmosphere for hundreds to thousands of years. For example, seaweed cultivation and nutrient fertilization methods, including artificial upwelling, aim to increase the amount of carbon dioxide that is turned into organic biomass in the surface ocean, which is then sunk through the water column to the deep ocean, delaying its reentry to the atmosphere. Artificial downwelling is the downward transport of surface water, which aims to increase the amount of carbon that is transported to the deep ocean.

Coastal habitats which serve as carbon sinks are known as coastal blue carbon. At NOAA, we recognize that activities that enhance coastal blue carbon typically focus on restoration and/or conservation of naturally occurring ecosystems services, but under the right circumstances may also contribute to local and regional carbon removal. When these methods are carefully carried out alongside appropriate monitoring, reporting and verification, they can contribute to a carbon dioxide removal portfolio. A coastal blue carbon project may be considered a land- or ocean-based approach depending on the methodology (e.g. mangroves vs seagrass projects).

Due in part to growing interest in the voluntary carbon market and development of compliance markets, some companies are already pursuing small-scale pilot studies for a variety of these technologies. As a Department of Commerce agency, NOAA recognizes the importance of enabling emerging markets and wants to ensure that the methods are effective, verifiable, and accountable, while minimizing risk to ocean ecosystems and communities. At the same time, NOAA is focused on improving its knowledge base regarding the safety, efficacy, and sustainability of each marine carbon dioxide removal pathway. Private industry is already moving forward with carbon dioxide removal pilot projects, highlighting the urgent need for more research. Alongside growing our foundational knowledge, we must partner across the Federal government to develop standards to support an accountable, rigorous carbon market[1].

Other countries are pushing ahead with marine carbon dioxide removal - and some American companies are moving abroad to gain easier access to permission and economic incentives to test and scale their technologies. As other countries and companies explore altering the ocean to

[1] https://www.whitehouse.gov/briefing-room/statements-releases/2024/05/28/fact-sheet-biden-harris-administration-announces-new-principles-for-high-integrity-voluntary-carbon-markets/

draw down atmospheric carbon dioxide, the U.S. must grow our own knowledge around various marine carbon dioxide removal pathways including potential effects on the ocean and its ecosystems, and must maintain and expand our observing capabilities, in order to ensure we are informed and able to respond to global marine carbon dioxide removal activities. We cannot afford to remain on the sidelines of this field of research – for the climate, for the economic potential of the sector, and, as international interest grows, for our national security.

2. NOAA'S LEADING ROLE IN ADVANCING AND COORDINATING FEDERAL AND NON-FEDERAL MARINE CARBON DIOXIDE REMOVAL RESEARCH

NOAA has four main functions in the Federal approach to marine carbon dioxide removal. First, it is the key agency for foundational ocean and atmospheric research, leveraging its deep oceanic expertise to lead efforts to build knowledge about the efficacy of and potential ecological responses to various marine carbon dioxide removal pathways, as well as leveraging and expanding its oceanic observing capabilities and Earth-system models to better understand the natural baseline condition and variability of the ocean. Second, as a result of this leadership in research, NOAA is a central coordinator of Federal, academic, and philanthropic marine carbon dioxide removal research to inform policymaking. Third, NOAA may issue incidental take authorization under the Marine Mammal Protection Act to the Federal permitting agencies or conduct consultation with the permitting agencies under the Endangered Species Act and/or Magnuson-Stevens Fishery Conservation and Management Act. NOAA also supports the Federal permitting agencies by providing technical guidance on these statutes. Finally, NOAA stewards marine carbon dioxide removal research data within its environmental archive to ensure the data are findable, accessible, interoperable, and reusable by researchers, decision makers and the public.

NOAA is a world leader in understanding the effects of changing ocean carbon chemistry across a broad tapestry of marine species thanks to its ongoing research into the impacts of ocean acidification. The knowledge and facilities from this effort could be leveraged to explore similar effects from marine carbon dioxide removal pathways. Under the 2009 Federal Ocean Acidification Research and Monitoring Act (FOARAM), the Joint Subcommittee on Ocean Science and Technology of the National Science and Technology Council established the Interagency Working Group on Ocean Acidification (IWGOA) to coordinate Federal activities on ocean acidification among thirteen Federal agencies. The scope of science called for under the FOARAM Act expressly includes "oversee[ing] the development of adaptation and mitigation strategies to conserve marine organisms and ecosystems exposed to ocean acidification" to which some proposed marine carbon dioxide removal methods could contribute. Therefore, the IWGOA maintains active coordination around aspects of marine carbon dioxide removal science which intersect with ocean acidification. Examples of this coordination include sustaining national ocean carbon monitoring capacity that encompasses observations obtained from research vessels, volunteer private industry ships, fixed time-series stations, autonomous underwater and surface vehicles, and state water quality monitoring programs. Importantly, the IWGOA is presently engaged in an initiative to ensure long-term continuity of ocean carbon chemistry reference materials which will be critical to marine carbon dioxide removal Measurement, Monitoring, Reporting, and Verification (MMRV) as the industry emerges.

NOAA's marine carbon dioxide removal research portfolio is presently anchored by its investments via the National Oceanographic Partnership Program (NOPP). In FY22 NOAA began a multi-agency pilot project in collaboration with an industry partner and the Department of Energy (DOE) to explore the feasibility and impact of ocean alkalinity enhancement. This was followed up in FY23 with the first large-scale public and multi-partner competitive research opportunity that sought to examine a broad suite of marine carbon dioxide removal approaches. In total, the initiative supports 17 projects, including laboratory experiments, assessment of biological responses, modeling, field-based studies, and community engagement to be conducted over the next three years. The projects include 47 unique institutions and 79 researchers, from leading academic institutions, industry, NGOs, and government, including five NOAA laboratories. The initiative is primarily made possible by funding provided by Congress through the Inflation Reduction Act, which enables the Administration to advance its commitment to curbing climate change and positioning the US as a leader in cutting-edge science. And, while led by NOAA, this funding call includes funds from other government partners, including U.S. National Science Foundation, Office of Naval Research, and DOE, as well as funds from the nongovernmental organization Climateworks.

Congress has previously given NOAA direction on mCDR research through the NOPP report language in Fiscal Years 23 and 24. Additionally, some of the most high-profile legislation passed in the last four years, including the Bipartisan Infrastructure Law, the Inflation Reduction Act, the Energy Act of 2020, and the CHIPS and Science Act, has included carbon dioxide removal sections, with the IRA providing funding for the previously discussed NOPP research portfolio led by NOAA. Beyond these recent legislative efforts, Congress has also previously provided NOAA with mandates to lead oceanic research via the agency's modeling, monitoring, laboratory and sensing expertise and the statutory authority to ensure the conservation and management of marine resources. All of these capabilities are critical for the extensive foundational research into the efficacy and impacts of marine carbon dioxide removal that the Federal government is undertaking and seeking to expand.

NOAA is also leading these efforts beyond its research portfolio. NOAA is co-chairing, alongside the White House Office of Science and Technology Policy, a Fast Track Action Committee on Marine Carbon Dioxide Removal (MCDR-FTAC), which convened representatives from across the Federal government to produce a research strategy for marine carbon dioxide removal science and to inform potential deployment decision making to inform potential deployment decision making. This will be a Federal plan that outlines how the U.S. government can support and fill critical knowledge gaps relating to mCDR while identifying environmental, social, and human health responses. The plan highlights goals, principles, and recommendations that will responsibly produce sound science to guide future decision-making. The MCDR-FTAC solicited input from the public, marine carbon dioxide removal invested communities and experts, Tribes and local communities to inform the development of a safe and responsible marine carbon dioxide removal research strategy, which will be released in the Fall.

Beyond the MCDR-FTAC, NOAA has been working very closely with other agencies, particularly DOE, on fostering a whole-of-government collaborative approach to marine carbon dioxide removal work. In June 2024, NOAA and DOE's Office of Fossil Energy and Carbon Management, Office of Science, and Office of Energy Efficiency & Renewable Energy Water Power Technologies Office announced they had signed a Memorandum of Agreement establishing the basis for a collaborative relationship on marine carbon dioxide removal research and development. We are working hand in hand with the DOE to grow both agencies' involvement in marine carbon dioxide removal work, and to coordinate to ensure that there is no duplication of effort and that each agency is focusing its work on areas which play to its strengths. In this relationship, NOAA is leading on basic research into marine carbon dioxide removal's efficacy and potential impacts and co-benefits, as well as ocean, atmosphere, and carbon monitoring capabilities. DOE is poised to lead in scaling up marine carbon dioxide removal pathways, technology development and associated carbon markets. This productive relationship extends back prior to the MOA, with multiple offices in DOE providing funding as part of the NOPP call, including the Office of Fossil Energy and Carbon Management and Water Power Technologies Office. NOAA has also served in an advisory role with DOE's Advanced Research Projects Agency - Energy (or ARPA-E) funding call for innovative sensor technology development projects for marine carbon dioxide removal MRV and plans to continue to do so for future DOE funding calls. NOAA and DOE also currently have a joint Fellow working on marine carbon dioxide removal.

3. THE FUTURE OF MARINE CARBON DIOXIDE REMOVAL AT NOAA

In May 2023, NOAA released its first ever Strategy for Carbon Dioxide Removal Research.[2] The NOAA Strategy lays out a vision for how NOAA can work with its partners to address carbon dioxide removal knowledge gaps, and highlights the agency's four key asset classes that are the critical foundation for marine carbon dioxide removal research. First, NOAA has the largest network of marine carbon observations in the world – leveraging and expanding this network to ensure robust, sustained, and verifiable ocean observations is critical to assess the efficacy of marine carbon dioxide removal. This is not only important for research, but critical to ensure that

[2] https://sciencecouncil.noaa.gov/wp-content/uploads/2023/06/mCDR-glossy-final.pdf

future carbon credits from marine carbon dioxide removal are accountable and verifiable. Second, NOAA's Earth system models are currently being expanded to assess the impact of marine carbon dioxide removal on the global climate, as well as to examine the potential harms and co-benefits on ecosystems from scaled marine carbon dioxide removal research and deployments. Third, research on environmental responses must be carried out alongside research into marine carbon dioxide removal efficacy. Observations and assessments of marine species and ecosystems are critical for evaluating the potential impacts of marine carbon dioxide removal approaches, including those focused on fisheries and protected species. NOAA is a leader in ocean observations, modeling, and foundational ocean knowledge, and has considerable infrastructure from the related field of ocean acidification and carbon cycle science.

The NOAA Strategy also lays out three waves of research to achieve our vision of an effective, informed, and responsible marine carbon dioxide removal field. The first wave is focused on foundational research. Specific items include conducting laboratory bench studies, designing and growing local to regional ocean carbon observations, developing modeling packages, supporting permitting processes and stakeholder engagement. Some of this work, specifically lab and modeling work, is ongoing. NOAA is exploring options for increasing future resources for this work. Wave 2 focuses on engaging with field trials and scaling approaches through the year 2030. Actions include synthesizing research results, process studies on ecosystem impacts including higher trophic levels, taking part in large-scale controlled demonstration projects, assessments of risks of approaches, and comparing/contrasting cost-benefit analysis studies. Lastly, Wave 3 involves mature global monitoring of gigaton-scale marine carbon dioxide removal. This would support expansion of public-private partnerships and increase safeguarding of the marine environment from marine impacts of large-scale deployment.

4. SUMMARY OF THE COMMITTEE'S PROPOSED LEGISLATION

NOAA appreciates the Committee's dedicated work on legislation to guide marine carbon dioxide removal work.

Section two of the bill provides clear and accurate definitions of relevant terms. Section three authorizes NOAA, in collaboration with DOE, to establish an mCDR research program. It further provides a comprehensive list of activities and research topics for each agency, clearly delineating each agency's role and encouraging the continued collaborative work that the mCDR-FTAC has started. NOAA notes that the bill does not authorize additional appropriations, which would require NOAA to reduce other activities to fund new MCDR activities.

Section four establishes an mCDR steering committee composed of federal and non-federal experts to establish a national mCDR research plan, including providing environmental analysis of potential sites for mCDR Research Centers. The proposed research plan would include sections on the current understanding of mCDR, a code of conduct, the suitability of freshwater environments for mCDR, and performance-based criteria, among others, though NOAA notes it may in places be duplicative of work that the FTAC has already carried out. Section five directs DOE, in collaboration with NOAA, to establish the mCDR Research Centers discussed in the steering committee's report, and seeks to ensure the Centers avoid duplication of effort across the government. It also directs the centers to, among other things, consistently engage local communities particularly to promote economic growth. Finally, section six establishes NOAA as the federal government's lead agency for international mCDR coordination and U.N. engagement. NOAA appreciates this role, but notes that the Department of State is the lead U.S. agency for all engagement in international fora such as the United Nations; agencies such as NOAA can provide State with expertise as needed.

NOAA is happy to provide technical assistance to Congress as they further consider this bill.

5. CONCLUSION

NOAA is the nation's foremost source of ocean science expertise. The ongoing climate crisis will continue to drive interest in developing the field of marine carbon dioxide removal. With many outstanding questions about proposed marine carbon dioxide removal pathways' effectiveness and ecosystem responses, NOAA has a critical role to play in building the knowledge necessary to keep the U.S. positioned as a responsible leader in the field and in climate mitigation more broadly. NOAA cannot do this alone, however; partnerships within and outside of the government enable a comprehensive response to the scientific, technical, and economic questions and opportunities raised by marine carbon dioxide removal.

Sarah Kapnick, Ph.D.

Chief Scientist

Sarah Kapnick, Ph.D., is chief scientist for NOAA. In this role, Dr. Kapnick is responsible for advancing policy and program direction for NOAA's science and technology priorities.

Dr. Kapnick has extensive experience at the intersection of climate science and economics. Most recently, she served as a managing director at J.P. Morgan in the role of senior climate scientist and sustainability strategist for asset and wealth management. While at J.P. Morgan, she supported sustainability and climate action efforts and served as an advisor on new business and investment opportunities and risks.

Previously, Dr. Kapnick was a physical scientist and deputy division leader on seasonal to decadal variability and predictability at NOAA's Geophysical Fluid Dynamics Laboratory (GFDL). At GFDL, her work spanned seasonal climate prediction, mountain snowpack, extreme storms, water security and climate impacts. She was an expert and reviewer for NOAA's Small Business Innovation Research Program, a member of its Eastern Region Climate Team, a science panelist for Climate.gov and the NOAA team lead for the NASA High Mountain Asia Team.

Dr. Kapnick is a member of the American Geophysical Union, American Meteorological Society and American Association for the Advancement of Science. Prior to her graduate studies, she spent two years as an investment banking analyst with Goldman Sachs covering financial institutions. She received a Ph.D. in atmospheric and oceanic sciences with a certificate in leaders in sustainability from UCLA, and an A.B in mathematics with a certificate in finance from Princeton University.

Chairman MILLER. Thank you very much. I now recognize Mr. Ben Tarbell for 5 minutes to present his testimony.

TESTIMONY OF MR. BEN TARBELL,

CEO AND CO-FOUNDER, EBB CARBON

Mr. TARBELL. Thank you. Chairman Williams, Chairman Miller, Ranking Member Bowman, Ranking Member Ross, and Members of the Subcommittees, thank you for the opportunity to testify today. My name is Ben Tarbell, and I'm co-founder and CEO of Ebb Carbon, a U.S.-based marine carbon removal and ocean health company. Ebb Carbon's mission is to remove billions of tons of excess CO_2 from the atmosphere. To achieve this, we're pioneering an approach called ocean alkalinity enhancement, which boosts the ocean's natural ability to safely capture and store carbon by removing excess acid from seawater.

According to reports by both NOAA and the National Academy of Sciences, our approach offers one of the most scalable and cost-effective solutions of any durable carbon removal pathway. Since 2023, Ebb Carbon has been demonstrating our technology in partnership with DOE and NOAA at the Pacific Northwest National Laboratory (PNNL) in Sequim, Washington. This work is designed to ensure that every step we take from research to deployment is grounded in rigorous science. At Ebb we say that how we remove the first 1,000 tons of CO_2 will determine how we remove the next billion.

We're following our demonstration at Sequim with a pilot-scale project right down the road in Port Angeles, Washington, so we can translate what we've learned in the lab to real-world operations. We're the first company to apply for a permit to operate a project like this under the *Clean Water Act,* and we're working closely with State and Federal agencies and local communities as part of that process.

We founded Ebb because we saw the immense potential of marine CDR to mitigate climate change. Oceans cover over 70 percent of the Earth's surface and play a vital role in regulating our climate. The ocean has already removed billions of tons of excess atmospheric CO_2. And yet, despite this potential, marine CDR has yet to receive investment proportionate to its potential.

As such, our ability to advance the science and the industry is limited in the United States, but this can change. I know this because I've seen it from my previous work helping grow the solar energy industry. In the early years, solar technology was promising, but not widespread. By the 1970's, solar panels were available but cost over $100 per watt, way too expensive for most practical uses.

Despite its promise, the industry struggled to gain traction, and it was decades before its recent dramatic hockey stick growth. The breakthrough came from two key factors. First, public-private partnerships; and second, smart policy enablement. While DOE labs like NREL (National Renewable Energy Laboratory) were critical to enabling the foundational science, the cost trajectory was driven down by commercial demonstrations and deployments, which allowed the promise of solar to be realized beyond the lab and into the real world.

While the national labs provided answers that helped unlock the market, smart Federal policies accelerated the private capital investments required to deploy at scale. Key initiatives such as the investment tax credit provided financial incentives and market derisking, making solar investments more attractive. As a result, the industry flourished, and the cost of solar panels plummeted to less than 50 cents per watt. What was once a niche technology has now become a cornerstone of global energy production.

Today, DOE's PNNL and NOAA's PMEL (Pacific Marine Environmental Laboratory), alongside academic labs, continue to lead the research so critical to advancing the field of marine CDR. But as with solar, industry partnerships are critical to demonstrating in the real world and advancing the science required to deliver a planetary-scale solution. Unlike with solar, we don't have decades to get this right.

It is with this context that I'd like to suggest three areas of priority for consideration. First, direct innovation and deployment funding to marine CDR proportionate to its potential as a climate solution. This can and should include Federal funding for research and development, as well as the expansion of incentives and enablements for industry deployments.

Second, enable public-private partnerships to advance the field safely, effectively, and responsibly, including accounting for the role of the private sector in creating business models and deployments that can scale climate impact.

Third, modernize permitting pathways. The basic science around ocean alkalinity enhancement is well established. Moving the field forward requires permits for in-water pilots to advance our collective understanding and ultimately to reach scale safely.

We're at an inflection point where we have a narrow moment to move from possibility to reality from R&D to a scale where we can have a substantive positive impact on the climate. Congress has a unique opportunity to enable the burgeoning marine CDR industry at this critical time. We know marine CDR has a huge role to play in stemming the worst impacts of climate change, and we're excited to work with the Federal Government to move the field forward.

Thank you.

[The prepared statement of Mr. Tarbell follows:]

Testimony of Ben Tarbell, Founder and CEO
Ebb Carbon

before the

U.S. House of Representatives
Committee on Science, Space, and Technology
Joint Environment and Energy Subcommittees

Navigating the Blue Frontier: Evaluating the Potential of Marine Carbon Dioxide Removal Approaches

September 19, 2024

Chairman Williams, Chairman Miller, Ranking Member Bowman, Ranking Member Ross, and members of the Subcommittees, thank you for the opportunity to testify today. My name is Ben Tarbell, and I am Co-founder and CEO of Ebb Carbon, a US-based marine carbon removal and ocean health company.

Ebb Carbon's mission is to remove billions of tonnes of excess CO_2 from the atmosphere. To achieve this, we are pioneering an approach called Ocean Alkalinity Enhancement which boosts the ocean's natural ability to safely capture and store carbon by removing excess acid from seawater. According to reports by both NOAA and the National Academy of Sciences, our approach offers one of the most scalable and cost-effective solutions of any durable carbon removal pathway.

Since 2023, Ebb Carbon has been demonstrating our technology in partnership with the DOE and NOAA at the Pacific Northwest National Laboratory in Sequim, WA. This work is designed to ensure that every step we take, from research to deployment, is grounded in rigorous science. At Ebb we say that how we remove the first 100 tonnes of CO2 will determine how we remove the next billion. We're following up our demonstration at Sequim with a pilot-scale project right down the road in Port Angeles, WA so we can translate what we've learned in the lab to real world operations. We are the first company to apply for a permit to operate a project like this under the Clean Water Act, and we are working closely with state and federal agencies and local communities as part of that process.

We founded Ebb because we saw the immense potential of marine CDR to mitigate climate change. Oceans cover over 70% of the Earth's surface and play a vital role in regulating our climate. The ocean has *already* removed billions of tonnes of excess atmospheric CO2. Yet, despite this potential, marine CDR has yet to receive investment proportionate to its potential. As such, our ability to advance the science and the industry is limited in the United States. But this can change. I know because I've seen it before from my previous work helping grow the solar energy industry.

In the early years, solar technology was promising but not widespread. By the 1970s, solar panels were available but cost over $100 per watt—too high for most practical uses. Despite its promise, the industry struggled to gain traction and it was decades before its dramatic "hockey stick" growth.

The breakthrough came from two key factors: public-private partnerships and smart policy enablement. While DOE labs like NREL were critical to enabling the foundational science, the cost trajectory was driven down by commercial demonstrations and deployments, which allowed the promise of solar to be realized beyond the lab and into the real world.

While the national labs provided answers that helped to unlock the market, smart federal policies accelerated the private capital investments required to deploy at scale. Key initiatives, such as the Investment Tax Credit provided financial incentives and market de-risking, making solar investments more attractive. As a result, industry flourished and the cost of solar panels plummeted to less than $0.50 per watt and what was once a niche technology has now become a cornerstone of global energy production.

Today, DOE's PNNL and NOAA's PMEL alongside academic labs continue to lead the research so critical to advancing the field of mCDR. But as with solar, industry partnerships are critical to demonstrating in the real world and advancing the science required to deliver a planetary-scale solution. Unlike with solar, we don't have decades to get this right.

It is with this context that I'd like to suggest three areas of priority for consideration:

1. **Direct funding to marine CDR, proportionate to its potential as a climate solution.** This can and should include Federal funding for research & development as well as the expansion of incentives and enablements for industry deployments.
2. **Enable public-private partnerships to advance the field safely, effectively and responsibly.** Including accounting for the role of the private sector in creating business models that can scale climate impact.
3. **Create fit-for purpose regulatory pathways.** The basic science around OAE is well established - moving the field forward requires in-water pilots to advance our collective understanding and ultimately reach scale safely.

We are at an inflection point where we have a narrow moment to move from possibility to reality, from pilot-scale R&D to a scale where we can have a substantive positive effect on the climate. Congress has a unique opportunity to enable the burgeoning mCDR industry at this critical time. We know mCDR has a huge role to play in stemming the worst impacts of climate change, and we're excited to work with the Federal Government to move the field forward.

About Ben
Ben Tarbell is Co-Founder and CEO of Ebb Carbon. Previously, Ben was the VP of Products at SolarCity as it grew from 0 to 375MW+ of solar assets installed, 50,000+ customers, 2,500+ employees, and IPO growing to $6B+ valuation. He went on to lead the launch of Mosaic's residential solar loan program which is now one of the largest sources of residential solar financing in the U.S., providing several billion USD of solar loans per year. Ben later joined Google X and led the team launching new climate technologies and businesses. Ben has successfully invested in dozens of climate technology startups as an angel investor as well as while working at climate-focused venture capital firms. He serves on the board of GlobalGiving and has both an MS in Engineering and an MBA from Stanford University in addition to a BS in Mechanical Engineering from Cornell University.

About Ebb Carbon
Ebb Carbon is pioneering a new carbon removal solution by enhancing the ocean's natural ability to safely store CO2. Ebb's technology is designed to integrate with existing industrial facilities that process seawater, like desalination plants, which today represents over a billion tonnes of carbon removal once integrated. Ebb's approach has the potential to be one of the largest scale and lowest cost approaches to removing excess CO_2 from the air, while reducing ocean acidity locally.

Chairman MILLER. Thank you very much.

I now recognize Dr. Scott Doney for 5 minutes to present his testimony.

TESTIMONY OF DR. SCOTT DONEY, JOE D. AND HELEN J. KINGTON PROFESSOR IN ENVIRONMENTAL CHANGE, THE UNIVERSITY OF VIRGINIA

Dr. DONEY. Good morning, Chairman Miller, Chairman Williams, Ranking Member Ross, and Ranking Member Bowman, Members of the Subcommittee. My name is Scott Doney. I'm a the Kington Professor of Environmental Change at the University of Virginia. Thank you for the opportunity today to talk about the challenges, potential risks, and also benefits of marine carbon dioxide removal. While some of these approaches show great promise, none is ready yet for deployment at scale because of gaps in our knowledge, knowledge of science and engineering, of intended and unintended environmental consequences, and of social impacts.

At present, we emit about 40 billion tons of carbon dioxide to the atmosphere every year, primarily from fossil fuel combustion. In order to stabilize climate, we need rapid decarbonization of the global economy, and eventually we need to reach a net-zero human emissions of carbon dioxide and other greenhouse gases. A portfolio of land-based and ocean-based carbon dioxide removal could contribute to that effort by balancing hard-to-abate emissions, but only if these carbon dioxide removal approaches can scale safely and economically to the tens to hundreds of billions of tons of carbon dioxide per year scale.

Numerous approaches have been put forward to enhance carbon dioxide uptake of the ocean. As already mentioned, the ocean naturally takes up about a quarter of human emissions through geochemical pathways. These geochemical approaches, such as ocean alkalinity enhancement, would extend that uptake by adding alkalinity and increasing the solubility of carbon dioxide in seawater and enhancing the flux of gas across from the atmosphere into the ocean.

Direct ocean capture would actually remove carbon dioxide from the ocean and either use it or store it in geologic reservoirs. Biological approaches have been put forward that would enhance either the biomass of carbon in organisms or in detrital material in marine sediments and coastal regions. It could also act by enhancing the biological pump. This is an action by marine organisms, particularly phytoplankton, that removes carbon from the surface ocean and transports it to the deep sea. These range from approaches such as ocean fertilization and marine aquaculture to artificial upwelling.

Demonstration of safe and effective marine carbon dioxide removal requires targeted research on efficacy, additionality, and durability of these different approaches. Research and development are also needed on engineering constraints, energy demands, resource demands, scalability, and technical readiness.

Progress also depends on robust and transparent validation methods—measurement, monitoring, reporting, and verification (MRV)—that incorporate field observations, autonomous platforms, remote sensing, and numerical modeling in an integrated fashion. This is particularly challenging in the turbulent ocean, where ocean mixing and stirring transports any perturbation to the ocean that's been added by humans away from the original site and dilutes it over time.

We need targeted efforts to measure the effect of any marine CDR on air-sea gas exchange because none of these approaches actually removes carbon directly from the atmosphere. They change conditions in the ocean and implicitly expect that that will enhance air CO_2 flux into the ocean. We also need assessment of environmental and social impacts, better stakeholder engagement, and agreed-upon research codes and government structures in order to move forward with field testing.

A Federal program is essential in determining whether some form of green carbon dioxide removal can serve in the future as a safe and effective scalable climate solution. Federal investments provide the unique framework for rigorous and independent and transparent research, including both validation and environmental impact assessment. Without a substantial ramp-up in Federal research, the rapid technology development and ongoing pressures to address mounting climate change damages may outpace our scientific understanding. That scientific understanding is critical if we are to make informed decisions on deployment of marine CDR.

Thank you, and I look forward to your questions.

[The prepared statement of Dr. Doney follows:]

WRITTEN TESTIMONY OF
SCOTT C. DONEY, Ph.D.
UNIVERSITY OF VIRGINIA[1]

HEARING ON
NAVIGATING THE BLUE FRONTIER: EVALUATING THE POTENTIAL OF MARINE CARBON DIOXIDE REMOVAL APPROACHES

BEFORE THE
U.S. HOUSE OF REPRESENTATIVES
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
JOINT ENVIRONMENT AND ENERGY SUBCOMMITTEES

SEPTEMBER 19th, 2024

Introduction

Good morning, Chairmen Miller and Williams, Ranking Members Ross and Bowman, and members of the Environment and Energy Subcommittees. Thank you for the opportunity to speak with you today on marine carbon dioxide removal. My name is Scott Doney, and I am the Kington Professor in Environmental Change at the University of Virginia in Charlottesville, Virginia. My research focuses on interactions among climate, the ocean and global carbon cycles, and coastal and marine ecosystems.

For today's hearing, you asked me to discuss the benefits and risks of marine carbon dioxide removal (mCDR) approaches as they relate to carbon capture and sequestration, as well as ecosystem and community side effects. My testimony touches on the current state of the science along with research opportunities to address critical knowledge gaps. My comments are based on several scientific assessments compiled by the ocean research community (e.g., GESAMP, 2019; Gattuso et al., 2021; NASEM, 2022) as well as a recent review article based on the available scientific literature (Doney et al., 2024a).

Summary

Scenarios to stabilize global climate and meet international climate agreements require rapid reductions in human carbon dioxide (CO_2) emissions, often augmented by substantial carbon dioxide removal (CDR) from the atmosphere. While some ocean-based removal techniques show potential promise as part of a broader CDR and decarbonization portfolio, no marine approach is ready yet for deployment at scale because of gaps in both scientific and engineering knowledge. Marine CDR spans a wide range of biotic and abiotic methods, with both common and technique-specific limitations. Further targeted research is needed on CDR efficacy, permanence, and additionality as well as on robust validation methods—measurement, monitoring, reporting, and verification—that are essential to demonstrate the safe removal and long-term storage of CO_2. Engineering studies are needed on constraints including scalability, costs, resource inputs, energy demands, and technical

[1] The views expressed here are my own and do not necessarily represent those of the University of Virginia

readiness. Research on possible co-benefits, ocean acidification effects, environmental and social impacts, and governance is also required.

Rationale for Carbon Dioxide Removal

Over the past several centuries, large human perturbations to the global carbon cycle have increased atmospheric CO_2 by 50% and methane CH_4 by more than 150% relative to preindustrial levels (IPCC, 2023). Elevated atmospheric levels of CO_2, CH_4, and other minor greenhouse gases absorb infrared radiation and alter planetary radiative forcing; greenhouse gas perturbations are the dominant factor behind the observed global surface warming of +1.1°C (average for 2011–2020) above preindustrial levels (IPCC, 2023). Climate change, ocean warming, and ocean acidification from rising atmospheric CO_2 have widespread ramifications for ocean physical–biogeochemical dynamics, marine ecosystems, and dependent human coastal communities.

Natural processes have limited capacity to remove excess atmospheric CO_2 on human timescales, and therefore the current elevated levels of atmospheric CO_2 and resulting climate change will take decades to centuries or longer to dissipate (Canadell et al., 2021). Continued human emissions of CO_2 will only further exacerbate these problems, and stabilization of global surface temperatures will require human CO_2 emissions to drop sharply to near zero in the coming decades (IPCC, 2018; IPCC, 2023). The international climate Paris Agreement commits to hold global surface warming to below +2.0°C and to pursue a more ambitious target of only +1.5°C warming above preindustrial levels. The +1.5°C and +2.0°C climate thresholds may be reached in only a decade to a few decades, respectively, if human CO_2 emissions continue at current rates (Friedlingstein et al., 2022). Rapid decarbonization of the global energy system and overall economy is needed, therefore, to meet the Paris Agreement climate targets. Many scenarios for climate stabilization augment decarbonization with substantial levels of carbon dioxide removal (CDR), approaches that actively remove and store CO_2 away from the atmosphere for long periods of time (IPCC, 2018; IPCC 2023).

The scope of the required levels of decarbonization and CDR for a below +1.5°C climate scenario is substantial (Fuhrman et al. 2023). For the decade 2012–2021, fossil fuel CO_2 emissions averaged 9.6 ± 0.5 Pg C y^{-1}, where 1 Pg C = $1x10^{15}$ g C = 1 Gt C (1 billion metric tons) (Friedlingstein et al. 2022), and emissions are projected to be stable or increase under no-climate-policy scenarios; note that some literature and policy documents use mass of CO_2 rather than C, with 1 Pg C = 3.66 Pg CO_2. Dramatic decarbonization transitions across the energy system (e.g., more renewable electricity generation and electrification of transportation and heating) are needed to reduce sharply fossil fuel emissions. However, there likely will remain economic sectors that are difficult or expensive to decarbonize, such as some heavy industry and maritime shipping, with residual emissions of 1–3 Pg C y^{-1}. CDR or negative emissions may be required to compensate for these residual emissions in order to reach net-zero human CO_2 emissions by midcentury. Even larger amounts of CDR (>3 Pg C y^{-1}) and net-negative CO_2 emissions may be required for the latter half of the century to compensate for continued human CH_4 and other greenhouse gas emissions.

To date, only a subset of possible CDR approaches has been incorporated into the climate models and other climate policy tools, with an emphasis on land-based techniques (NASEM, 2019; Fuhrman et al., 2020; IPCC, 2023); there is a notable lack of marine CDR approaches, reflecting, in part, more limited scientific and techno-economic information and lower technical readiness (NASEM, 2022). Even across land-based CDR techniques, generalizations warrant caution because of the different principles used for reducing and storing CO_2 away from atmosphere. Proposals span from restoring and enhancing natural carbon sinks (e.g., afforestation, soil carbon, and enhanced weathering) to more industrial solutions (e.g., direct air capture or bioenergy coupled with geologic carbon sequestration). Each approach comes with distinct constraints associated with scaling potential, costs, energy use, land and resource demand, environmental damage, governance, and interactions with other societal objectives, such as the United Nations Sustainable Development Goals (Fuhrman et al. 2019). Deploying CDR technology or a combination of technologies at a scale of removing 1 Pg C y^{-1} within a few decades poses significant scientific, engineering, and societal challenges (IPCC 2018, NASEM 2019).

Proposed coastal and marine CDR methods cover a broad mix of nature-based and technological approaches that alter either ocean biotic or abiotic carbon cycles (see Figure and Table below) (GESAMP 2019, Gattuso et al. 2021, NASEM 2022). Abiotic marine CDR approaches are mediated by inorganic chemical reactions that alter the ocean CO_2 solubility pump by shifting seawater CO_2 solubility equilibrium and enhancing air–sea CO_2 uptake. Ocean alkalinity enhancement utilizes geochemical or electrochemical methods to add alkalinity to seawater, while direct ocean capture or removal utilizes electrochemical techniques to strip CO_2 from the surface ocean. Prospective biotic marine CDR approaches attempt to increase the marine storage of carbon in biomass and organic detritus or strengthen the marine biological pump, which transfers carbon from the atmosphere–upper-ocean system into the deep sea. Biotic methods include habitat and ecosystem protection and restoration (e.g., coastal and ocean blue carbon) and enhancement of the marine biological carbon pump (e.g., ocean fertilization, artificial upwelling, and macroalgal aquaculture).

Unlike many terrestrial CDR approaches, ocean-based methods typically do not directly remove CO_2 from the atmosphere; rather, they act indirectly by increasing carbon in marine biomass, enhancing biological carbon export from the surface to the deep ocean, elevating seawater CO_2 solubility, or stripping CO_2 from seawater for onshore or sub-seabed geologic sequestration. Most marine CDR methods thus implicitly depend on perturbations internal to the ocean that will result in carbon removal from the atmosphere via enhanced downward air–sea CO_2 flux into the ocean. The validation of marine CDR is thus complicated by the large natural background of ocean carbon storage and cycling as well as the substantial contemporary ocean anthropogenic CO_2 sink that is about 30% of human fossil fuel emissions (Friedlingstein et al. 2022). The coastal domain is a likely site for many marine CDR experiments. However, it is particularly complex and spatially heterogeneous, with regions of both CO_2 uptake and release, large seasonal variability, and competing climate effects from emissions of other greenhouse gases, CH_4 and nitrous oxide (N_2O), that partially compensate for net CO_2 uptake for the global coastal ocean (Resplandy et al., 2024).

Efforts are underway to develop guidelines for marine CDR measurement, monitoring, reporting, and verification (MMRV; see below), which is essential for CDR carbon accounting and will require a combination of field observations and modeling (Fennel et al., 2023; Ho et al., 2023) (see Figure below). There are significant issues related to marine CDR that include potential environmental and social impacts, governance, and ethical concerns (Cooley et al., 2023). These issues have similarities with those faced by land-based CDR and sub-seabed geological CO_2 sequestration linked to power- and industry-sector carbon capture. These concerns suggest the need for careful consideration and management of marine CDR technologies. Assessment of environmental and socioeconomic impacts, public stakeholder engagement, and agreed-upon research codes of conduct should be a component of any marine CDR field testing (NASEM 2022).

Contemporary Ocean Carbon Cycle

Marine CDR experiments and any potential future large-scale CDR deployments would perturb an already dynamic and complex ocean carbon cycle. The ocean has large and evolving carbon reservoirs, and significant fluxes occur among internal organic and inorganic carbon pools, sediments, and the atmosphere. Additionally, human activities have altered rivers, coasts, and oceans, adding another layer of complexity to the system.

Carbon dioxide gas dissolves in and reacts with alkaline seawater to create dissolved inorganic carbon (DIC), the sum of the concentrations [ ] of aqueous CO_2, carbonic acid H_2CO_3, bicarbonate HCO_3^-, and carbonate CO_3^{2-} concentrations (Millero, 2007):

$$DIC = [CO_2(aq)] + [H_2CO_3] + [HCO_3^-] + [CO_3^{2-}]$$

At seawater pH, the concentration of H_2CO_3 is negligible relative to that of CO_2(aq), and the two are often combined into a single effective term. Dissolved inorganic carbon is the dominant ocean carbon reservoir (pre-industrial DIC inventory ~37,100 Pg C; DeVries, 2022) followed by a smaller ocean dissolved organic carbon pool (~662 Pg C). The marine biomass stock is quite small (~6 Pg C; Bar-On et al., 2018), with mostly rapid turnover times. Coastal, shelf, and deep-ocean sediments contain substantial carbon reservoirs with widely varying timescales for water-column exchange.

The pre-industrial dissolved inventory reflects, to a great extent, CO_2 solubility equilibrium between the vast deep-ocean and atmosphere CO_2 reservoirs. CO_2 solubility is dependent on temperature and alkalinity, a measure of the acid/base balance and a result of rock weathering (Millero, 2007):

$$Alkalinity = [HCO_3^-] + 2[CO_3^{2-}] + [B(OH)_4^-] + [OH^-] - [H^+] + minor\ species$$

More CO_2 will partition into a colder, more alkaline ocean, thus lowering the atmosphere CO_2 mixing ratio on geologic time scales. The ocean solubility pump response to rising atmosphere CO_2 mixing ratio, modulated by rates of surface-deep ocean physical circulation, also largely explains the ocean uptake of anthropogenic CO_2, increasing the pre-industrial DIC inventory by 175 ± 35 Pg C (Friedlingstein et al., 2022).

The contemporary global air-sea CO_2 flux is the net difference between ingassing of anthropogenic CO_2 and a now smaller pre-industrial outgassing from riverine carbon inputs. Air-sea CO_2 flux can be computed from an empirical gas transfer velocity k_w and the difference between surface ocean and atmosphere equilibrium $CO_2(aq)$ concentrations:

$$F_{CO2} = k_w([CO_2^{atm}(aq)] - [CO_2(aq)])$$

The flux equation is often recast as partial pressures pCO_2 by including a solubility term. The equilibration time of surface ocean CO_2 relative to air-sea flux is long, order months to a year, because of the large DIC pool and shifts in seawater acid-base chemistry.

Carbon dioxide can be added to seawater either directly by gas injection or by the respiration of organic matter. The additional $CO_2(aq)$ elevates pCO_2 and thus net CO_2 outgassing, increases seawater dissolved inorganic in a 1:1 mole ratio, and enhances HCO_3^- and hydrogen ion H^+ concentration, shifting pH lower towards more acidic conditions.

$$CO_2 + H_2O \rightarrow HCO_3^- + H^+ \qquad CO_3^{2-} + H^+ \rightarrow HCO_3^-$$

$$pH = -log_{10}[H^+]$$

Seawater alkalinity is not affected by adding CO_2. Alkalinity is enhanced by adding carbonate ion, CO_3^{2-}, through the dissolution of mineral calcium carbonate $CaCO_3$, for example, or through the addition of hydroxide ions, OH^- or soluble mineral oxides such as brucite $Mg(OH)_2$. Alkalinity enhancement increases seawater pH, lowers pCO_2, and causes net CO_2 ingassing.

The marine biological pump transfers DIC from the surface to the deep ocean, substantially enhancing the vertical DIC gradient, elevating the preindustrial DIC inventory by ~2,800 Pg C (DeVries, 2022) and reducing atmosphere CO_2. Surface ocean photosynthesis and inorganic CO_2 uptake, ~50 Pg C y^{-1}, is nearly balanced by respiration (forward and backward reactions):

$$CO_2 + H_2O + energy \leftrightarrow CH_2O + O_2$$

The net imbalance of ~10 Pg C y^{-1} is exported as organic matter to the subsurface ocean, with only a small fraction of the organic C export is transferred to depths greater than 1000 m with an even smaller fraction buried in deep ocean sediments (Doney et al., 2024b). Comparable carbon burials occur in the much smaller areas of estuaries, coastal wetlands, and on the continental shelf.

Framing Ocean-Based Carbon Dioxide Removal

To serve as safe and effective climate mitigation options, marine CDR approaches must meet a combination of scientific and engineering criteria, address environmental and social concerns, and be amenable to validation through transparent MMRV. Scientific assessment centers on efficacy, permanence, additionality, and scalability (GESAMP 2019; NASEM 2019 and 2022; Gattuso et al. 2021) where:

- Efficacy: the removal of CO_2 from the atmosphere, as opposed to the simple redistribution of carbon pools within the ocean
- Permanence: the sequestration of CO_2 away from the atmosphere for climate policy–relevant time periods of decades to centuries; also called durability
- Additionality: CO_2 removal that is due to deliberate human actions and not natural processes or background oceanic uptake of anthropogenic CO_2

- Scalability: an assessment of biophysical, geochemical, engineering, environmental, and social constraints for potential deployment of CDR method at climate policy–relevant scales

Efficacy requires an approach that removes CO_2 from the atmosphere rather than simply redistributing carbon within ocean pools. This can be difficult to demonstrate directly because of the large natural concentrations and time/space variability in ocean dissolved inorganic carbon and the substantial upper-ocean concentrations and ongoing ocean uptake of anthropogenic CO_2 that is independent of CDR efforts. Evaluation of CDR efficacy is also challenging because of physical circulation, turbulence, and mixing and the long timescale or order a year for CO_2 gas exchange equilibration timescale, all of which combine to transport, disperse, and delay CDR perturbation signals in CO_2 air–sea flux and storage.

The permanence (or durability) of CDR-induced changes in ocean CO_2 storage requires sequestration away from the atmosphere for time periods sufficiently long enough to contribute to climate policy goals, typically multiple decades to centuries. While MMRV observations and modeling are essential for quantifying near-term changes in ocean biogeochemistry and net ocean CO_2 uptake from the atmosphere (Palter et al. 2023), ocean biogeochemical models likely provide the only viable, though imperfect, measure of long-term marine CDR permanence (Siegel et al. 2021). Additionality for CDR requires demonstrating that any observed CO_2 removal is due to deliberate human actions rather than natural processes and would not have occurred naturally or from the ongoing oceanic uptake of anthropogenic CO_2. Assessments of CDR efficacy, permanence, and additionality should also include the CO_2 and other greenhouse gases emitted in carrying out the ocean-based CDR project (e.g., emissions from energy use during deployment, material production, and transportation), highlighting the importance of full life cycle analysis for any marine CDR approach.

All marine CDR approaches require the allocation of energy, capital, and/or other resources for pumping, chemical/material processing, aquaculture, and/or (re)distribution of materials in the ocean. Returns on public and private investment in marine CDR, like its terrestrial counterpart, will therefore hinge upon (correctly) understanding how costs, impacts, and efficacy vary with the scale of deployment. Despite the large cumulative capacity for ocean uptake of CO_2 from the atmosphere on geologic timescales, the usefulness of marine CDR in addressing climate change on decadal to centennial timescales will be constrained, in practice, by removal rates achievable at a reasonable cost, as well as the pace at which supporting infrastructure and institutions can be scaled to realize those rates. These issues could be exacerbated in the case of marine CDR given the tendency of ocean water to circulate globally, requiring more sophisticated MMRV, and the often far higher costs required to operate in marine environments. Corrosion control and severe weather protection for pumping systems and offshore structures over the full life cycle of marine CDR projects will be critical considerations when moving from the lab and demonstration scale to the required large-scale deployments (tens to hundreds of teragrams of CO_2 per year, where 1 Tg = 1 Mt, or 1 million tons) implied by climate model results. Reallocation of a substantial portion of bulk materials shipping capacity to alkalinity enhancement and/or ocean iron fertilization could serve as another technical barrier to scaling up these marine CDR approaches, irrespective of policy, legal, and social concerns (NASEM, 2022).

Marine Carbon Dioxide Removal Approaches

Scientific and engineering characteristics, validation and MMRV challenges, and social–environmental impacts for the broad abiotic and biotic categories marine CDR are summarized here and also in a Table (see below).

Ocean alkalinity enhancement seeks to accelerate rock natural weathering processes and for this reason may also be termed enhanced or accelerated weathering (Renforth and Henderson, 2017; Eisaman et al., 2023). Under ocean alkalinity enhancement, alkaline materials would be mined and then pulverized into small particles to increase their reactive surface area and accelerate their dissolution into proton acceptors, resulting in higher seawater bicarbonate (HCO_3^-) and carbonate (CO_3^{2-}) ion concentrations and lower aqueous CO_2 concentration. The alkalinity could be added to the ocean in solution or in soluble mineral particle form; some methods would pre-equilibrate alkaline solutions with elevated CO_2 gas streams prior to ocean release, thus linking CDR with carbon capture and sequestration. The resulting pH increase would also directly counteract anthropogenic CO_2–induced ocean acidification that is negatively impacting marine ecosystems (Doney et al. 2020).

Electrochemical marine CDR approaches utilize acid–base chemistry to either decrease pH and force CO_2 offgassing or increase pH to induce carbonate precipitation (Eisaman et al., 2018; La Plante et al., 2021). When the aqueous CO_2 is removed, the discharged seawater can take up more gaseous CO_2 from the atmosphere to restore equilibrium. Electrochemical processes can also be used to increase seawater alkalinity directly and thus can be a special case of ocean alkalinity enhancement. Pre-equilibration of alkaline water generated from alkalinity enhancement with excess CO_2 prior to discharge to the ocean may alleviate some of local environmental impacts and the MMRV challenges associated with tracking changes in air-sea CO_2 fluxes.

Marine conservation efforts have the potential co-benefit of carbon dioxide removal through the protection, recovery and restoration of benthic, pelagic, and offshore ocean ecosystems, including macroalgae and marine animals (Christianson et al. 2022). Potential CDR benefits extend beyond direct biomass carbon storage because marine flora and fauna generate a substantial fraction of surface biological carbon export, though there are substantial challenges including quantifying net changes in ocean carbon storage as well as the extent to which biogeochemical feedbacks and nutrient reallocation may reduce CDR efficacy. Although likely smaller in scale than other CDR approaches, marine conservation- and restoration-based methods are likely to enjoy more widespread public support owing to the real and perceived environmental co-benefits.

Macroalgal aquaculture can also be pursued coupling seaweed farming with deliberate sinking or pumping of macroalgae biomass into deep ocean. Many questions remain about methods for large-scale farming, harvesting, and conveying biomass carbon to depth, particularly if offshore sites are required to avoid local coastal environmental damage and competition for coastal space with fisheries or other ocean activities. Biological constraints on scalability include natural or artificial substrate, light, and nutrient growth requirements, where large-scale aquaculture will feed back on local and downstream nutrient concentrations (Berger et al. 2023). Detrimental environmental impacts could include local ecological modification as well as deoxygenation and acidification for the deep-ocean ecosystems where biomass is ultimately sequestered (Ross et al. 2022).

Artificial upwelling that enhances nutrient input and phytoplankton productivity could serve as a form of marine CDR (Dutreuil et al. 2009). An important caveat is that respiration and nutrient remineralization are typically closely linked, and artificial upwelling will be effective for CDR only in locations where the ratio of nutrients to excess or metabolic dissolved inorganic carbon in upwelled water is greater than the elemental stoichiometry of plankton organic matter production. Open-ocean field testing of artificial upwelling devices has been limited by costs and technological barriers (White et al. 2010). Theoretical and modeling studies suggest a global scalability of artificial upwelling CDR of only order 10 Tg C y^{-1} (Koweek, 2022).

Ocean fertilization could act as a potential marine CDR pathway by enhancing the marine biological carbon pump that transports carbon from the surface to deep ocean, effectively removing the carbon from contact with the atmosphere for some period of time. Multiple open-ocean fertilization field experiments conducted over the past several decades demonstrated that phytoplankton primary production can be stimulated in situ at mesoscale (10–100 km) in specific regions through the addition of the micronutrient iron or macronutrients (Boyd et al. 2007). Studies have also indicated, to varying extents, shifts in plankton community structure to larger cells (such as diatoms), increases in sinking particulate organic carbon flux, and biological drawdown in surface pCO_2 and dissolved inorganic carbon. Ocean iron fertilization at scale would purposefully alter the structure and function of plankton ecosystems over large ocean regions, with a variety of possible, often poorly characterized environmental risks, including harmful algal blooms and impacts on fisheries and higher trophic levels, with substantial disagreements within the scientific community (Buesseler et al. 2008, Strong et al. 2009, Buesseler et al., 2024).

Measurement, Monitoring, Reporting, and Verification (MMRV)

Demonstrating effective ocean CDR requires robust MMRV methods for detecting and attributing the causes behind changes in ocean inorganic carbon inventories and surface-ocean pCO_2 for air–sea CO_2 gas fluxes. Transparent MMRV is also a crucial step in the development of standard marine CDR protocols and certification processes needed for carbon account and incorporation into carbon markets. Abiotic CDR approaches will require additional measurements of seawater chemistry, in particular alkalinity as well as trace constituents. Biotic approaches will require information on organic carbon biomass and detrital stocks as it enters the various export pathways of the marine biological carbon pump. One challenge facing MMRV for marine CDR strategies is that natural variability in the marine carbon cycle is large. While initial signals following CDR perturbations to the ocean likely will be well resolved with ship- and shore-based analysis with high precision/accuracy, climate-level measurement uncertainties, the signal-to-noise ratio may be more challenging for distributed observing systems and autonomous platforms with lower precision/accuracy, more weather-level measurement uncertainties (Tilbrook et al. 2019).

Compared with terrestrial CDR strategies, MMRV of strategies in marine environments is inherently more difficult because the ocean is a turbulent fluid that stirs and mixes scalars. This creates challenges for two main reasons: (a) a concentrated signal will eventually be diluted to a level that is below measurement limits, and (b) perturbations to tracers such as added alkalinity, dissolved inorganic carbon, and the partial pressure of CO_2 gas (pCO_2) are effectively stirred into filaments that can be difficult to observationally resolve and can be transported far from the deployment site. For example, a patch with a plausible enhanced alkalinity will be stirred by surface-ocean currents and quickly deformed, stretched, and transported laterally, resulting in rapid dilution over a few weeks over large portions of the patch to near the uncertainty limit for autonomous sensor measurements. Ocean turbulence at the scales of kilometers to tens of kilometers can also act to remove tracers from the mixed layer into the ocean subsurface. This latter point is especially important as perturbations to the carbon system designed to reduce upper-ocean pCO_2 cannot enhance air–sea fluxes if the perturbation is transported to depth, an issue exacerbated by the long air–sea CO_2 equilibration timescales compared with surface-ocean dynamics.

Field observations from emerging biogeochemical autonomous platform technologies, augmented by numerical modeling and remote sensing where applicable, will provide valuable insights for marine CDR MMRV in a turbulent sea. A long-duration observational backbone can be created by using arrays of gliders, profiling floats and drifters, and moorings. However, due to operational constraints and costs, the observational array density may be relatively sparse and suboptimal without sufficient modeling support. For pulse-release experiments, denser autonomous arrays backed by ship sampling could be deployed for relatively short time periods. After release and before perturbed tracers are dispersed and diluted below detectable limits, it is advisable to leave a reduced number of autonomous observational assets in place to track longer-term responses to ocean carbon storage, air–sea CO_2 flux, and biological variables that may have response time lags. Observations are required inside and outside the perturbed patch to characterize baseline values and natural variability. For continuous-release experiments where tracer perturbation levels could be maintained for an extended period and growing patch size, experimental design and asset allocation will differ somewhat.

Measurement suites will vary depending on the CDR approach, with at a minimum the inclusion of the perturbation tracer (e.g., alkalinity, iron, upwelled nutrients, and macroalgal biomass), technique-specific responses (e.g., alkalinity loss from secondary mineralization, phytoplankton productivity, and export flux), and sufficient observations to constrain changes in ocean inorganic carbon storage and air–sea CO_2 gas exchange. Requirements include a minimum of temperature, salinity, pressure, and two of four inorganic CO_2-system variables (dissolved inorganic carbon, alkalinity, pH, and pCO_2). Standardized CO_2-system methods at climate-level uncertainty are available for discrete samples, surface underway sampling, and mooring pH and pCO2 (Sloyan et al., 2019; Wanninkhof et al., 2019). Substantial advances have also occurred for CO2-system and biogeochemical sensors on autonomous platforms, including profiling Argo floats and surface saildrones (Bushinsky et al. 2019).

While air–sea CO_2 flux is critically important for CDR MMRV (Bach et al. 2023), most studies will likely estimate rather than directly measure flux perturbations using air–sea pCO_2 data, wind speed, and empirical gas transfer parameterizations. Where feasible, air–sea flux estimates should be generated prior to the CDR perturbation and inside and outside the patch over a spatial region large enough to account for expected patch dispersion. Pilot studies using dual-tracer release experiments (e.g., $^3He/SF_6$) should be considered for validating gas transfer parameterizations for different systems. Simultaneous release of dye-like tracers (e.g., rhodamine, SF_6) can also be used to track water parcel motion and visualize three-dimensional patch dispersion. Surface-water horizontal motion can be diagnosed through satellite-tracked Lagrangian drifters, ideally deployed in strategic patterns to track evolution of pairs or triplets, and for coastal applications, high-resolution surface velocities can be measured by coastal high-frequency radar arrays that can be used to generate simulated parcel trajectories and locate areas of convergence or divergence where vertical motions might be important.

Numerical ocean models at different scales and levels of physical–biogeochemical complexity will be essential tools for marine CDR MMRV (Fennel et al. 2023). Model comparisons between control (no-perturbation) and perturbation scenarios can assess CDR efficacy and additionality for field experiments when combined with observational, statistical, and climatological baseline and natural variability estimates. Simulations also provide utility on longer timescales as patches disperse more widely and are subducted into the ocean thermocline. They can be used to track biological and biogeochemical interactions and feedbacks that occur far away from the CDR site. In addition, simulations can quantify deep-ocean perturbations where autonomous sampling capability is more limited and weaker CDR signals may be spread over a larger vertical water column. Models further help address the permanence or durability of uncompensated CO_2 released at depth, where sequestration timescales—the time before water parcels and excess CO_2 are returned to the ocean surface and contact with the atmosphere—are on the order of decades (thermocline) to centuries (deep sea) (Siegel et al. 2021). Coupling with regional mesoscale coastal and open-ocean models provides an avenue for assessing larger time/space aspects of CDR efficacy and additionality, and large-scale scalability and permanence questions will likely rely on global models already used for reconstructing past and projecting future ocean climate change, anthropogenic CO_2 uptake, and acidification.

Concluding Thoughts

While some aspects of marine CDR are relatively well understood, grounded in decades of basic ocean science, left unresolved are many applied questions on the science, engineering, and validation needed to determine whether some form of marine CDR can serve as a safe, effective, and scalable climate solution. Trade-offs exist for all CDR techniques across different evaluation criteria, but further research investment is likely warranted to support future deployment decisions if the studies are rigorous, independent, and transparent and include adequate support for in-depth MMRV and environmental impact assessment. Even though marine CDR is a fast-moving scientific field, rapid technology development (Cornwall, 2023; Service, 2024) and pressure to address mounting climate change damages may outpace our scientific understanding without a substantial ramp-up in marine CDR research.

Summary Points

1. Rapid decarbonization of the global economy, as well as potential carbon dioxide (CO_2) removal (CDR) deployment at a scale of billions of tons of CO_2 per year, is crucial for reaching net-zero human greenhouse gas emission targets and stabilizing global climate change.
2. Numerous abiotic and biotic marine CDR approaches have been put forward to enhance CO_2 removal and storage in the ocean, which already acts as a large sink of excess anthropogenic CO_2 from the atmosphere.
3. While some techniques may show promise, no marine CDR approach is ready yet for deployment at scale because of knowledge gaps on the science, engineering, validation, and environmental and social impacts of CO_2 removal and long-term storage.
4. Demonstration of safe and effective marine CDR requires targeted research on efficacy, additionality, and permanence as well as on engineering constraints such as scalability, costs, resource inputs, energy demands, and technical readiness.
5. Marine CDR methods typically do not directly remove CO_2 from the atmosphere; instead, they depend implicitly on the fact that perturbations internal to the ocean will enhance downward air–sea CO_2 gas flux into the ocean.
6. Progress on marine CDR depends on robust and transparent validation methods—measurement, monitoring, reporting, and verification—that incorporate field observations, autonomous platforms, remote sensing, and numerical modeling.
7. Assessment of environmental and socioeconomic impacts, public stakeholder engagement, and agreed-upon research codes of conduct should be a component of any marine CDR field testing.
8. Research and development efforts should emphasize bidirectional information sharing between experimental and demonstration-scale marine CDR projects and modeling frameworks, including regional and global ocean biogeochemical models and integrated assessment models.

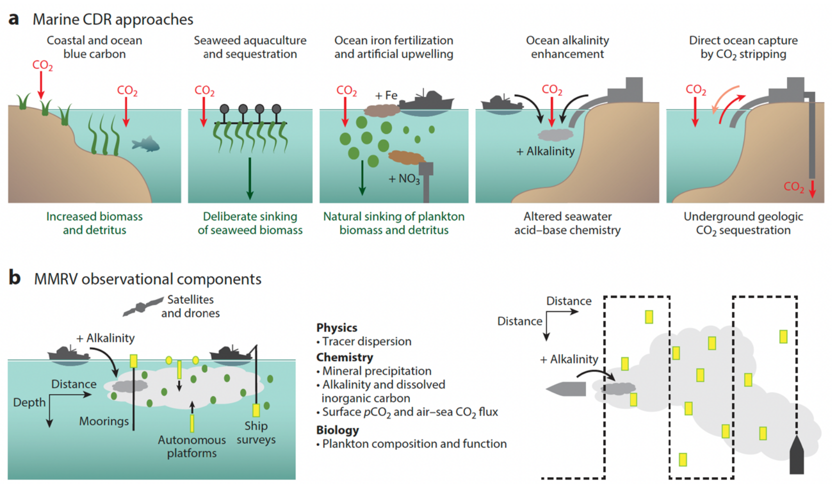

Figure: (a) Schematic of possible biotic and abiotic marine carbon dioxide removal CDR techniques. The downward red arrows mark carbon dioxide (CO_2) removal from the atmosphere into the ocean; depending on the method, carbon storage can occur in inorganic or organic carbon form and in the water column, sediments, or deeper geologic reservoirs. (b) Schematic of observational components for MMRV for an illustrative ocean alkalinity enhancement CDR field experiment. The two subpanels present a depth section (left) and horizontal plan view (right), with moorings and autonomous platforms such as biogeochemical profiling floats denoted as yellow symbols in the plan view. Abbreviations: CDR, carbon dioxide removal; nutrients, Fe for iron and NO_3 for nitrate; MMRV, measurement, monitoring, reporting, and verification. From Doney et al. (2024a).

Approach	Sequestration potential (Pg CO_2 y^{-1})	Cost (\$ t CO_2^{-1})	Efficacy	Durability	MMRV challenges	Social considerations	Environmental risk	Co-benefits
Biotic CDR								
Nutrient fertilization	0.1–1	<\$50	Medium–high confidence	Medium	Medium–high	Potential conflicts with international treaties on ocean dumping and protection of biodiversity	Medium–high (intended effect is to change surface-ocean biology; potential for undesirable geochemical and ecological consequences)	Potential enhancements to fisheries; surface-ocean decreases in acidity
Artificial upwelling and downwelling	<0.1	\$100–150	Low confidence	Low–medium	High	Potential conflicts with other uses	Medium–high (changes in ocean surface temperature and nutrient balances)	Localized enhancement of aquaculture and fisheries
Seaweed cultivation	0.1–1	\$100	Medium confidence	Medium–high	Low–medium	Potential for jobs in seaweed cultivation; conflicts with other marine uses	Medium–high (increases in acidification, hypoxia, and eutrophication in areas where seaweed is sequestered)	Colocation with aquaculture could alleviate environmental impacts; biofuels production
Ecosystem conservation	<0.1	<\$50	Low–medium confidence	Medium	High	Competition with other uses of coastal ecosystems	Low (generally positive impacts associated with increased biodiversity and ecosystem restoration)	Biodiversity and ecosystem services
Abiotic CDR								
Ocean alkalinity enhancement, including geochemical and electrochemical approaches	>1	\$100–150	High confidence	Medium–high	Low–medium	Expansion of mining; potential conflicts with international treaties on ocean dumping	Medium (unknown impacts of elevated alkalinity; potential for toxic effects of trace metals and reduced seawater clarity; mining impacts on land)	Direct amelioration of ocean acidification
Electrochemical ocean capture	0.1–1	>\$150	High confidence	Medium–high	Low–medium	Similar to alkalinity enhancement and other industry	Medium–high (local impacts associated with high salinity and pH at effluent discharge points; need to treat and safely dispose of excess acid)	Mitigation of ocean acidification; potential to colocate with desalinated water; H_2 and Cl_2 co-production

Table: Summary of marine CDR approaches. The CDR scalability reflects biophysical, geochemical, engineering, environmental, and social constraints for the potential deployment of a CDR method at climate policy–relevant scales. Note that the protection and restoration of coastal blue-carbon systems are not included in the ecosystem conservation row (NASEM 2019). Abbreviations: CDR, carbon dioxide removal; MMRV, measurement, monitoring, reporting, and verification. Table adapted by Doney et al. (2024a) with permission from NASEM (2022).

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Scott Doney, Professor, Department of Environmental Sciences, University of Virginia
Prof. Scott Doney's expertise spans oceanography, climate and biogeochemistry, with particular emphasis on the application of numerical models and data analysis methods to regional and global-scale questions. Much of his research focuses on how the global carbon cycle and ocean ecosystems respond to natural and human-driven climate change. Current areas of study include ocean acidification and carbon dioxide removal. He is the author of over 380 peer-reviewed research publications and co-author of a well-regarded graduate-level textbook on data analysis and modeling methods for the marine sciences.

Prof. Doney was the inaugural chair of the U.S. Ocean Carbon and Biogeochemistry (OCB) Program, a convening lead author for the Oceans and Marine Resources chapter of the 2014 U.S. National Climate Assessment, member of a number of National Academy of Sciences reports, and served on both the NSF Geosciences and NSF Environmental Research and Education Advisory Committees. He chaired the 2022 report on marine carbon dioxide removal by the National Academies of Sciences, Engineering, and Medicine. He is a past Director of the Ocean and Climate Change Institute and Chair of Marine Chemistry and Geochemistry Department at the Woods Hole Oceanographic Institution (WHOI). He served as the Assistant Director for Ocean Climate Science and Policy (mid-2022 to early-2024) in the White House Office of Science and Technology Policy (OSTP).

Prof. Doney was awarded the James B. Macelwane Medal from the American Geophysical Union (AGU) in 2000 and the Huntsman Award for Excellence in Marine Science from the Royal Society of Canada in 2013. He is a fellow of the American Geophysical Union (2000), Aldo Leopold Leadership program (2004), American Association for the Advancement of Science (AAAS) (2010), and the Association for the Sciences of Limnology and Oceanography (ASLO) (2021).

Prof. Doney graduated with a BA in chemistry from the University of California, San Diego in 1986 and went on his first oceanographic expedition in 1984 with Sea Education Association. He completed his PhD in chemical oceanography from the Massachusetts Institute of Technology/Woods Hole Oceanographic Institution Joint Program in Oceanography in 1991. He was a postdoctoral fellow and later a scientist at the National Center for Atmospheric Research, before returning to the Woods Hole Oceanographic Institution as a scientist in 2002. In August 2017, he joined the University of Virginia as the first Joe D. and Helen J. Kington Professor in Environmental Change.

Chairman MILLER. Thank you very much. I'd like to thank all the witnesses for their testimony this morning,

The Chair now recognizes himself for 5 minutes of questions.

Dr. Kapnick, most of the conversation around mCDR is in the context of oceans, but as I mentioned in my opening statement, the district that I represent borders Lake Erie, the 10th largest freshwater lake in the world. So I'm interested to know, is there potential for mCDR approaches to be utilized and scaled up in freshwater environments, including the Great Lakes? And can you walk us through any challenges that might exist when talking about ocean-based approaches versus freshwater approaches?

Dr. KAPNICK. Chairman Miller, I love this question as a Midwesterner myself who grew up in the Great Lakes.

Chairman MILLER. Nice.

Dr. KAPNICK. We do not have sufficient observational data to be able to constrain the amounts of mCDR capable in the Great Lakes right now, and so there is a need for additional observations and modelings for us to better understand what that is. It does hold potential. And a lot of the research outlined and the research that is necessary to develop mCDR could be applied in the Great Lakes region.

Chairman MILLER. Yes. Can you just touch on, if any at all, maybe some of the bigger challenges that we may face while moving into this?

Dr. KAPNICK. The challenges are ensuring that we have the observations to know how much is being sequestered. It's the importance of measurement, monitoring, reporting, and verification. And so that sensor technology, the automated technology that we can put into the Great Lakes would allow us to be able to create that information to know how much is sequestered, but then also use it in the models to model how it's moving around, predicting it months in advance, years in advance of how it may evolve in time. We need to build that robust program to be able to understand it and quantify what the value will be there.

Chairman MILLER. Thank you very much for the detail. It's very helpful for me, as I don't know everything, and it's impossible to and probably helpful for the Members on the Committee as well, so thank you very much.

Mr. Doney, you previously served in the White House's Office of Science and Technology Policy, OSTP, I'm familiar with it, where you oversaw the establishment of the mCDR Fast Track Action Committee. I too served in the White House, so I know how frustrating it can be to try to push interagency coordination with Committees. It's basically like herding cats. It's not that much fun. But can you tell us the general level of interest and engagement there is regarding marine carbon removal across the Federal Government? We obviously have DOE and NOAA sitting here today, so if you could maybe speak to anyone else who might be interested or isn't interested but probably should be.

Dr. DONEY. Yes, and I—of course, I'm back at a university, so I don't want to overstep from my Federal colleagues. I mean, there was a lot of interest when we developed the Ocean Climate Action Plan across agencies in climate solutions that were ocean-based, and that included marine carbon dioxide removal. So I think in addition to NOAA, there are a number of agencies that have a strong ocean science portfolio, so NSF (National Science Foundation), NASA (National Aeronautics and Space Administration). The Smithsonian has done a lot of work in coastal regions, but also there was interest from EPA, Army Corps. So I think there's a pretty wide space. Now, coordinating that, of course, is my colleagues' job.

But from the research perspective, I think one of the important things is how we would move forward in marine carbon dioxide removal in a way that complements the ongoing investments that we make in ocean science, and particularly documenting and quantifying the uptake of anthropogenic CO_2 that's already happening by the ocean. So we need to understand, is that continuing, would that be affected by other activities by climate change, and how do we integrate that across—how do we—would we integrate marine CDR into that existing framework?

Chairman MILLER. Yes, thank you very much. And just once again, thank you to all the witnesses.

You know, like I mentioned earlier, we have Lake Erie, one of the Great Lakes, right in our district. And moving into the subject matter of expertise, an area in which you all have a great depth of knowledge on, is exciting because we can actually help our area in the 7th District get a little bit better. So thank you for your time this morning.

I now would like to recognize Ms. Ross, the Ranking Member, for 5 minutes of questioning.

Ms. ROSS. Thank you, Mr. Chairman.

While marine carbon dioxide removal seems promising as a climate solution, the integrity of voluntary—of the voluntary carbon market must be carefully monitored. This will require thoughtful development of monitoring, reporting, and verification. I know Dr. Kapnick just alluded to this, MRV, and we need strategies to ensure that the claims of carbon uptake are trustworthy.

Dr. Doney, can you describe the current status of MRV approaches for marine CDR and also tell us what's challenging about quantifying ocean carbon uptake from the atmosphere.

Dr. DONEY. I think we're at a pretty good state in terms of understanding if we were to perturb the ocean to add alkalinity or ocean iron fertilization, which has been—there are multiple decades of experiments—we're able to quantify what happens on short time scales of weeks to maybe a couple of months. I think one of the real challenges is, as those signals get mixed and diluted away in the ocean, how do we monitor that on long time scales?

And it's going to be some combination of autonomous platforms. You know, NOAA has an excellent depth of expertise in autonomous platforms that can measure aspects of the carbon system, combined with numerical modeling. Because once we're gone, most of our work has been you go out on a ship, you do something for a few weeks, and you watch the perturbation. Months later, years later, this carbon needs to stay away from the atmosphere for many, many years. And one of the big challenges right now is, how long does water stay at the surface? Because I said what we're trying to do is modify the gas exchange. If that water gets subducted away from the surface, it's no longer in connection with the atmosphere. So that's a key area that a lot of both observationalists and modelers are working on.

Ms. ROSS. Great, thank you. And that's perfect—a perfect segue to my question for Dr. Kapnick. How would ocean observations need to be expanded to support mCDR MRV activities?

Dr. KAPNICK. We would need to be able to better model and constrain what is happening with the carbon in the ocean system, as was just mentioned by Dr. Doney. With this, it is—it depends on the scale of the activities and where we plan to do them. But to create a really robust system of understanding, we need more ocean observations, particularly our autonomous observations, to be able to know where carbon is moving through the system.

The goals of it are at least 100 years of sequestration into the ocean system, so we need to be able to model that out with the observations that we have as they go in, but also our observing system over—our modeling system over time, predicting where that is going to go, where in the currents, where in the column of the ocean. But then, to do that, and to do our—to do types of pilot studies and modeling and understanding the ocean, we need to have observations at those different depths of the oceans to be able to track it and understand it and also give predictive capabilities of where things will go into the future.

Ms. ROSS. And that costs money.

Dr. KAPNICK. Yes.

Ms. ROSS. Just pointing that out. We—you might need some more money because we talked about the bill, and I know that there's no additional funding in the bill, so—great.

So my final question is for Dr. Kapnick and Mr. Deich. I had the good fortune last year of going to Norway to visit Equinor's Northern Lights carbon storage terrestrial carbon capture project. And I know from my previous conversation with Dr. Kapnick that there are demonstration projects that deal with mCDR in Singapore and Canada and the U.K. So how can the Federal Government responsibly collaborate with other nations to advance mCDR research and development?

Dr. KAPNICK. Importantly, on the science side, we have our scientists' collaboration and working across the world on these types of problems. Part of the reason we're seeing these projects go overseas is they are providing incentives to companies to go there. And so here in the United States, important parts of the protection of that and—of the field and the development of technology, we've been working with U.S. Patent and Trademark Office to make sure that there is patent protection for these things, so if they are also going overseas, that they have that protection.

Mr. DEICH. And I'll add, from the DOE's perspective, we enjoy great bilateral collaboration on the R&D side with many of those nations that you mentioned, but also through the mission innovation platform, there is a dedicated carbon removal working group, and they are exploring how we can harmonize the standards for measurement, reporting, and verification across that system. And so I think there are opportunities internationally to work both bilaterally and multilaterally to advance this field responsibly.

Ms. ROSS. Thank you, and I yield back.

Chairman MILLER. Thank you, Ms. Ross.

I now recognize Mr. Bowman. Excuse me. I now recognize Mr. Williams. My apologies. Rough morning for me, huh?

Mr. WILLIAMS. It's New York either way.

Chairman MILLER. That's true.

Mr. WILLIAMS. Good morning. Thank you for your testimony.

Dr. Kapnick, one of the effects of the increasing levels of CO_2 in our atmosphere is said to be increasing the acidity of the ocean. Can you talk about that, the effect of increasing acidity in the ocean?

Dr. KAPNICK. Yes, increasing acidification in the ocean, so that is, as the carbon dioxide in the atmosphere is absorbed into the ocean, the sea water becomes more acid. This has documented negative impacts on ecosystems and marine life. One of the most well-known examples of that that's very visual is the change in shell formation, the ability of shells to form. And so we see these effects on small plankton and small animals, but we also are seeing it in larger and larger animals, in Dungeness crab and different types of shellfish. And that can affect the entire ecosystem as it continues, which is why marine carbon dioxide removal also can play an important role because one of the co-benefits of it is that, particularly ocean alkalinity enhancement can have a local impact that reduces that local acidification.

Mr. WILLIAMS. Isn't the purpose—and forgive, this is an honest question—isn't the purpose to actually sequester CO_2 from the atmosphere into the ocean, isn't that the purpose of mCDR?

Dr. KAPNICK. MCDR's primary purpose and the reason we're talking we're talking about it is the removal of carbon dioxide from the atmosphere and sequestration. But one of the——

Mr. WILLIAMS. Into the ocean.

Dr. KAPNICK. Into the ocean.

Mr. WILLIAMS. OK.

Dr. KAPNICK. But one of the co-benefits of that would be you can have local reduction in acidification. So you add crushed limestone and impacts into the ocean or through electrochemical processes, you actually reduce the local CO_2 in the ocean, which then can also counter those effects of the rising acidification due to the natural processes. So this is actually——

Mr. WILLIAMS. I actually know a lot about cementitious chemistry and materials. So, again, just to make sure I understand—excuse me—that we are looking at ways of affecting the ocean to absorb more CO_2, and then we're going to treat the ocean with things to raise the pH, the calcium oxides to actually mitigate the effect of having just increased the acidity of the ocean. Is that correct?

Dr. KAPNICK. The——

Mr. WILLIAMS. I'm pretty sure that's just what you said. I think—if I mischaracterized that, I'd like to know.

Dr. KAPNICK. It's not—so also with the biological capabilities of mCDR, it is taking that into storing in biology, so in seaweed, in nutrient fertilization, into biology that then sinks to the ocean floor. And so it's removing it from the surface ocean and from the atmosphere, storing it away in a biological sense that then sinks to the bottom.

Mr. WILLIAMS. But not necessarily transferring it directly to the water?

Dr. KAPNICK. Correct.

Mr. WILLIAMS. You said it's bound, perhaps, in seaweed, et cetera?

Dr. KAPNICK. Yes.

Mr. WILLIAMS. OK. You know, it's interesting. You brought up Dungeness because the Dungeness Spit, which is right next to Sequim Bay, which is right next to Port Angeles, is also right next to Admiralty Inlet and the Strait of Juan de Fuca, where my submarine operated. And I have a lot of time going in and out of those waters and have spent a lot of time even in Sequim Bay in particular. And that was actually Dr.—or, Mr. Tarbell, the—can you describe a little bit more about how calcium oxide is added to the ocean to counteract these—the effects of mCDR?

Mr. TARBELL. Yes. So in Ebb's process, we have an electrochemical system that removes acid from the ocean, so we're not adding calcium oxides. Instead, we're removing acid. And, as we do, it enables the ocean chemistry to shift to convert CO_2 to bicarbonate.

Mr. WILLIAMS. So you're binding acids basically in the oceanwater, but it's an additive product that you're adding to——

Mr. TARBELL. We're returning deacidified ocean—so oceanwater back to the ocean. We separate acid from the oceanwater, and then we remove——

Mr. WILLIAMS. If I may, just for the last few minutes, either Mr. Deich or Dr. Kapnick, can you talk about the national security—I'm sorry to cut you off—but the national security implications that you mentioned just in the last few seconds? What specifically are you concerned about for national security and the role that mCDR can play for that?

Dr. KAPNICK. With so much interest in what—the investments that we're seeing overseas, particularly in China with over $300 million over the next 15 years to develop this technology, we will—we need to continue to advance our technologies and ability in the United States to both have this technology ourselves, but also with the observing system and information around the ocean to be able to know if other actors are able to sequester when they start making claims about this. If we don't have the observing and modeling systems, we will not be able to know if the claims are true or not.

Mr. WILLIAMS. Thank you very much. I yield back.

Chairman MILLER. Thank you, Mr. Williams.

I now recognize Mr. Bowman.

Mr. BOWMAN. Thank you, Mr. Chairman.

Mr. Deich, the DOE is no stranger to community engagement for projects in sensitive ecosystems. Can you describe how DOE and their labs would involve the local community and ensure that their concerns are heard before conducting any marine carbon dioxide removal demonstration projects?

Mr. DEICH. Yes. Thank you, Mr. Bowman.

So for all of our projects, the Department of Energy requires community benefit plan frameworks to be considered. These are multifaceted processes to both engage the communities and really understand not just the environmental impacts, but the broader social, economic, and workforce impacts of these projects. We think that's a critical element of our program evaluation and project evaluation specifically, alongside the more conventional, technical, economic, and other considerations we have. So that's embedded in our project evaluation framework.

We've also released responsible carbon management principles, which we hope will help inform developers across the carbon management space, including the marine CDR space, as just a starting point for how they can engage with communities and what communities are expecting from them in terms of engagement and making sure that projects are done responsibly.

Mr. BOWMAN. Thank you.

Dr. Doney, what type of negative impacts of mCDR should cause researchers to stop and reassess or consider ceasing development of a given mCDR approach? In other words, what are some possible showstopping issues for mCDR?

Dr. DONEY. Some of the areas that we still have uncertainty is, as we perturb the ocean, how is it going to affect marine life, and particularly marine life that's, you know, protected species or commercial fisheries or other parts of the ecosystem that are culturally or economically valuable. So I think it's hard to say where that line is and a showstopper because, of course, there are going to be tradeoffs. Any aspect of carbon dioxide removal will have tradeoffs.

But I think what—right now, what we need to better understand is, for example, alkalinity enhancement. You know, how is that going to affect organisms? As Dr. Kapnick talked about, there's been a lot of work by NOAA on looking at how organisms respond to acidification. There's been less work on the opposite side. If you add alkalinity, you make the water more basic. What's going to be the impact short term and long term on organisms?

Mr. BOWMAN. Thank you. And last, Dr. Kapnick, what are the most pressing concerns about the impact of mCDR on the marine environment? How can we monitor for these impacts in the research and development process so that they can be properly mitigated or avoided?

Dr. KAPNICK. Yes, and that's why I know it's critical in this space due to our mission of stewardship. It's—we not only monitor what is the ocean chemistry, modeling where the carbon is, where it's moving through the system, but it is also our mission of fisheries, of the ecosystem health, of ensuring what we are doing doesn't have impacts and being able to have an understanding and tracking of what those impacts might be. And it's not only out in the ocean, but we also—in all of our work we do laboratory tests and understanding. And we have—I welcome any of you to come to our laboratories that have coral reefs where you can actually go see the corals, where we understand how they're affected by acidification and different factors. We actually have them in tanks.

So we are able to do the end-to-end research on what is happening with ecosystems to understand it and then use our models to also envision future worlds and what may happen in future worlds to be able to assess that further. And so it's—having a holistic fundamental research program is critical to understanding this problem and what it will look like into the future to be able to answer all the questions that you have. Thank you for your question.

Mr. BOWMAN. Thank you.

Thank you, Mr. Chairman. I yield back.

Chairman MILLER. Thank you, Mr. Bowman.

I now recognize Mr. Kean out of New Jersey for 5 minutes of questions.

Mr. KEAN. Thank you, Mr. Chairman. And thank you to all of our witnesses for being here today.

Marine and ocean technologies provide Americans with significant benefits across numerous industries, contributing $432 billion in goods and services to the United States economy and supporting nearly 2.3 billion—excuse me, 2.3 million jobs annually, according to NOAA. Dr. Doney, how do investments into developing marine CDR technologies benefit Americans outside of emissions reduction potential?

Dr. DONEY. I think that depends if some of the approaches have co-benefits. You know, we've—we know quite a bit now about the sort of coastal blue carbon space whereby protection and restoration of carbon-rich marshes and seagrasses we could actually provide, you know, huge conservation benefits, biodiversity benefits, and also carbon removal. One of the areas of research we need to pursue is, are there similar co-benefits, for example, by expanding—you know, protecting seaweed beds, natural seaweed beds.

For things like alkalinity enhancement, some of the electrochemical approaches actually generate co-products. Some of the companies out there, through the electrochemical approaches, are generating, for example, hydrogen. And so we need to look at what these co-benefits are and see how they fit in.

Some of the country—companies that are pursuing direct ocean capture are looking at reusing that carbon dioxide, so rather than sequestering it, bringing it back into the economy. So you'd have to balance out, you know, how much carbon is removed, versus what are these economic and other co-benefits that might occur.

Mr. KEAN. And what are some of the economic benefits for States that—and entities that do invest in this type of technology? And how could more research help understand these benefits?

Dr. DONEY. Well, as Dr. Kapnick and Dr. Deich have noted, you know, we need to observe the ocean, both in its current state and for marine carbon dioxide removal. These are very advanced technologies. I work a lot with folks at Rutgers who have developed glider technology for measuring off the continental shelf, adding new sensors. We could be at the forefront of these autonomous platforms and sensors. We've done a lot of the work already, but we need to maintain that position. And the sensors that are developed have lots of other marine applications, so I think an investment in this technology could really expand our ability to work in that space.

Mr. KEAN. In your testimony, you state that there are—tradeoffs exist for all CDR technologies across different evaluation criteria, but further research investment is likely warranted to support future deployment decisions. With that in mind, in the broader conversation of carbon dioxide removal and emissions reductions, are there any particular removal techniques that you would say do not warrant future deployment, and if so, for what reasons?

Dr. DONEY. I guess I'd say the—I'd maybe frame it as the techniques that I think show real promise. I think some of the alkalinity approaches—because—you know, the reason why the ocean takes up carbon dioxide from the atmosphere anyway is because it's alkaline. And in fact, the long-term fate of all the carbon we emit to the atmosphere, almost all of it will eventually end up in the ocean because weathering products add alkalinity to the ocean. So in that sense, the more geochemical approaches are just accelerating an ongoing natural process, speeding up the ocean uptake. And I think there's a lot of promise there.

Mr. KEAN. OK. Thank you.

And, Mr. Tarbell, in your testimony, you state that public-private partnerships have the potential to advance the field as it relates to the safety and efficacy of marine carbon dioxide removal. To date, what advancements have you seen in this space already, where the private sector is making a difference in mCDR that the Federal Government could not on its own?

Mr. TARBELL. So this has been the focus of our collaboration with NOAA and DOE and in our work at Pacific Northwest National Labs, and it's focused on the science of safety. It's focused on the science of efficacy, of proving that we're pulling CO_2 out of the air. Excuse me. And I think what private industry does well is innovation and pace of scale. And what the government is proving to do well is supporting basic research, supporting science, supporting guardrails and guidelines. And so the collaboration between the two is helping us advance a solution that has promise.

Mr. KEAN. Yes. OK. Thank you. I yield back.

Chairman MILLER. Thank you, Mr. Kean.

I now recognize the Ranking Member of the Full Committee, Ms. Lofgren, for 5 minutes of questions.

Ms. LOFGREN. Thank you, Mr. Chairman.

First, I'd like to ask unanimous consent to put my statement into the record.

Chairman MILLER. Without objection, so ordered.

[The prepared statement of Ms. Lofgren follows:]

Good morning and thank you, Chairman Miller, Ranking Member Ross, Chairman Williams, and Ranking Member Bowman, for holding this important hearing today.

I believe that marine carbon dioxide removal, or m-C-D-R for short, has the potential to play a significant role in our nation's and indeed the world's efforts to mitigate and even reverse the growing impacts of the climate crisis. That is why I am very happy that this Committee has worked together in a strong, bipartisan fashion to craft this hearing, and to put together draft legislation that considers both the costs and benefits of these proposed solutions.

And I do want to be very clear about this: we do not yet know if the projected benefits of any of the approaches to m-C-D-R will outweigh their possible environmental risks. That is precisely why we need a robust research program to better inform policymakers regarding the pros and cons of potentially employing m-C-D-R methods and technologies in our fight against climate change.

I also want to be clear that while I am quite supportive of developing and using any safe, verifiably effective technologies that could substantially remove harmful greenhouse gas emissions from our atmosphere, this is no substitution for the urgent need to decarbonize our energy use as quickly as possible. The problem is far too large at this point for us to sufficiently address it through carbon capture alone.

Further, several carbon removal technologies are quite energy intensive, and will need widely deployable, zero-emission sources of 24/7 power like fusion energy to actually be effective in reducing net carbon emissions. This is yet another reason that we need to be fully funding the Science part of the *CHIPS and Science Act.* We've certainly made a lot of progress, but I believe that the next generation of technologies will be absolutely essential in ensuring our clean energy future. And to get there, we need to put our money where our mouth is.

With that, I would like to thank you all again for being here. I'm looking forward to a productive discussion this morning, and I yield back.

Ms. LOFGREN. And then I'd like to say I think this is one of the most important hearings that the Science Committee has had this year and maybe in many years.

We're at a point where eliminating emissions is not enough. We're going to need to remove carbon to have a future as a planet. We know that. And the role of carbon removal in our oceans is an important one, but not an easy one.

Listening to all of you and reading your testimony, you know, we've got a situation where the ocean itself is in trouble. I mean, we've seen the reefs dying off, and that will have implications for the planet in terms of food supply and the like. How we are going to remove carbon safely and permanently is something that we're grappling with.

Now, one of the things that I'm interested in, Mr. Deich, if that—I hope I'm pronouncing your name correctly. I'm wondering, has the Department done any analysis on which mCDR technologies are likely to be the most energy-intensive? And I'm also wondering if we've examined the value of potential future clean energy sources like fusion, which this Committee, on a bipartisan basis, is working hard to support. I ask that because, it's successful, fusion would be able to provide large amounts of 24/7 energy anywhere without an emission problem. What is your answer to that?

Mr. DEICH. So it's a great question. We haven't looked specifically at a ranking of which of these technologies are most energy efficient, but instead are really focusing our strategy for innovation to understand the energy balance associated with a wide range of technologies. Our goal is to assess not just the energy impacts, but a wide range of performance and environmental impacts of these technologies and, as we learn more from early R&D efforts, use that information to inform future pilots and then larger-scale demonstrations as appropriate.

We also are pursuing, as a department, many different clean energy solutions. The Earthshots represent—our Moonshots in that direction. We've explored how we can work with carbon removal more broadly to some energy sources like nuclear, but we have not done specific analysis on how they could couple to marine CDR approaches yet, but it's an area of importance and one that we think is worthwhile pursuing in the future.

Ms. LOFGREN. Well, I'm wondering if any of you can answer how we calculate, if at all, the net removal of carbon dioxide for the various mCDR technologies, even land-based CDR technologies, related to emissions for the energy source that might be used. I mean, you know, if we're using fossil fuels to support this, we're defeating ourselves. How are we calculating that?

Mr. DEICH. So whenever we think about the carbon impacts of a technology, we look at the what we call cradle-to-grave lifecycle impacts, and so we try and understand all of the upstream emission impacts, as well as the carbon storage benefits of this for all of our approaches. And DOE has published guidelines for some carbon removal solutions. We hope to expand that in the future. And we also support our national labs to conduct analysis on that topic and are eager to support a wide range of carbon removal solution efforts to make sure that we do capture all of the upstream and downstream impacts of these technologies.

Ms. LOFGREN. Mr. Tarbell, thank you so much for your testimony and for the work that you're doing. How do you ensure that the energy used for mCDR comes from clean energy sources? And, additionally, if you are using clean energy sources, that that is not diverting clean energy from other uses so that they would need fossil fuels, can you address that?

Mr. TARBELL. Yes, so our approach, starting with first principles, is one of the lowest energy-intensity approaches to electrochemical marine CDR, and so we start by using less energy. When we use energy, we can use it intermittently, so our system is quite flexible, and that's intentional in order to accommodate low-carbon sources of energy that are prevalent today like wind and solar. We can essentially use industry best practices to account for the hourly energy, you know, carbon intensity on the particular node of the grid that we're operating. And so we can essentially sum up the carbon emissions associated with that generation and then subtract that from what we have removed from the atmosphere.

Ms. LOFGREN. You're not able, I'm sure, to monitor diversion of those energy sources from other potential uses?

Mr. TARBELL. One of the intriguing possibilities here is because we're operating intermittently, because we can be flexible in the way that we demand energy, we can actually support the growth of intermittent sources like wind and solar. So instead of necessarily taking away from the production of low-carbon energy, we can actually stimulate the growth of wind and solar on the grid.

Ms. LOFGREN. I could see that, as a concept that makes sense, but it's not a monitoring scheme. So I look forward to further research on this.

And I know my time is up, so I yield back, Mr. Chairman.

Chairman MILLER. Thank you, Ms. Lofgren.

I now recognize Mr. Fong out of California for 5 minutes of questions.

Mr. FONG. Thank you, Mr. Chairman.

Mr. Deich, you mentioned—is that how you pronounce—yes, all right. You mentioned the need for a strong and science-driven market for carbon credits in your testimony. Broadly speaking, what are some of the challenges right now with the voluntary carbon market at present where science-driven decisionmaking is not necessarily occurring?

Mr. DEICH. Yes, thank you. I think when we think about the voluntary carbon market, the product that we're really delivering is integrity. Without that integrity, nobody believes that the carbon that you're claiming is real, and that credit has very little value. And so our Administration has committed to a set of voluntary carbon market principles really focused on additionality, permanence, a number of criteria about ensuring that all carbon market credits in the voluntary context are done with the highest integrity possible.

We see a significant opportunity for CDR approaches to have really high integrity. And at DOE, that's really where we contribute to the voluntary carbon market. And many of our investments are designed specifically to that. The Chairman mentioned our ARPA–E program really focused on making sure that the sensors and modeling are robust for these technologies because we see that as equally important as the actual technology development itself.

But the flip side of that coin is that the voluntary market is still far too small to support carbon removal at the scale that we ultimately will need and in—critically in the near term for it to commercialize. So one of the key things is to make sure that not only we do technology development and really robust measurement reporting and verification, but that corporate leaders continue to step up and invest more in these high-integrity credits, even if they cost more than what the market has historically paid for carbon credits, knowing that that integrity is really robust.

Mr. FONG. So that leads to my next question, which is, given your experience working in carbon capture removal in both of the private sector and now at the Department of Energy, you know, can you explain what warrants Federal investment in marine carbon dioxide removal? Like in what—in other words, what does the Federal Government stand to gain through the millions of dollars being invested in this type of R&D?

Mr. DEICH. So I think investment in this field can provide a number of really important benefits. The first is expanding our toolkit as we think about how do we actually achieve the carbon removal outcomes that we need and making it more accessible to a broad community of stakeholders across the United States.

The second piece is the co-benefits that have been mentioned. And if we can figure out how to deliver carbon removal really responsibly, in many cases, we can unlock a wide range of co-benefits, as we've heard here from local reduction in ocean acidification, potentially helping bring on more clean electricity to the grid, as well as many other local benefits to ecosystems. And only by investing in that early stage R&D will we be able to figure out how to do that in a responsible manner.

Mr. FONG. And my last question, certainly, this hearing is focused on marine carbon dioxide removal. How do you how compare it to other carbon capture technologies?

Mr. DEICH. So when we think about the carbon removal portfolio, we are not trying to pick winners at the Department of Energy. We've actually worked with Livermore National Lab to produce what—a report called the "Roads to Removal" report. And if you think about carbon removal broadly, there are opportunities across almost every county in the United States if you think broadly.

And so what we're trying to do is encourage technology development across a lot of different pathways. There are still uncertainties across all of them, and our work is designed to try and minimize some of those uncertainties and make sure that there are opportunities for the communities across the United States.

Mr. FONG. Got you. So versus air—direct air capture or this or that, you're agnostic in terms of what that would—what would be the benefits?

Mr. DEICH. We don't think of it as versus. We think of it as yes/and. Direct air capture has a role in many communities, ocean CDR and others. If we can figure out how to develop those in parallel, it will enable us to deliver the overall CDR outcome more effectively.

Mr. FONG. I certainly appreciate that.

Mr. Chairman, I yield back.

Chairman MILLER. Thank you, Mr. Fong.

I now recognize Ms. Bonamici from Oregon for 5 minutes of questions.

Ms. BONAMICI. Thank you. And thank you to the Chairs and the Ranking Members, but especially to the witnesses.

I represent a significant portion of the Oregon coast. I also cochair the Oceans Caucus and have served on this Committee for years, working on a bipartisan basis on both ocean acidification legislation and blue carbon legislation, so I'm grateful for the conversation today.

More recently, I've been working with Mr. Tonko of this Committee on a—the best approach, science-based approach to strengthen Federal mCDR research to provide robust community engagement, including community benefit planning, which I know came up this morning, and to build a foundation to really evaluate these technologies for future development. And I look forward to working not only with Mr. Tonko, but others on this Committee, with NOAA, and other stakeholders as we introduce this bill. Also, we're watching—which I understand is coming out soon—for the Fast Track Action Committee's report and recommendations, hopefully soon.

And I know that some of these issues have been addressed, but I want to really dive in. Dr. Kapnick, thank you for being here. I know with a—with Dr. Spinrad being an Oregonian, he's very familiar with this important work. As we've discussed, mCDR has great potential to remove emissions, but we have to be mindful, of course, weighing the climate advantages and potential environmental and community consequences. Potential harms could be localized, especially on research sites in coastal communities, affecting residents, fisheries, coastal tribes.

So what can NOAA and the scientific community do to build trust with stakeholders and community members? Which of these actions—and we want, you know, to include compliance. What would you do to include compliance with the marine CDR research code of conduct? And what role should NOAA play to really facilitate that community engagement, including providing the expertise and permitting for future research and testing?

Dr. KAPNICK. First, thank you very much for your question and for all of your leadership on ocean issues, especially on ocean acidification. I—especially with this question—thank you for allowing me the opportunity to talk about communities and the work that NOAA does, particularly with Sea Grant, where we have the engagement capacity in coastal States to be able to work with them on the engagement. It is critical for this type of work. It's critical for the development of the research plan when it's happening in our universities, but as it goes into the communities and as we experiment and then beyond, we need to work with all the communities on understanding the science, understanding what is being done, the impacts, and working hand in hand with them.

Additionally, on the question of permitting, EPA and U.S. Army Corps of Engineers are the leads on permitting, and NOAA consults on those, as required by law. So it's important for us to have our deep research program to be able to provide all the support that we need to in the engagements that we do in local communities.

Ms. BONAMICI. Thank you. Thank you for mentioning the great Sea Grant program.

And I want to ask Mr. Tarbell, you mentioned you're working closely with local communities. Briefly, because I might want to get a question—another question in, what are you hearing from them?

Mr. TARBELL. Yes. So coastal communities are some of the most impacted by climate change, as you know, and so, you know, as we talk to them, we are understanding some of the potential tangible benefits to them. Ocean acidification is affecting local industries. You know, the shellfish industry in the northwest, Pacific Northwest——

Ms. BONAMICI. I'm very familiar with that word.

Mr. TARBELL. Yes, had to, you know, lose billions of oysters in the last 20 years. And so, you know, the opportunities we're seeing are around helping mitigate ocean acidification, keeping homegrown innovation at home, rejuvenating local industrial sites that we'll be locating at. But, yes, there's a——

Ms. BONAMICI. Thank you. And I might need to follow up on the record because I want to ask Dr. Doney.

As you noted, natural-based solutions like blue carbon are more well understood. We understand the benefits. We have existing processes in place, but other methods like the ocean alkalinity enhancement or direct ocean capture require, certainly, a lot more research. So how can we guarantee that research is precautionary and doesn't lead to more environmental or social harm? And what guardrails should we have in place to enforce that?

Dr. DONEY. Well, I think one of the things that the Federal Government is already doing is playing a role in setting up rules for permitting that, as we move from small-scale lab experiments to mesocosms to field pilot studies, we have the right framework. Are we doing the right validation? Are we looking at environmental consequences? Are we engaging with local communities that might be affected?

So I think one of the things that the Federal Government can do in terms of private and philanthropic approaches is to lay out those clear guidelines and rules, and I think that's what the agencies are doing. I look forward to seeing the Fast Track Action Committee report as well.

Ms. BONAMICI. Yes, thank you. As someone who's experienced this over the last more than a decade, I just can't emphasize enough the importance of that community engagement with the stakeholders, with tribes, and others. So thank you.

I'm out of time and yield back.

Chairman MILLER. Thank you very much.

I now recognize Mr. Baird out of Indiana for 5 minutes of questions.

Mr. BAIRD. Thank you, Mr. Chairman. And I appreciate the witnesses being here.

My questioning starts off with Dr. Kapnick. You know, earlier this year, I passed the *Carbon Sequestration Collaboration Act,* a first-of-its-kind Federal research plan that required the Department to collaborate with, coordinate with, and share data with other agencies engaged in carbon sequestration research. Collaborating agencies include the Department of Agriculture, the National Labs, the U.S. Forest Service, just to name a few.

So in light of NOAA's intent to engage in carbon sequestration with our oceans, can you give us some idea on your perspective on the importance of the collaboration with these agencies in sharing data, in coordinating research plans?

Dr. KAPNICK. Absolutely. Thank you for the question. We—all of our data and information that we produce abides by our principles for transparency and making it available, interoperable, being able to find it. We see an importance in building the infrastructure for that data management and availability. And in this field in particular, due to the importance in the equities of Department of Energy, we pursued an MOA with them to be able to help us outline how we should work together and to be able to launch that capability for working together. And I will even add, we even have a Sea Grant fellow working between our agencies as a fundamental glue to ensure that we are working as closely together as we can.

Mr. BAIRD. So any other witness have anything you'd like to add to that? Yes, sir?

Mr. DEICH. So from the Department of Energy's perspective, we have a long history with carbon sequestration on the terrestrial side. The National Energy Technology Lab has done an amazing job of creating the EDX (Energy Data eXchange) platform to share a lot of that learnings, and it has benefited industry. And so I think the lab in particular has amazing capabilities to be able to deliver on that transparent data-sharing across the carbon sequestration world.

Mr. BAIRD. Well, you know, you have—I really—I'm really impressed with the amount of computer capability and quantum computing that the Department of Energy has, and then to share that data across different agencies, I think, increases efficiency and provides opportunity to discover additional pieces of information that we might not have now.

So, Mr. Deich, is that—if I pronounced that correctly, since you spoke up, I'm going to ask you a question. The Department of Energy's Fossil Energy and Carbon Management has invested in a number of ocean-based carbon management R&D projects and a number of projects that are located in States without an ocean on their borders such as Pennsylvania, Kentucky, and North Dakota. So could you talk to us about the value of marine CDR research to all States like Indiana, for example, with a number of world-class research institutions not just near the ocean?

Mr. DEICH. Yes. So the Department of Energy works with world-class researchers, not just at our national labs, but across academic institutions around the United States. And there's actually amazing expertise on the ocean, not necessarily located in coastal States, as you mentioned. And so I think there's an amazing opportunity to link many of those world-class research institutions with some of the early research and development projects that we're doing in order to understand how these projects work, not just from a technical and economic perspective, but from all of the other ecosystem and environmental impacts.

Mr. BAIRD. Thank you. Does any other witness have anything to add to that?

Hearing none, I yield back.

Chairman MILLER. Thank you, Mr. Baird.

I now recognize Mrs. Foushee out of North Carolina for 5 minutes questions.

Mrs. FOUSHEE. Thank you, Mr. Chairman. And thank you to the witnesses for being here with us today.

I represent North Carolina's 4th Congressional District, and while my district does not represent coastal communities, North Carolina has over 300 miles of coastline that play a vital role in the country's economy, including soon-to-be energy development within offshore wind sector.

Dr. Kapnick, in addition to Federal interagency coordination, can you talk about the interstate cooperation and collaboration that needs to take place, specifically amongst coastal States like mine, to ensure that marine carbon dioxide removal research and development is executed effectively?

Dr. KAPNICK. Thank you very much for your question. Because we're working with the ocean and there are ocean currents, things move around. Ecosystems move around. Whales move around. Having knowledge and building up the understanding and working across all of the States is absolutely critical as we are able to predict and project where things are moving and the lifecycle of carbon over time.

I will also add something that hasn't come up is there is an entire supply chain potentially for this technology coming from Department of Commerce. It—the benefits won't just be in the coastal States because the whole—if you looked holistically at the supply chain of what is needed to do these activities, it may include economic development that can occur far from the coast.

Mrs. FOUSHEE. Can you describe any current or planned interstate regional collaborations with Federal agencies on marine carbon dioxide removal?

Dr. KAPNICK. Sea Grant—thank you for the question. Sea Grant is actually setting up a law and policy symposium and—on mCDR that will be occurring in a couple of months, and the reason for that is we are seeing interest across different Sea Grant programs. And so they are bringing that together to have the discussion across all the programs and do the community outreach on this issue on legal and policy issues to think through some of those hard issues that you're raising.

Mrs. FOUSHEE. Thank you. And, Mr. Chairman, I'll yield back the balance of my time.

Chairman MILLER. Thank you very much.

I now recognize Mr. Weber of Texas for 5 minutes—excuse me. Yes. Yes. I will now recognize Mr. Weber of Texas for 5 minutes of questions.

Mr. WEBER. Phew, thanks. All right.

Mr.—is it Deich or Deich?

Mr. DEICH. Deich.

Mr. WEBER. Deich, thank you. I appreciate you being here.

In October 2023, DOE announced funding for 11 projects across eight States. I'm sure you know that. I feel like I'm telling Noah about the flood. One of those projects housed at the University of Texas in Austin will study the ecosystem activity and the efficacy of storing carbon in shallow seagrass beds. Given the importance of diverse ecosystems that support recreation and the economy across my district—I'm the three really coastal counties, starting at the Louisiana border, that other foreign country, and going down, those situated along the Texas Gulf Coast. Our ecosystem that supports recreation across my district situated across the Texas Gulf Coast, are you able to share with us any updates on that particular project?

Mr. DEICH. Thank you for the question. I don't have specific updates on that project, but I can say that where we are starting our research at DOE is really not just understanding the technology, but understanding exactly those impacts to communities from an ecosystem and economic perspective as well because we recognize how important that is. And from the very beginning of these research projects, we want to understand what those impacts will be so we can inform future deployments.

Mr. WEBER. Well, we do, too, given all the recreation and this—and the—and actually the economy that's from our seven ports. I guess we could probably reach out at the University of Texas there in Austin, maybe get an update on what they're finding.

What role do you see for the Gulf of Mexico in the development of marine carbon dioxide removal, both in testing and implementation going forward?

Mr. DEICH. Yes, it's a great question. I think one of the important aspects of the diversity of marine carbon removal solutions is some work better in cold waters, other in warm waters, and the fact that the United States has opportunity to test both is really important, as well as in shallow versus deep water ecosystems. And so I think it's going to be a critical field where we're able to test many of the carbon removal approaches that work best.

Mr. WEBER. Yes, I was wondering about that with your exchange with the lady before me. I think she says she's from North Carolina. Of course, that's—Gulf of Mexico is a lot warmer water than, of course, Atlantic Ocean is.

Mr. Doney, in your testimony, you describe potential benefits to the ecosystems and marine life from using different techniques. For example, in referencing ocean alkalinity enhancement, you stated, quote, "The resulting pH increase would also directly counteract anthropogenic CO_2-induced ocean acidification that is negatively impacting marine ecosystems," end quote. You're—you know what I'm referring to? OK. I was a little late getting in because I was with Energy and Commerce, so I didn't get to hear everybody's testimony.

Mr. Doney—is it Doney?

Dr. DONEY. Yes.

Mr. WEBER. OK. Can you expand on the potential benefits of marine carbon dioxide removal and any potential pitfalls? You know, we want to also know that—we want to know not just the good, but the bad. This is one of those good, bad, and ugly movies. Expand on potential benefits of marine carbon dioxide removal and any potential pitfalls to these ecosystems that are critical to coastal communities such as my district, as I've described it, warm water Gulf of Mexico.

Dr. DONEY. Right. So you already mentioned the seagrass project from University of Texas. I think one of the, in some ways, safer approaches are these conservation and restoration approaches such as restoring damaged wetlands or protecting carbon-rich ecosystems because these are systems that already—are already functioning biologically, and if they have the benefit of adding carbon, as well as biodiversity and recreation, fisheries, that's great. Where I think we have more concerns is where we're manipulating the biology in a way that's different than the natural state.

Mr. WEBER. I was just thinking about that. In my district in the Gulf of Mexico, we have a lot of oyster beds, and so I guess—I'm 71 years old. I've grown up in a 20-mile radius all 71 years old, although a lot of people consider I'm not really grown up. But—so if it was working for oyster beds, and if it—if the natural habitat was working, are we concerned that we're changing that level somehow?

Dr. DONEY. Yes, that is one of the concerns with adding—for example, adding alkalinity that—we haven't done as much work on the local effects of what's going to happen on the ecosystem. Over long time scales, as it gets diluted out, it's probably not as big of a concern, but locally at the distribution point, it might shock some of the organisms. And, as Dr. Kapnick has talked about, there's a lot of work in NOAA on the acidification side, less so on the alkalinity enhancement side.

Mr. WEBER. Have you been to the Gulf Coast of Texas?

Dr. DONEY. Oh yes.

Mr. WEBER. We want you to come back and spend lots of money. I yield back.

Chairman MILLER. I now recognize Mr. Casten out of Illinois for 5 minutes of questioning.

Mr. CASTEN. Thank you. So I really appreciate—thank you to the Chair for having this hearing. I'm getting flashbacks. When I first joined this Committee about 6 years ago, I think one of the first hearings I was in I made the observation that the conversation about whether we need to get to zero CO_2 emissions by 2030 or 2050 is sort of dumb because a—human supporting—the kind of civilization we want needs CO_2 to be below 350 parts per million, which means we need to stop emitting CO_2 by about 1995. And in the absence of a time machine, we need what you all are doing, so we need to do it more and do it faster.

Dr. Kapnick, I'd like to start with you just because, first, I just want to make sure I've got my numbers right because I was looking things up on the internet, and that's always dangerous. If I understand right, on the margin, if we emit another ton of CO_2 to the atmosphere, about 30 percent of it ends up in the ocean. Is that right?

Dr. KAPNICK. Yes, that is correct.

Mr. CASTEN. OK. Chalk up one to the internet. And then, No. 2, that for every additional unit of heat that the atmosphere takes in because of anthropogenic global warming, I think about 90 percent of that heat ends up in the ocean. Do I have that about right?

Dr. KAPNICK. That is also correct. The majority is in the ocean.

Mr. CASTEN. OK. That latter number scares the dickens out of me. So I wonder if you could help out because if we're—given as we are heating the ocean much faster than the atmosphere, and we all appreciate that—what we feel in the atmosphere, how concerned should we be about feedback loops, particularly on ocean acidification, right? Because if we're—if the ocean's heating up, we're increasing the solubility of CO_2, is that 30 percent moving? Are we seeing accelerations in acidification?

Dr. KAPNICK. Yes, there are concerns that it is not going to remain exactly the same over time, and that is why we have a robust program for understanding how ocean uptake may change over time. And mCDR, the thinking of doing some of the research of it was originally to understand the carbon cycle in the ocean, understand what might happen in the future. But then, as we potentially do this, it speeds up the natural processes of carbon uptake into the ocean and accelerates it to potentially being above that 30 percent level through active management of how the carbon is uptaken by the ocean.

Mr. CASTEN. But just to be clear—and I think everybody said this up here. I want to make sure that we're all clear that none of us are encouraging technologies that would increase ocean acidification. Is that correct?

Dr. KAPNICK. Correct.

Mr. CASTEN. OK.

Dr. KAPNICK. We do not want to increase ocean acidification. We are trying to manage locally.

Mr. CASTEN. OK. So then, given the higher rates of heat, how confident are you—and, Mr. Deich, if you want to chime in on this as well. How confident are we that we feel good about the upwelling and downwelling plays? Because if the ocean is warming up, you know, I mean, we've got plausible risk that the Gulf Stream shuts down because places that we trusted were reliable upwelling and downwelling spots don't work anymore. It seems to me that if we're putting carbon in a place where we think we're confident it's going to stay down and all of a sudden there's an upwell, are we confident of that? Like what's the—how should we be thinking about that?

Dr. KAPNICK. Thank you for the technical question. I believe what you're referring to is the fact that we have large ocean occurrence in the Atlantic meridional overturning circulation, and there is a fear that in the coming decades that may reduce its efficacy of changing where the ocean is sinking. That is why this type of research and understanding and understanding of its impacts requires not just understanding the impacts as something goes into the ocean, then you model it out for a couple of years. It is—requires multi-decade, multi-century review of it because the goal of mCDR is to at least sequester for at least 100 years, and it can be thousands of years, depending on where it's placed.

Mr. CASTEN. So——

Dr. KAPNICK. So——

Mr. CASTEN [continuing]. To that end—and Ms. Ross had mentioned this trip we did to Norway together where we went to that longshore—longshore, I think that's what's it's called, long—where they pumped it, but they're pumping beneath the ocean surface so it stays permanently down. I haven't heard about that. Is that one of the things that's in mCDR, or are we thinking about that in a different bucket? Because at least that way we're not worrying about ocean acidification, and presumably, we're relatively confident it stays down.

Mr. DEICH. Yes. So at DOE we think of that as a different bucket. That's very similar to the geologic storage we do onshore here in the United States. It's similar types of technology and formations. Those——

Mr. CASTEN. OK.

Mr. DEICH [continuing]. Storage formations are just offshore.

Mr. CASTEN. Are you all monitoring—I guess it's Longship. Are you monitoring that Longship process——

Mr. DEICH. Yes, we——

Mr. CASTEN. There are some lessons learned there, I would hope.

Mr. DEICH. That's right. We collaborate closely. We have a bilateral agreement with the Norwegians, and we actually exchange a lot of technology learnings. They have a technology innovation center there that complements our National Carbon Capture Center.

Mr. CASTEN. OK. And I see I'm about out of time, so if we don't have time—if the Chair will allow you to respond, great. If not, kick this for the record. We have to do what you're talking about, and the scale scares the dickens out of me. There's been some talk about operating costs, but when we were in Iceland a while ago, we were talking with the Climeworks people, and we were just sitting there back—which is a fascinating technology now, direct air capture, pulling this out, and we sort of back-of-the-enveloped, and I said, OK, if we want to take 100 parts per million out of the atmosphere to get back below 350, that's like 800 billion tons. Then we said, OK, take this facility, cost you $15 million, how many would you have to build to take out 10 parts per million? And we ran the math, and that was like 100 percent of global GDP (gross domestic product).

And so like, as we think about these technologies, are there anywhere we look at and say, this has the potential physically and financially to scale to a point that matters? Because we can do a ton of these small things, but, you know, whatever, we'll sell some voluntary carbon credits, but if it doesn't matter, what's the point?

Mr. DEICH. So this technology is more or less where solar was back in 1995, and that probably would have been a similar calculation if you took the price then——

Mr. CASTEN. Well, but I guess my challenge is that like—these are like pumps and filters. This is mature technology, right?

Mr. DEICH. We actually see massive potential for innovation——

Mr. CASTEN. OK.

Mr. DEICH [continuing]. Across it——

Mr. CASTEN. All right.

Mr. DEICH [continuing]. And cost reduction.

Mr. CASTEN. To be continued. Thank you for giving me a few more seconds. I yield back.

Chairman MILLER. Thank you.

I now recognize Ms. Lee out of Pennsylvania for 5 minutes of questions—Mr. Collins for 5 minutes of questions.

Mr. COLLINS. I'm out of Georgia.

Chairman MILLER. Out of Georgia, yes, I'm aware. It's been a rough morning, Mike.

Mr. COLLINS. Too much carbon dioxide. Thank you, Mr. Chairman.

And I'm bad about mispronouncing names, too, so is it Mr. Tarbell?

Mr. TARBELL. It is.

Mr. COLLINS. OK. All right. Thank you. Mr. Tarbell, I think it's important that, as we talk about the growth of marine carbon removal, we ensure it doesn't turn into the wild west where some companies are claiming to do extraordinary things that end up not actually materializing. And I want to avoid anyone, especially the Federal Government, from being sold a pipedream and investing heavily in bad actors perpetrating what would be—amount to fraud. So how do you engage with DOE's Pacific Northwest National Laboratory to conduct measurement, reporting, and verification so that the folks in the Federal labs know and trust the technologies that you're developing?

Mr. TARBELL. Yes, so we have a very close collaboration with the scientists at both NOAA and DOE at the project we're working on at the Pacific Northwest National Labs. It's critical for us as we grow for there to be stringent standards and transparency around the way that we measure and report on and quantify how much CO_2 is coming out of the air. The way we do it is through, you know, different methods of measurement, monitoring, and modeling.

Mr. COLLINS. Can you get into what kind of data there asking for?

Mr. TARBELL. So the data that's available is—there's—you know, there's baseline data of the ocean chemistry. There's data around how much alkalinity we're adding to the ocean. And then there's models around how the ocean currents and ocean conditions change based on the perturbation that we're adding.

Mr. COLLINS. Do you think the data they are asking for, has it been helpful? Has it——

Mr. TARBELL. Certainly, the collaboration with DOE and NOAA has been extremely helpful in enabling us to say with confidence how much CO_2 we're pulling out of the air.

Mr. COLLINS. OK. How quickly do you think your technology can be scaled upward in the next 5 years?

Mr. TARBELL. So the system that we've installed at Pacific Northwest National Labs is 100 ton per year scale system. Our goal in the next 5 years is to have deployed a million tons per year of removal capacity. And the way we scale is by co-locating with existing industrial facilities, so desalination plants, mining installations, you know, existing industrial facilities that are moving oceanwater. We couple our system to those facilities. One large desalination plant alone can comprise a million tons a year of capacity.

Mr. COLLINS. I think that—and that leads into my last question about—and you've pretty much answered, but if you've got any more—who's going to be the primary investors besides the Federal Government?

Mr. TARBELL. So our investors to date are primarily venture capital investors, and, as we grow, as we're deploying systems, it will be more infrastructure investors, so investors doing project financing, you know, similar to the investors that fund the development of power plants or other infrastructure like that.

Mr. COLLINS. OK. So they'll be investing and then latching on to like the desalinization plant?

Mr. TARBELL. That's right. We co-develop projects with operators or owners of, for example, desalination plants——

Mr. COLLINS. Right.

Mr. TARBELL [continuing]. And we bring in outside money from project finance investors.

Mr. COLLINS. OK. Thank you.

Mr. Chairman, that's all I got. I'm going to yield back.

Chairman MILLER. Thank you, Mr. Collins.

I now recognize Ms. Lee out of Pennsylvania for 5 minutes of questions.

Ms. LEE. Thank you, Mr. Chairman.

In October of last year, the University of Pittsburgh received over $2 million in funding from the U.S. Department of Energy to develop marine carbon capture technologies and accelerate novel climate solutions. The Pitt team will be using this ARPA–E funding to develop optical fiber sensors that will measure pH and carbon dioxide in seawater from the ocean's surface and the seafloor. Sensing technology like this could be a gamechanger for integration into other applications like public infrastructure to help prevent disasters, for instance, like the collapse of the Fern Hollow Bridge in my district last year, so I look forward to seeing, you know, this particular project developed.

But, you know, just to get down to it, I was elected to this office by communities and constituents that simply seek practical solutions to everyday problems that they face. So, as I continue to learn more on this subject matter, I'm curious to hear from our witnesses today how marine carbon dioxide removal plays into the bigger questions addressing the climate crisis.

Mr. Tarbell, could you share more the type and volume of resources required to carry out mCDR operations?

Mr. TARBELL. Yes, there's several different buckets of activity that are required to deploy one of our systems. So, first, our focus historically has been R&D, so designing and engineering systems that work, that address the science and demonstrate safety and efficacy. As we scale, we veer more into the realm of deployment and the capital required to actually build out plants. And so, you know, the resources required there are around capital investments in building out equipment.

The—you know, the opportunity for us to accelerate the growth of this through partnership and investments from the Federal Government are—you know, primarily what we're looking for is an opportunity to level the playing field, to be tech neutral in the incentives to enable the best solutions to rise to the top. And so, you know, we're looking for opportunities to fund R&D, to stimulate the growth of the best technologies, and then opportunities for deployment of the technologies that are most promising.

Ms. LEE. Thank you. Mr. Deich, R&D is experimental at its fundamental core. How can the Department commit to partner with communities to ensure equity in reaping the benefits of carbon removal without potentially causing harm to ecosystems, our local communities in poor, vulnerable regions through mCDR experimentation?

Mr. DEICH. That's a great question, and it's the core of how we're approaching our early investments in research and development. We're requiring the projects to build community benefit plans around their projects that look at the broad not just environmental impacts, but workforce impacts as well. And we're also trying to understand through these early research projects what those environmental impacts are so that we can inform not just how to mitigate any risks, but how to take advantage of any benefits that this could provide to local communities in terms of environment, economy, and workforce.

Ms. LEE. Thank you. Mr. Tarbell, again, is it a failure if R&D teaches us that this technology is not scalable to address CO_2 removal at the needed level to meet our climate goals?

Mr. TARBELL. We should be focusing our investments on the technologies that can have an impact. Our company's mission is to remove billions of tons of CO_2 from the air, and if the technology we're working on is not capable of that, we need to shift our focus to something that will.

Ms. LEE. So the climate crisis, from extreme heat to unprecedented flooding, disproportionately affects Black and Brown communities. How will the R&D of mCDR improve the lives of families who struggle to combat the daily realities of the climate crisis in their homes and communities, if at all? And that's for any who would like to answer.

Dr. DONEY. I do want to say, you know, so the Federal Government published the "Ocean Justice Strategy" last winter. There are a lot of—whether it's minority communities or indigenous communities, there are a lot of complicated issues that I don't think the sort of—a lot of the research community have really addressed. And I see this as an opportunity, as we move forward, to do this in a better way than we've done previous research where we've done research independently of the communities. So I see the community engagement as a really crucial part. And in part, we need to find out what the right questions to ask are.

Ms. LEE. Thank you. Thank you. I really do appreciate that answer, and I appreciate you all being here today. And that's my time, and I yield back.

Chairman MILLER. Thank you very much. In closing, I just want to thank all the witnesses sincerely for the valuable testimony here this morning and the Members for their questions. The record will remain open for 10 days and additional comments and written questions from Members. Thank you very much again.

This hearing is adjourned.

[Whereupon, at 11:45 a.m., the Subcommittees were adjourned.]

Appendix I

Answers to Post-Hearing Questions

ANSWERS TO POST-HEARING QUESTIONS

Responses by Mr. Noah Deich

U.S. HOUSE OF REPRESENTATIVES

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

Navigating the Blue Frontier: Evaluating the Potential of Marine Carbon Dioxide Removal

Mr. Noah Deich, Senior Advisor, Office of Fossil Energy and Carbon Management,
U.S. Department of Energy

QUESTIONS FROM REPRESENTATIVE BRIAN BABIN

Q1. Can you please explain the use of olivine sand to remove carbon and if its use could also aid with protecting coastline communities and fragile ecosystems?

A1. The use of olivine sand to remove atmospheric carbon dioxide is considered a method of ocean alkalinity enhancement. Olivine is a natural silicate mineral ($(Mg, Fe)_2SiO_4$), which consumes carbon dioxide (CO_2) as it dissolves with water through its weathering process. This chemical reaction then produces bicarbonate ($HCO3-$), thereby increasing the alkalinity of surrounding ocean waters. Additionally, alkalinity allows the ocean to draw down more atmospheric carbon dioxide while also reducing ocean acidification. Efforts to speed up this process, for example by spreading finely pulverized olivine on coastlines, could potentially contribute to climate-relevant carbon dioxide removal, and local ocean acidification mitigation. These efforts may be able to be combined with conventional methods of protecting coastline communities, such as introducing olivine sand into material used for beach restoration. The resulting increase in pH and buffering capacity may be able to mitigate ocean acidification in nearby waters, helping fragile fisheries and coral ecosystems that are sensitive to more acidic (lower pH) water. This is an active area of ongoing research. Additional research and development are needed to comprehensively assess these local ecosystem impacts and evaluate the scalability and efficacy of carbon dioxide removal delivered through these approaches before pursuing deployment at large scale.

Q2. Our coasts in Texas, especially in Galveston and surrounding areas, need assistance and all the sand they can acquire for various coastal protection projects, and if we can protect our coasts while removing carbon, that sounds like a win-win. I've heard a little bit about this and wondering what is being done to evaluate the use of olivine sand as part of mCDR research?

According to NOAA's Strategy for Carbon Dioxide Removal (CDR) Research, the category of mCDR known as ocean alkalinity enhancement (OAE) stands out as the lowest cost and effective approach, with respect to scalability and net carbon removal efficiency. Likewise, this strategy acknowledges that many mCDR approaches provide co-benefits.

A2. There is active ongoing research in this area, both federally and privately funded. The first federally permitted mCDR small-scale field trial in the United States led by the public benefit, for-profit corporation, Vesta, and approved by the U.S. Army Corps of Engineers, is actively conducting a field trial to assess the efficacy and potential ecological effects of olivine dissolution via nearshore placement of ground olivine in waters offshore from Duck, North Carolina.

Multiple research projects funded through National Oceanic and Atmospheric Administration's (NOAA) National Oceanographic Partnership Program (NOPP) mCDR portfolio are also pursuing research questions related to ocean alkalinity enhancement, which is sometimes done by enhanced rock weathering such as with olivine. The Department of Energy is providing funding for one of these projects, specifically looking at the effects and risks of ocean alkalinity enhancement on the physiology and functionality of corals and crustose coralline algae under ocean alkalinity enhancement conditions.

Q3. What U.S. based companies are actively leading field trials in OAE, and what are the unique co-benefits of these company's approaches?

A3. The first and only permitted U.S. field trial of an mCDR technology, that DOE is aware of, is being carried out by Vesta. Vesta is conducting a field trial to assess the efficacy and potential ecological effects of olivine dissolution via nearshore placement of olivine offshore of Duck, North Carolina. Additionally, Ebb Carbon is leading research efforts in electrochemical ocean alkalinity enhancement approaches. However, mCDR is a rapidly evolving field and many research institutions and private sector entities are actively engaged with EPA, USACE, and other authorized state permitting agencies to pursue field trials.

Through rigorous chemical, biological, and ecological monitoring compliant with federal, international, and subnational regulatory frameworks, field trials enable research entities and companies to carry out the research necessary to determine the extent to which ocean alkalinity enhancement reduces carbon dioxide and helps protect fragile fisheries and coralline ecosystems that are sensitive to more acidic (lower pH) water. Small-scale field trials are a critical component of the needed action to ensure that informed decisions are made about potential scaling of mCDR.

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QUESTIONS FROM REPRESENTATIVE SUZANNE BONAMICI

Q1. The National Academies recommend nearly $2.5 billion over ten years for research activities related to marine carbon dioxide removal, but NOAA does not have a dedicated program with authorized funding to work on this important issue. Why should Congress authorize and appropriate these substantial new resources?

A1. Marine carbon dioxide removal (mCDR) is a relatively new climate mitigation option that faces several technical, financial, and social challenges that must be addressed to realize its potential as a climate mitigation option. Like other technologies where Congress has appropriated funding to address these types of challenges, government-supported efforts on mCDR research and development can address these challenges and potentially lead to safe, responsible, and expeditious development of mCDR as a climate mitigation option. Researching mCDR approaches is an important component of the U.S. government's Ocean Climate Action Plan and may provide substantial climate benefits alongside benefits to local ecosystems and coastal communities.

Q2. What specific resources, including updated programmatic funding levels, would be most useful to conduct this work?

A2. To date, funding for mCDR research, development, and demonstration efforts has been supported by the CDR program budget, within the Office of Fossil Energy and Carbon Management (FECM) and Energy Efficiency and Renewable Energy's (EERE) Water Power Technology Office (WPTO). For example, FECM has issued funding opportunities under the CDR program that will provide up to $10M to abiotic mCDR technologies for the conceptual design of mCDR systems, and as appropriate, field validation and testing. Additionally, in FY24 Congress provided FECM $250,000 to develop, test, and evaluate mCDR in collaboration with other agencies. The President's Budget requested $90M for the Carbon Dioxide Removal Program in FY25. These funds are allocated and managed across discretionary and congressionally directed programming that supports

DOE's full portfolio of statutorily authorized approaches, including but not limited to, direct air capture (DAC), enhanced geological weathering, bioenergy with carbon capture and storage, agricultural practices and mCDR. To contextualize this level of support, Congress has appropriated $3.5 billion for DAC Hubs to facilitate the large scale (multiple 1 million tone CO_2 capture per year hubs) demonstration of DAC technologies. For many technologies, as they advance from lab and bench-scale to small and large pilots and demonstrations, funding levels can increase by an order of magnitude for each step to reach commercialization.

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QUESTIONS FROM REPRESENTATIVE KEVIN MULLIN

Q1. How is DOE working with other federal agencies to ensure that there are pathways to commercialization for nascent mCDR technologies?

A1. To maximize complementary capacities and minimize duplication of efforts, DOE has a formal collaboration with the National Oceanic and Atmospheric Administration (NOAA). This collaboration is important to DOE's mCDR programming as NOAA leads U.S. research on and prediction of changes in climate, weather, the dissemination of this information, and the conservation and management of coastal and marine ecosystems and resources. A five-year Memorandum of Agreement (MOA) was signed in June 2024. In fiscal years 2022 and 2023, DOE collaborated with NOAA through the NOAA-managed National Oceanographic Partnership Program (NOPP) to support several mCDR projects. Together, NOAA and DOE will continue building on our strengths to advance mCDR technology that can contribute meaningfully to climate goals while protecting communities that rely on the ocean, ecosystems, and U.S. national security and economic interests.

DOE was a member of and an active participant in the Fast Track Action Committee (FTAC) on Marine Carbon Dioxide Removal convened by the Subcommittee on Ocean Science and Technology of the National Science and Technology Council. This FTAC convened agencies across the U.S. government to publish a National Marine Carbon Dioxide Removal Research Strategy in November of 2024. DOE worked with other member agencies to assess and scope the role of DOE in mCDR research as well as opportunities for future coordination among agencies with equities and expertise relevant to mCDR.

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Q2. How does DOE engage with local communities where mCDR research and development take place?

A2. DOE has established rigorous technical and community engagement standards for research, development, and demonstration of nearly all its technology investments, including carbon dioxide removal technologies. The Carbon Negative Shot™, DOE's all-hands-on-deck call for innovation in carbon removal pathways including mCDR, prioritizes information sharing and engagement with communities that could participate in or be affected by CDR approaches. Of particular importance to carbon dioxide removal technologies are appropriate permitting and environmental assessment, engineering studies, life cycle analyses, and techno-economic assessments. These assessments and studies are typically required deliverables for R&D projects supported by the Office of Fossil Energy and Carbon Management (FECM) and are critically evaluated at the end of budget periods and upon project completion. The National Energy and Technology Laboratory maintains a public database that provides Summary Information for External R&D Awards. This resource provides a comprehensive list of R&D projects supported by FECM, including project updates, progress reports, and publications.

Specifically, to carbon management, which includes mCDR, DOE issued a list of principles, following extensive public input, under the Responsible Carbon Management Initiative. These Responsible Carbon Management Principles provide guidance across a variety of important topics including but not limited to community engagement, workforce development and quality jobs, air, water and soil quality, transparency, and long-term stewardship. In 2024, FECM published the Carbon Management Resources Portal, which provides an extensive list of DOE and external publications and digital tools on carbon management technologies and DOE-supported projects. For example, the Portal includes a

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Carbon Management Interactive Diagram that provides information on technologies and DOE's community engagement efforts.

Q3. What permit requirements exist for mCDR pilot projects and what are the expected timelines related to each? How do these requirements impact businesses in their decisions to conduct research in the United States versus international locations?

A3. Field research is necessary to answer the critical questions surrounding mCDR as the approaches and technologies advance towards potential future deployment. Field research activities that involve the release of materials to the ocean will require permits from Environmental Protection Agency (EPA), United States Army Corps of Engineers (USACE), or an authorized state agency under the *Marine Protection, Research and Sanctuaries Act* or *Clean Water Act.* Depending on the nature and location of the research proposal other requirements under relevant Tribal, federal, state or local laws or policies may apply. Other federal agencies, such as NOAA Fisheries and U.S. Fish and Wildlife Service, provide a supplemental role in reviewing permitting agency analyses through inter-agency consultations regarding effects to protected species, essential fish habitats, and other trust resources for projects that are federally funded, conducted or permitted. Federal permitting agencies also follow policies for consultation with states, territories, and Tribes on proposed actions that may affect their unique rights. EPA has information available on their mCDR permitting website about MPRSA permits and Clean Water Act Section 402 (National Pollutant Discharge Elimination System) permits for mCDR activities in coastal and ocean waters. EPA and USACE can provide further detail on the permit requirements and expected timelines for permitting of mCDR pilot projects.

Permitting frameworks that protect ecosystems and communities and provide clear information to applicants regarding the requirements for applications and permitting processes can help businesses make investment decisions on mCDR.

DOE can provide insights to regulatory agencies from research and development efforts.

The U.S. Geological Survey is positioned to conduct in-situ monitoring and collaborate with Department of the Interior (DOI) bureaus to monitor, report, and verify results from pilot efforts in the coastal environment as well as evaluate the impacts of biogeochemical changes and disturbance to population persistence of DOI Trust Species (e.g., Threatened and Endangered) and their habitats as well as DOI managed land and water resources.

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QUESTIONS FROM REPRESENTATIVE MAXWELL FROST

Q1. If one or more of these techniques starts to be clearly impractical or dangerous to the environment, does NOAA and DOE have an offramp for their additional funding?

A1. No field trial should occur without strong foundational science, informed by robust laboratory and modeling evidence that demonstrates any significant negative impacts, including potential impacts to harvested species such as oysters, scallops, and waterfowl, can be avoided and, if occurring, remedied. Field trials for mCDR research and development are subject to permitting and regulatory frameworks focused on protection of the marine environment and human health. Field research activities that involve the release of materials to the ocean will require permits from Environmental Protection Agency (EPA), United States Army Corps of Engineers (USACE), or an authorized state agency under the *Marine Protection, Research and Sanctuaries Act* or *Clean Water Act.* Depending on the nature and location of the research proposal other requirements under relevant Tribal, federal, state or local laws or policies may apply. Other federal agencies, such as NOAA Fisheries and U.S. Fish and Wildlife Service, provide a supplemental role in reviewing permitting agency analyses through inter-agency consultations regarding effects to protected species, essential fish habitats, and other trust resources for projects that are federally funded, conducted or permitted. Federal permitting agencies also follow policies for consultation with states, territories, and Tribes on proposed actions that may affect their unique rights. Permitting processes generally require an applicant to provide information to demonstrate that the proposed activities will not unreasonably degrade the marine environment or human health, or harm protected species, and that it complies with other applicable criteria and regulations. DOE follows all statutes, rules, regulations and Departmental guidance regarding project management.

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Selected research, development and demonstration projects must meet various performance metrics and acquire and operate according to required permits. If projects are not progressing technically, DOE can pursue corrective actions, including cancellation of the award. If projects are not meeting the standards set forth in their permits, the permitting authority can also take necessary action.

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QUESTIONS FROM REPRESENTATIVE SEAN CASTEN

Q1. I am concerned about the scalability of marine carbon dioxide removal (mCDR) technologies and projects, especially as relates to their space needs, ecological impacts, cost, and energy efficiency. Have we reached a stage yet at which we can identify the technologies and projects most likely to scale and meet our other tests? If not, when do you anticipate reaching that stage? If we have, what technologies seem most promising to you? Would it make sense to invest mostly in those and come back to the rest once those have gotten deployed?

A1. No, we have not reached a stage yet where we can identify those technologies most likely to scale up to deployment because all mCDR pathways are in the early stages of research and development. Maintaining flexibility to enable these nascent pathways and technologies to compete on merits, such as technoeconomic assessment, scalability, modeled and avoided adverse ecological impacts, cost, net-removal efficiency, durability/permanence of carbon storage and rigor of measurement, reporting and verification, will help ensure the most promising technologies are identified. However, the Department of Energy has been directed by Congress to specifically support certain pathways within funding calls (e.g., Office of Fossil Energy and Carbon Management (FECM) programming to fund feasibility assessment, design, and field validation of abiotic pathways), based on technical knowledge or capabilities within its programs and funding availability. Generally, as has been seen with other CDR technologies, it can take a particular technology anywhere from 2-5 years to be adequately tested in a laboratory environment before it moves into smaller-scale pilot or field tests, where another 3-5 years of testing may be necessary before it can move to first of a kind large-scale pilot or demonstration tests. It generally makes sense to have a portfolio of technologies under development at various stages. For example, some first-generation technologies to demonstrate and provide key learnings, while simultaneously investing in more advanced technologies that can lead to further cost reductions and optimization.

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QUESTIONS FROM REPRESENTATIVE PAUL TONKO

Q1. How should the federal government help guarantee that local communities are meaningfully included in decision-making processes for marine carbon dioxide removal trials and projects?

A1. It is essential for the responsible testing and potential scaling of the mCDR field that communities are engaged, respected, and involved. There are several Federal-level processes that involve communities in science and will either be expected or leveraged as mCDR scales. For example, as part of funding calls, FECM requires and evaluates Community Benefits Plans, which include efforts to educate and engage communities. Federal funding decisions are supported by NEPA analyses. Federal efforts such as NOAA's Sea Grant program can serve as models for education and community engagement on ocean-related issues and could be both learned from and leveraged in the context of mCDR. Interested and invested members of the public can participate in the EPA and USACE permitting processes through the public review and comment processes for proposed permitting actions. However, as mCDR research and development programs advance, it will be crucial to continue to enhance and tailor education and engagement efforts, to ensure equitable and appropriate scaling of mCDR.

Q2. How should we craft comprehensive research codes of conduct to ensure that mCDR projects both protect marine ecosystems and safeguard the livelihoods of those dependent on them?

A2. The Department has in the past worked to develop comprehensive codes of conduct for various research areas through an interagency process that considers the expertise and equities of invested and impacted agencies. As outlined in the National Marine Carbon Dioxide Removal Research Strategy, a code of conduct should "span the life cycle of an mCDR project, engage the public, build public trust, inform research design, develop awareness of social and environmental

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impacts, and enforce scientific integrity and ethical stewardship of materials and data." Codes of conduct for mCDR research are likely to require localized and meaningful community engagement efforts to address and incorporate regional concerns. These codes of conduct can ensure both rigorous scientifically informed research and robust community engagement and education. We are happy to work with the Committee on what a successful development process might look like in the mCDR space. Other federal agencies who may be involved in funding, conducting, or permitting mCDR projects would also have a role in the development and implementation of a research code of conduct.

Q3. The F-TAC has brought together agencies beyond NOAA and DOE, including NIST, NSF, and NASA. Given the multidisciplinary nature of mCDR, would you agree that these agencies play an essential role in advancing research, development, and demonstration efforts? What steps can we take to ensure their contributions are fully realized?

A3. Yes, the FTAC has made it clear that multiple agencies can drive the advancement of the mCDR field. While at present NOAA, DOE, and the National Science Foundation lead mCDR research and development efforts, all agencies involved in the FTAC will have unique contributions to and equities in a scaled mCDR field. Additionally, permitting agencies including the U.S. Army Corps of Engineers and the Environmental Protection Agency (EPA) have important roles in clarifying and advancing the regulatory landscape for mCDR research and development. Continued collaboration through existing mechanisms such as FTAC and other interagency coordination efforts can ensure their contributions are realized.

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QUESTIONS FROM REPRESENTATIVE DEREK KILMER

My district is home to the Pacific Northwest National Laboratory in Sequim, which houses the only marine research facility in the Department of Energy complex, and a unique and thriving maritime sector.

I'm proud to have introduced legislation that will supercharge marine energy research, including marine carbon dioxide removal (mCDR), the Blue Ocean Energy Innovation Act. I am excited to see these technologies advance to keep our oceans healthy and our coastal communities strong.

Q1. What research infrastructures can support progress on mCDR? Additionally, how can we ensure that this research infrastructure is established in the locations that it can be most impactful, whether through access to resources or through colocation of the power source and sensing technologies?

A1. The mCDR community has expressed that a lack of mCDR testing infrastructure creates a temporal and financial burden on individual projects that are already financially constrained. Establishment of mCDR testbeds support mCDR research and development in this critical stage of the field, when we are still learning which climate solutions can be safe, responsible, and expeditious. We can ensure mCDR testing infrastructure is established where it can be most impactful by soliciting stakeholder input, identifying the critical questions that must be addressed for the various mCDR technology pathways, and conducting thorough analysis and evaluation of the resources required to support mCDR testing infrastructure.

Responses by Dr. Sarah Kapnick

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Representative Brian Babin, D.D.S.

1. ***Can you please explain the use of olivine sand to remove carbon and if its use could also aid with protecting coastline communities and fragile ecosystems?***

   When minerals break down at the Earth's surface through a process called chemical weathering, they produce ions or molecules that can increase the alkalinity of seawater. Mineral chemical weathering and subsequent alkalinity addition to the ocean has controlled Earth's climate over geologic timescales – ocean alkalinity enhancement, one type of marine carbon dioxide removal (mCDR), aims to speed up this process. Olivine is a silicate-rich mineral (primarily magnesium or iron orthosilicate, $(Mg^{2+}, Fe^{2+})_2SiO_4$) which is already prone to breaking down at the Earth's surface. Pulverizing a mineral like olivine into sand accelerates the chemical weathering process. This alkalinity enters the ocean system and allows the ocean to draw down more carbon dioxide while serving as a buffer against ocean acidification.

   Current ocean alkalinity enhancement projects using olivine are primarily being researched in coastal areas to determine the effectiveness of this approach for drawing down carbon dioxide from the atmosphere and to understand potential environmental impacts. Beach nourishment, or replacing sand lost to erosion or storms, is a potential co-benefit that could combat beach erosion along the U.S. coastline. To effectively nourish a beach or wetland, the olivine sand (or olivine-enriched sediment) would need to be placed in an appropriate location where the wave or current action would result in a beach nourishment effect. However, mining, transporting, and grinding olivine to achieve carbon removal and beach nourishment is an energy intensive process, which has potential to limit the scale of these activities.

2. ***Our coasts in Texas, especially in Galveston and surrounding areas, need assistance and all the sand they can acquire for various coastal protection projects, and if we can protect our coasts while removing carbon, that sounds like a win-win. I've heard a little bit about this and wondering what is being done to evaluate the use of olivine sand as part of mCDR research?***

   Foundational research, particularly in field settings, is currently ongoing to understand the efficacy of olivine weathering to draw down carbon dioxide. Factors like temperature, grain size, water movement, and water chemistry have a considerable effect on how

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quickly the olivine dissolves to enhance alkalinity. Additionally, mining, transporting, and grinding olivine to optimal size to facilitate dissolution could be energy-intensive, potentially negating some of the carbon removal benefits. NOAA is currently supporting research to better understand these questions on safety, efficacy for removing atmospheric carbon dioxide, and potential for large-scale implementation of enhanced weathering of olivine.

More research, including laboratory studies and long-term monitoring of field pilots, is required to understand environmental responses to this approach and the effectiveness of this approach for removing carbon dioxide from the atmosphere under various environmental conditions. Because the addition of olivine to an environment changes the habitat, the mineral addition has the potential to adversely affect living marine resources. In addition, olivine contains heavy metals (e.g., nickel and chromium) in trace amounts. Depending on the amounts and dissolution conditions, trace heavy metals present in olivine may create concerns for toxicity to marine organisms in areas where olivine might be applied in high concentrations. Therefore, further studies are needed to understand the ecological thresholds and sensitivity of marine species, including culturally and economically important species. However, research is already underway to explore the effects of trace heavy metals in sediments placed in marsh settings for mCDR, coastal protection, and wetland conservation. Further research is also warranted to fully understand the effects of olivine addition, including the environmental and carbon impacts of mining, processing, and transporting the mineral, the impact on marine and coastal habitats, the scale of olivine addition that can be supported with domestic supply chains, and the effectiveness of the technique for removing carbon dioxide from the atmosphere through ocean alkalinity enhancement. Although outside the purview of NOAA, mining and processing of olivine also has environmental impacts.

As a Department of Commerce agency, NOAA recognizes the importance of enabling emerging markets and wants to ensure that the methods are effective, verifiable, and accountable, while minimizing risk to ocean ecosystems and communities including potential impacts to harvested species such as oysters and scallops. NOAA's research portfolio strongly encourages public-private partnerships and will work closely with industry partners on research, monitoring, and evaluation of potential strategies at scale.

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3. ***According to NOAA's Strategy for Carbon Dioxide Removal (CDR) Research, the category of mCDR known as ocean alkalinity enhancement (OAE) stands out as the lowest cost and most effective approach. Likewise, this strategy acknowledges that many mCDR approaches provide co-benefits.***

   What U.S. based companies are actively leading field trials in OAE, and what are the unique co-benefits of these company's approaches?

   Due to the potential profitability offered by growth in voluntary carbon markets, and to a lesser extent in compliance carbon markets, some companies are already pursuing small-scale pilot studies for a variety of mCDR technologies. There are a number of private industry groups working towards and/or executing ocean alkalinity enhancement pilot projects, which include, in no particular order:

   - Ebb Carbon (electrochemical OAE approach, addition of sodium hydroxide (NaOH) to seawater as alkalinity source); recently received a permit to conduct a pilot project near Port Angeles, WA, permit information is available on the State of Washington Department of Ecology website.)
   - Vesta (olivine addition to coastal / wetland areas)
   - Planetary Technology (mineral OAE approach, including additions of magnesium hydroxide ($Mg(OH)_2$) and calcium hydroxide ($Ca(OH)_2$). Note, Planetary is a Canadian company, but is currently a collaborator with a project moving forward in Norfolk, VA; they are also conducting OAE field trials in the Bedford Basin, Canada.
   - The Carbon To Sea Initiative, a U.S.-based non-profit company, has also been conducting OAE trials at sites in or near Iceland and in Canada.

   As a Department of Commerce agency, NOAA recognizes the importance of enabling emerging markets and wants to ensure that the methods are effective, verifiable, and accountable, while minimizing risk to ocean ecosystems and communities including potential impacts to harvested species such as oysters and scallops. NOAA's research portfolio strongly encourages public-private partnerships and will work closely with industry partners on research, monitoring, and evaluation of potential strategies at scale.

   Increasing seawater alkalinity has the co-benefit of mitigating ocean acidification (OA) by temporarily elevating pH in a localized area. For projects that involve the placement of solid alkaline sands in coastal areas, beach nourishment, the act of replacing sand lost to erosion or storms, is another potential co-benefit that could combat beach erosion along the U.S. coastline. However, more research is required to understand and optimize potential co-benefits and to understand potential ecological risks from metals contamination, habitat alteration and chemical changes.

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Representative Suzanne Bonamici

1. ***The National Academies recommend nearly $2.5 billion over ten years for research activities related to marine carbon dioxide removal, but NOAA does not have a dedicated program with authorized funding to work on this important issue. Why should Congress authorize and appropriate these substantial new resources? What specific resources, including updated programmatic funding levels, would be most useful to conduct this work?***

   We have a narrow opportunity to pursue action at home and abroad to reduce the concentration of greenhouse gases in the atmosphere to avoid the most catastrophic impacts of the climate crisis. Under current emissions trajectories, global surface temperatures will continue to rise, accelerating the need for carbon removal. With further warming of the Earth system, every region is projected to experience increasingly concurrent climate extremes, with impacts on our agriculture, environment, economy, public health and safety, food security, cultural heritage, and political stability, and indirectly, as a threat multiplier. One potential solution would be to remove carbon dioxide from the atmosphere with the assistance of ocean-based processes.

   NOAA has multiple programs and labs conducting marine carbon dioxide removal (mCDR)-relevant science. NOAA's Ocean Acidification Program has been expressly engaged in funding mCDR science both externally and internally to the agency, leveraging more than a decade of experience in facilitating applied carbon science to the research and data management needs of mCDR. NOAA brings extensive expertise in mCDR research through various specialized divisions. Ocean carbon observations are conducted by the OAR Pacific Marine Environmental Laboratory in Seattle, WA, and the OAR Atlantic Oceanographic and Meteorological Laboratory in Miami, FL. Atmospheric carbon observations are conducted by the OAR Global Monitoring Lab in Boulder, CO. The impact of ocean alkalinity enhancement (OAE) on marine ecosystems is studied at regional NMFS laboratories. Earth system modeling is conducted by the OAR Geophysical Fluid Dynamics Laboratory in Princeton, NJ. Data management is supported by NESDIS through the National Centers for Environmental Information's Ocean Carbon and Acidification Data System.

   NOAA has existing mandates to research mCDR, including those from appropriations report language in FYs 2023 and 2024, and from the 2009 Federal Ocean Acidification Research and Monitoring Act (FOARAM), which charges NOAA with the assessment of

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socioeconomic impacts of ocean acidification and development of adaptation and mitigation strategies to conserve marine organisms and marine ecosystems. Additional mCDR-specific authorizations and appropriations would expand these existing programs and capacities, and improve our understanding of mCDR, its potential benefits and any associated ecological risks.

As a Department of Commerce agency, NOAA recognizes the importance of enabling emerging markets and wants to ensure that the methods are effective, verifiable, and accountable, while minimizing risk to ocean ecosystems and communities including potential impacts to harvested species such as oysters and scallops. Assessing the effectiveness of CDR approaches is directly related to its mission. The Strategy for NOAA Carbon Dioxide Removal Research outlines what we know about existing technologies and what we need to learn to make the best decisions moving forward to meet climate goals.

As climate-related impacts increase and compound, the search is on for creative tools and techniques that will accelerate climate response. Scientific assessments state that carbon dioxide removal, in addition to deep emission reductions, is necessary to address climate change[1].

Although mCDR has potential to mitigate greenhouse gasses and ocean acidification, each of the methods also have ecological risks. Research is required to understand those risks to provide a scientific basis for permitting and other management decisions. Scientists across the NMFS Fisheries Science Centers are experts on the intersection of carbon chemistry and marine life (due to a decade of research on the impacts of ocean acidification) and more scientific research is needed in the Fisheries Science Centers to determine the risks to fisheries species and protected species to inform NOAA's management responsibilities. NMFS also led an International Council on Exploration of the Seas workshop focused on the topic of the potential risks of mCDR for marine life in October 2024 which helped identify key points for an international fisheries research agenda.

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[1] IPCC, 2023: Summary for Policymakers. In: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland, pp. 1-34, doi: 10.59327/IPCC/AR6-9789291691647.001

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mCDR could be part of the climate action toolkit, holding potential to remove carbon from the atmosphere and provide local mitigation of other issues in NOAA's purview such as ocean acidification, which affects culturally and economically important species. CDR also provides tremendous economic opportunity for the private sector. We need the foundational knowledge and science to develop standards to support an accountable, rigorous carbon market for the climate, for the economic potential of the sector, and, as international interest grows, for our national security.

NOAA's inaugural competitive grants portfolio leveraged $24.3M in funding from interagency partners, the Inflation Reduction Act, and philanthropy. We received eligible applications that totaled over $80M worth of funding requests for this funding opportunity. Given the momentum of the field, we expect the interest and need for a sustained research portfolio to increase.

2. ***My district is home to the Pacific Northwest National Laboratory in Sequim, which houses the only marine research facility in the Department of Energy complex, and a unique and thriving maritime sector. I'm proud to have introduced legislation that will supercharge marine energy research, including marine carbon dioxide removal (mCDR), the Blue Ocean Energy Innovation Act. I am excited to see these technologies advance to keep our oceans healthy and our coastal communities strong.***

   What research infrastructures can support progress on mCDR? Additionally, how can we ensure that this research infrastructure is established in the locations that it can be most impactful, whether through access to resources or through colocation of the power source and sensing technologies?

   NOAA is a central coordinator across Federal agencies for mCDR research. NOAA has been working very closely with other agencies, particularly DOE, on fostering a whole-of-government collaborative approach to mCDR work. In June 2024, NOAA and DOE's Office of Fossil Energy and Carbon Management, Office of Science, and Office of Energy Efficiency & Renewable Energy Water Power Technologies Office announced they had signed a Memorandum of Agreement (MOA) establishing the basis for a collaborative relationship on mCDR research and development. NOAA recognizes that mCDR research cuts across agency mission lines, and has also worked closely with the Fast Track Action Committee on mCDR and its member agencies to help produce the recent National mCDR Research Strategy to promote continued interagency collaboration and coordination.

We are working hand in hand with the DOE to grow both agencies' involvement in mCDR work, and to coordinate to ensure that there is no duplication of effort and that each agency is focusing its work on areas which play to its strengths. In this relationship, NOAA is leading basic research on mCDR's efficacy, potential impacts, and co-benefits, as well as ocean, atmosphere, and carbon monitoring capabilities. DOE is poised to lead in scaling up mCDR pathways, technology development, and associated carbon markets.

One of the first initiatives under this MOA will be to study what areas hold the most promise, and what infrastructure and capabilities are needed, to centralize mCDR research. Centralized research facilities could support projects as they progress from lab to field, and offer constrained and well-studied environments for small-scale field research, when appropriate. Facilities such as these make field research that is critically needed more feasible, by decreasing cost and diminishing risk per field trial. Centralized research facilities can also aid in minimizing ecological risks, improve ecological risk/benefit analysis, and in permitting processes. The National mCDR Research Strategy (p. 26-28) discusses how field trials will need to meet regulatory requirements of applicable statutes administered by multiple agencies and provides recommendations (p.30) on how federal regulatory agencies and research/funding agencies could continue to enhance interagency communication and coordination.

Additionally, expanded high performance computing and ocean observing infrastructure would greatly advance NOAA's progress on mCDR. NOAA is a global leader in ocean observations but will need to grow its network to maintain its current observing portfolio while providing authoritative observations of mCDR field trials. As previously noted, one of NOAA's key roles in this space is to provide the observations of baseline ocean conditions necessary to establish changes from mCDR, and the finer grained observations of specific projects to begin the development and refinement of measurement, monitoring, reporting, and verification (MMRV) standards. NOAA's oceans and ecosystem modeling expertise will also form a key portion of its contributions to mCDR research. However, the agency is already facing a research supercomputing shortfall; to maximize our contributions to mCDR research we will need to expand this critical infrastructure.

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Representative Kevin Mullin

1. ***What permit requirements exist for mCDR pilot projects and what are the expected timelines related to each? How do these requirements impact businesses in their decisions to conduct research in the United States versus international locations?***

   mCDR pilot projects are permitted by the EPA, USACE, or an authorized state agency pursuant to the Clean Water Act (Section 402 or Section 404) and the Marine Protection, Research, and Sanctuaries Act. EPA has information available on their mCDR permitting website about MPRSA permits and Clean Water Act Section 402 (National Pollutant Discharge Elimination System) permits for mCDR activities in coastal and ocean waters. Other requirements under Federal, state, Tribal, or local laws that would apply to a particular mCDR pilot project would depend on the location and nature of a proposed project. EPA and USACE can provide further detail on the permit requirements and expected timelines for permitting of mCDR pilot projects.

   In addition to expanded research on the ecological effects of mCDR, NOAA is committed to rigorous evaluation of proposed mCDR projects through its statutory responsibilities. Federal agencies that fund, conduct, or permit mCDR projects may need to consult with NOAA-NMFS pursuant to the Endangered Species Act (Section 7) or the Essential Fish Habitat provisions of the Magnuson-Stevens Act if the actions may impact protected species or essential fish habitats. In addition, project proponents may need to pursue an Incidental Harassment Authorization from NOAA-NMFS under the Marine Mammal Protection Act and potentially a permit under the National Marine Sanctuaries Act.

   The United States has long-standing laws that work together to ensure the protection of human health and the marine environment. These laws rely on project applicants to describe their proposed activities and consider the effects of their activities. Other countries may have different permitting requirements.

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Representative Maxwell Frost

1. ***Many of the proposed mCDR techniques pose significant dangers to our fragile ocean ecosystems. Possible environmental damage cannot be just another factor in marine carbon removal. How will NOAA ensure an absolute minimum of environmental damage in both the research and deployment of mCDR techniques?***

   NOAA takes its stewardship of our oceans extremely seriously. A critical component of our mCDR research is to understand how species and ecosystems will respond to various approaches. While there are risks associated with any emerging strategies to draw down carbon from the atmosphere, there are also increasing risks from climate change itself. Climate change and associated phenomena like ocean acidification are, and will continue to, harm species and ecosystems under current emissions trajectories. We need to understand the efficacy of mCDR and ecosystem responses to mCDR to enable policymakers to make fully informed decisions.

   This is why NOAA is currently supporting the foundational research that will allow us to assess the impacts of mCDR on ocean ecosystems. Most of the mCDR methods are currently in their infancy. Each mCDR approach presents specific potential environmental responses (both positive and negative) and foundational research can assess these potential environmental responses. For example, further research is needed into whether some approaches can mitigate or exacerbate ocean acidification, increase oxygen depletion (hypoxia), and other co-benefits or detriments to marine ecosystems, so we can make informed decisions.

   It is incumbent on the U.S. Government to understand all dimensions of proposed mCDR approaches. This includes social science studies and community engagement directed at understanding community perspectives of mCDR strategies along with their socioeconomic and environmental impacts. Programs to inform coproduction and co-development processes can empower communities towards evidence-based decision making about mCDR.

   Additional study by the entire research community is needed to assess technical readiness, effectiveness, efficiency, ecological risk, and socioeconomic impact, and help better articulate the risks associated with each method. Throughout any mCDR projects now and in the future NOAA will ensure full compliance with its broad legal authorities to protect ecosystems and marine life using all tools at its disposal including: required consultations, coordination with state and Federal partners, permits, and enforcement proceedings.

In addition to expanded research on the ecological effects of mCDR, NOAA and other Federal agencies are committed to rigorous evaluation of proposed mCDR projects through its statutory responsibilities under the Endangered Species Act, Magnuson-Stevens Act, Marine Mammal Protection Act, and National Marine Sanctuaries Act. Federal agencies that fund, conduct, or authorize (permit) an mCDR project may need to consult with NOAA-NMFS pursuant to the Endangered Species Act (Section 7) and the Essential Fish Habitat provisions of the Magnuson-Stevens Act. In addition, project proponents may need to pursue an Incidental Harassment Authorization from NOAA-NMFS under the Marine Mammal Protection Act.

2. ***If one or more of these techniques starts to be clearly impractical or dangerous to the environment, does NOAA and DOE have an offramp for their additional funding?***

mCDR technologies are in the early stages of development. At every step along the way, activities may need to be modified to ensure that mCDR-related activities comply with the requirements of the Endangered Species Act, Marine Mammal Protection Act, and other Federal statutes.

NOAA consultations to assess risks to ecosystems, particularly protected or economically important species, are required by law. Foundational research informs these consultations – therefore if research indicates unacceptable detrimental impacts to ecosystem and fisheries, further research would not move forward.

Finally, while standards and verification protocols are still in development by the community broadly, in general NOAA is guided by our charge to responsibly steward the marine environment and public resources. NOAA will continue to fund research into mCDR pathways to build the knowledge needed to determine pathway effectiveness and to understand the overall outcomes for the ocean.

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Representative Paul Tonko

1. ***How should the federal government help guarantee that local communities are meaningfully included in decision-making processes for marine carbon dioxide removal trials and projects?***

   It is clear that a successful mCDR research strategy at the agency will require centralized leadership, strong communication, and early invested community engagement. It is incumbent on the Federal government to expand social science efforts, community engagement, and communication so that we can better understand how communities perceive the approaches, incorporate community questions into project designs, and improve communication about the science behind these technologies. NOAA has a long history of working across all levels in the management of fisheries, endangered species and other marine resources, and understands the collective action of a community can greatly improve the research we do. Incorporating communities in mCDR co-design and decision making in U.S. ocean and coastal regions will allow NOAA to improve iterative pathways to align NOAA's research capabilities with community and rights holder's needs. NOAA's 2023 Strategy for CDR Research lays out a vision for how the agency can work with its partners in the Federal approach to mCDR. Additionally, NOAA and its partners on the Fast Track Action Committee for mCDR (mCDR-FTAC) held multiple listening sessions in the course of formulating its upcoming report, to ensure Tribes and other communities' voices were heard and considered in report writing.

   NOAA strives to transition research and development into operations, applications, commercialization, and other uses that have a positive impact on the lives of the American people every day. NOAA Sea Grant could serve as a mechanism to foster successful engagement on mCDR within communities. In FY24, Sea Grant announced funding for a Law and Policy Symposium on mCDR that will increase engagement and information sharing at the state and regional level. Sea Grant is a partnership program between NOAA and universities in every coastal and Great Lakes state, that brings science together with communities. Sea Grant's education programs, which effectively communicate scientific research to diverse local and regional audiences, can be utilized to raise awareness and understanding of proposed mCDR research projects. Sea Grant's regional and community-focused approach can help ensure the effectiveness and sustainability of mCDR initiatives while building trust, fostering collaboration, and ensuring that projects are informed by local knowledge and concerns.

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2. ***How should we craft comprehensive research codes of conduct to ensure that mCDR projects both protect marine ecosystems and safeguard the livelihoods of those dependent on them?***

   Responsible mCDR relies on a foundation of strong science with open and accessible data, invested community involvement, and environmental stewardship. NOAA has a long history of working with industry, nonprofits and governments at all levels in the management of fisheries, endangered species and other marine resources. NOAA must also engage with impacted Tribal nations and Indigenous communities, and conduct formal consultations when applicable. NOAA will also seek input from ocean-based and coastal industries to inform the co-development of such a code of conduct. NOAA engages robustly with the international research and ocean regulatory community, which is important given that some mCDR methods may be tested and deployed in open-ocean international waters in ways that would affect U.S. interests. In addition, concerns around ethical implementation of CDR are at the forefront of growing scientific research. Through active engagement with nonprofits and community organizations, NOAA would like to see a code of conduct align with our mission of science, service, and stewardship.

3. ***The F-TAC has brought together agencies beyond NOAA and DOE, including NIST, NSF, and NASA. Given the multidisciplinary nature of mCDR, would you agree that these agencies play an essential role in advancing research, development, and demonstration efforts? What steps can we take to ensure their contributions are fully realized?***

   The mCDR Fast Track Action Committee, or mCDR-FTAC, continues to stress the importance of coordination between all mentioned agencies, plus the Environmental Protection Agency, U.S. Geological Survey, the U.S. Army Corps of Engineers and other agencies, on mCDR research and development. NOAA strongly recognizes that mCDR research cuts across agency mission lines, which is why our interagency partnerships are of utmost importance. NOAA has led two marine carbon dioxide removal funding calls through the National Oceanographic Partnerships Program (NOPP), the latest in partnership with DOE, NSF, and the Office of Naval Research. We have formalized our partnership with DOE on mCDR through a five-year Memorandum of Agreement, signed in June 2024. The mCDR-FTAC released a National Marine Carbon Dioxide Removal

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Research Strategy[2] on November 12, 2024, which provides recommendations on how agencies can continue to collaborate on mCDR research and development. NOAA encourages any future legislation establishing new steering committees or reports on mCDR to align with the mCDR-FTAC's work and recommendations to ensure consistency with established goals.

[2] https://www.whitehouse.gov/wp-content/uploads/2024/11/U.S.-Marine-Carbon-Dioxide-Removal-Research-Strategy.pdf

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Representative Derek Kilmer

1. ***My district is home to the Pacific Northwest National Laboratory in Sequim, which houses the only marine research facility in the Department of Energy complex, and a unique and thriving maritime sector.***

   I'm proud to have introduced legislation that will supercharge marine energy research, including marine carbon dioxide removal (mCDR), the Blue Ocean Energy Innovation Act. I am excited to see these technologies advance to keep our oceans healthy and our coastal communities strong.

   What research infrastructures can support progress on mCDR? Additionally, how can we ensure that this research infrastructure is established in the locations that it can be most impactful, whether through access to resources or through colocation of the power source and sensing technologies?

   NOAA is a central coordinator across Federal agencies for mCDR research. NOAA has been working very closely with other agencies, particularly DOE, on fostering a whole-of-government collaborative approach to mCDR work. In June 2024, NOAA and DOE's Office of Fossil Energy and Carbon Management, Office of Science, and Office of Energy Efficiency & Renewable Energy Water Power Technologies Office announced they had signed a Memorandum of Agreement (MOA) establishing the basis for a collaborative relationship on mCDR research and development. NOAA recognizes that mCDR research cuts across agency mission lines, and has also worked closely with the Fast Track Action Committee on mCDR and its member agencies to help produce the recent National mCDR Research Strategy to promote continued interagency collaboration and coordination.

   We are working hand in hand with the DOE to grow both agencies' involvement in mCDR work, and to coordinate to ensure that there is no duplication of effort and that each agency is focusing its work on areas which play to its strengths. In this relationship, NOAA is leading basic research on mCDR's efficacy and potential impacts and co-benefits, as well as ocean, atmosphere, and carbon monitoring capabilities. DOE is poised to lead in scaling up mCDR pathways, technology development and associated carbon markets.

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One of the first initiatives under this MOA will be to study what areas hold the most promise, and what infrastructure and capabilities are needed to centralize mCDR research. Centralized research facilities could support projects as they progress from lab to field, and offer constrained and well-studied environments for small-scale field research, when appropriate. Facilities such as these make field research that is critically needed more feasible, by decreasing cost and diminishing risk per field trial. Centralized research facilities can also aid in minimizing ecological risks, improve ecological risk/benefit analysis, and in permitting processes.

Additionally, expanded high performance computing and ocean observing infrastructure would greatly advance NOAA's progress on mCDR. NOAA is a global leader in ocean observations, but will need to grow its network to maintain its current observing portfolio while providing authoritative observations of mCDR field trials. As previously noted, one of NOAA's key roles in this space is to provide the observations of baseline ocean conditions necessary to establish changes from mCDR, and the finer grained observations of specific projects to begin the development and refinement of measurement, monitoring, reporting, and verification (MMRV) standards. NOAA's oceans and ecosystem modeling expertise will also form a key portion of its contributions to mCDR research. However, the agency is already facing a research supercomputing shortfall; to maximize our contributions to mCDR research we will need to expand this critical infrastructure.

Responses by Mr. Ben Tarbell

Responses to Questions for the Record from the House Committee on Science, Space, and Technology

Submitted by Ben Tarbell, CEO & Co-Founder, Ebb Carbon

Questions from Representative Brian Babin

1. Can you please explain the use of olivine sand to remove carbon and if its use could also aid with protecting coastline communities and fragile ecosystems?

Ebb Carbon does not use olivine sand in its marine carbon dioxide removal (mCDR) approach, so we are not best suited to assess its specific benefits or drawbacks. Our technology focuses on ocean alkalinity enhancement (OAE) through an electrochemical process that removes acid from seawater, increasing its capacity to absorb and store atmospheric CO2 as bicarbonate. While olivine weathering is another promising method under the broader OAE umbrella, it involves the physical addition of crushed minerals to the ocean and carries different logistical, regulatory, and ecological considerations.

2. I've heard a little bit about this and wondering what is being done to evaluate the use of olivine sand as part of mCDR research?

While Ebb Carbon is not currently involved in olivine sand research, we recognize its potential and understand that other companies and research groups are actively studying it. For example, Project Vesta has been exploring coastal olivine deployment.

3. What U.S.-based companies are actively leading field trials in OAE, and what are the unique co-benefits of these companies' approaches?

Ebb Carbon is proud to be a U.S.-based leader in ocean alkalinity enhancement (OAE), conducting field trials in collaboration with federal agencies including the Department of Energy (DOE) and the National Oceanic and Atmospheric Administration (NOAA). Our electrochemical technology removes acidity from seawater, enhancing its natural ability to absorb atmospheric CO_2—without adding solid materials to the ocean. This process offers a key co-benefit: localized reduction in ocean acidity, which supports shell-forming organisms and acidification-sensitive ecosystems. By using brine—a salty byproduct of freshwater production—as our feedstock, we also help desalination facilities reduce their environmental footprint and convert waste into value.

Questions from Representative Suzanne Bonamici (and similar from Rep. Derek Kilmer)

1. What research infrastructures can support progress on mCDR? Additionally, how can we ensure that this research infrastructure is established in the locations that it can be most impactful, whether through access to resources or through colocation of the power source and sensing technologies?

Ebb Carbon's current projects benefit directly from co-located research infrastructure. Our collaboration with the Pacific Northwest National Laboratory (PNNL) in Sequim, Washington, has enabled us to test our system in a marine setting using DOE-supported infrastructure, analytical labs, and NOAA scientific guidance. Locations with access to seawater intakes, low carbon power, and marine science facilities are ideal for supporting mCDR research. To maximize impact, infrastructure investments should prioritize areas with relevant technical expertise, community interest, and power and ocean monitoring capabilities—such as university coastal campuses, marine labs, and areas impacted by acidification.

Questions from Representative Kevin Mullin

1. What permit requirements exist for mCDR pilot projects and what are the expected timelines related to each? How do these requirements impact businesses in their decisions to conduct research in the United States versus international locations?

Ebb Carbon was the first company to secure a National Pollutant Discharge Elimination System (NPDES) permit under the U.S. Clean Water Act for Project Macoma, our ocean alkalinity enhancement (OAE) pilot project in Washington State. In total, we obtained 10 local, state, and federal permits to enable the project. The foundational science behind OAE is well understood; the next critical step is enabling in-water pilot projects that advance field-scale understanding and inform safe, effective deployment.

To that end, we support federal efforts to modernize permitting pathways—to clarify, streamline, and adequately resource the process—so that science-based pilot demonstrations can move forward responsibly and efficiently. While Ebb can and will operate under the existing permitting regime, it is designed to mitigate waste byproducts, which outflows from Ebb projects are not. Because current permitting regimes are not fit for purpose for mCDR (which provides environmental benefits), we have proposed that the U.S. EPA, in coordination and consultation with interested States and Tribes, establish a general permit under the NPDES program specifically for marine carbon dioxide removal (mCDR) and OAE. This general permit should include a "fundamentally different factors" variance to authorize the discharge of alkaline-enhanced seawater with a higher-than-ambient pH for the purpose of drawing down and storing CO_2 as bicarbonate. Such a framework would provide regulatory clarity while maintaining strong environmental safeguards, enabling the U.S. to lead in the responsible advancement of ocean-based carbon removal.

Questions from Representative Maxwell Frost

1. We have to reduce the amount of carbon in our air as soon as possible. What makes the ocean alkalinity enhancement that Ebb Carbon deploys one of the most scalable types of marine carbon removal?

The National Academies of Sciences has identified enormous potential for ocean-based carbon removal, including Ocean Alkalinity Enhancement (OAE), which could remove up to 1–3 $GtCO_2$

per year globally by 2050 if scaled responsibly. Ebb Carbon's technology leverages the vast natural carbon sink of the ocean by removing acid from seawater. Our electrochemical process enhances the ocean's ability to store carbon durably and safely as bicarbonate. Modular and energy-efficient, our technology is designed for co-location with existing coastal infrastructure, such as desalination plants. This enables seamless integration with existing industries and paves the way for rapid, scalable deployment.

2. How does that scalability reflect the environmental concerns around OAE, especially when it comes to the mining of needed minerals and the introduction of toxic metals into the ocean?

Ebb Carbon's process does not introduce toxic minerals or new materials into the marine environment. Instead, our electrochemical system removes acid from seawater using membranes and returns the de-acidified seawater to the ocean. This enhances the ocean's natural ability to absorb and store atmospheric CO2 as bicarbonate. Environmental safety is central to our design, and our approach is intentionally engineered to minimize ecological impacts while providing the co-benefit of reducing local ocean acidity. Our systems are equipped with continuous monitoring capabilities during operations, and we have built-in control mechanisms that allow us to immediately shut down the system if any unexpected conditions arise, ensuring responsive and adaptive management at all times.

Questions from Representative Paul Tonko

1. How should the federal government help guarantee that local communities are meaningfully included in decision-making processes for marine carbon dioxide removal trials and projects?

The permitting process plays a vital role in ensuring community inclusion by promoting transparency and creating multiple opportunities for public input. In Washington State, where we have secured all necessary permits for our project, Ebb Carbon participated in three public comment periods tied to different stages of the permitting process. Beyond regulatory requirements, we have engaged for years with community stakeholders—including Tribal representatives, local governments, and NGOs—throughout the planning and development of our pilot project. This collaboration has been instrumental in shaping the project's design. One innovative outcome is a juvenile salmon study, co-developed with a local Tribe, that simulates in-water conditions young salmon may encounter near the project site to ensure the environment remains safe for marine life.

2. How should we craft comprehensive research codes of conduct to ensure that mCDR projects both protect marine ecosystems and safeguard the livelihoods of those dependent on them?

At Ebb Carbon, we follow the best available science, invite independent experts to review our work, and are committed to being transparent about our impacts and results. We believe that commercial projects have an important role to play in moving ocean-based carbon removal forward. By operating in the real world, projects like ours can produce valuable data, help form and improve best practices, and make sure research keeps pace with how the technology is being deployed. Pairing science and commercial deployment is key to creating a solution that is responsible, scalable, and grounded in evidence.

Responses by Dr. Scott Doney

U.S. HOUSE OF REPRESENTATIVES
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
Navigating the Blue Frontier: Evaluating the Potential of Marine Carbon Dioxide Removal

Dr. Scott Doney, Joe D. and Helen J. Kington Professor in Environmental Change, The University of Virginia

Questions submitted by Representative Brian Babin, D.D.S., Committee on Science, Space, and Technology

1. Can you please explain the use of olivine sand to remove carbon and if it's use could also aid with protecting coastline communities and fragile ecosystems?

Olivine is a magnesium-rich silicate mineral, and carbon dioxide reacts with olivine to form magnesium carbonates that are relatively soluble in seawater. This chemical weathering process potentially could be used as a form of ocean alkalinity enhancement; olivine sand grains added to beaches and shallow nearshore ecosystems will over time chemically react and dissolve into the ocean, but the natural dissolution process is relatively slow, which is why you can find olivine green sand beaches in some locations such as on the southern tip of the big island of Hawai'i. The rate or kinetics of dissolution tends to be faster for smaller sand grains because of the higher surface area to volume ratio; some studies have suggested grinding grains to very fine scale to increase dissolution. The slow dissolution complicates the measurement, monitoring, reporting and verification (MMRV) process that would involve tracking the resulting elevated seawater alkalinity and increased ocean carbon dioxide uptake signals. Also, mineral-seawater geochemistry is complex, and an additional caveat is that secondary minerals could be precipitated in olivine sands, lowering the amount of alkalinity added to seawater and reducing the efficiency of carbon dioxide removal.

Olivine-sand carbon dioxide removal could include co-benefits such as healthier coastal ecosystems and storm protection from rebuilt beaches and off-shore sand bars. A trade-off is that faster dissolution of olivine sands required for carbon dioxide removal simultaneously depletes the amount of sand remaining within replenished beaches or sand bars. One possible environmental concern with adding olivine sands is that in addition to magnesium and silicate olivine minerals and the associate ultramafic rocks contain iron and a wide range of trace elements that will be added to seawater as the olivine grains dissolve; some of these trace elements can be harmful to plankton and other organisms at sufficiently high concentrations.

2. Our coasts in Texas, especially in Galveston and surrounding areas, need assistance and all the sand they can acquire for various coastal protection projects, and if we can protect our coasts while removing carbon, that sounds like a win-win. I've heard a little bit about this and wondering what is being done to evaluate the use of olivine sand as part of mCDR research?

Olivine sand CDR approaches fit within the broader topic of ocean-based alkalinity enhancement. Much of the work in that field has been either theoretical and model-based or laboratory-based. Renforth and Henderson (2017) provides a good overview. There has been some research specifically on olivine sands including some recent laboratory scale dissolution experiments (e.g., Hangx and Spiers, 2009; Fuhr et al., 2022). USGS scientists and research partners are conducting studies on olivine addition to marshes to study the effectiveness for CDR (https://www.usgs.gov/news/science-snippet/can-oceans-store-more-co2-help-climate-change). I also understand the company Vesta has begun beach and near-shore field trials (https://www.vesta.earth/science).

Hangx SJT, Spiers CJ. 2009. Coastal spreading of olivine to control atmosphericCO2 concentrations: a critical analysis of viability. Int. J. Greenh. Gas Control 3:757–67. https://doi.org/10.1016/j.ijggc.2009.07.001

Fuhr M, Geilert S, Schmidt M, Liebetrau V, Vogt C, Ledwig B and Wallmann K (2022) Kinetics of Olivine Weathering in Seawater: An Experimental Study. Front. Clim. 4:831587. https://doi.org/10.3389/fclim.2022.831587

Renforth, P., and G. Henderson (2017), Assessing ocean alkalinity for carbon sequestration, Reviews of Geophysics., 55, 636–674, https://doi.org/10.1002/2016RG000533

According to NOAA's Strategy for Carbon Dioxide Removal (CDR) Research, the category of mCDR known as ocean alkalinity enhancement (OAE) stands out as the lowest cost and most effective approach. Likewise, this strategy acknowledges that many mCDR approaches provide co-benefits.

3. What U.S. based companies are actively leading field trials in OAE, and what are the unique co-benefits of these company's approaches?

As a university professor and research scientist, I am familiar with only a limited subset of the companies joining this rapidly evolving technology space. The non-profit organization Ocean Visions (https://oceanvisions.org/) is building an Ocean CDR community spanning across academia and industry. They have compiled a list of over two dozen companies with descriptions of their CDR approaches (https://community.oceanvisions.org/organizations?categories=company) with the caveat on the Ocean Visions website that "*All descriptions above are provided by the affiliated members of the organizations and not by Ocean Visions or the Ocean CDR Community*."

Questions submitted by Representative Suzanne Bonamici, Committee on Science, Space, and Technology

The National Academies recommend nearly $2.5 billion over ten years for research activities related to marine carbon dioxide removal, but NOAA does not have a dedicated program with authorized funding to work on this important issue.

1. Why should Congress authorize and appropriate these substantial new resources?

The funding recommendations in the 2022 National Academies report (NASEM, 2022) were based on the broad question "What research investments are needed in the near-term to develop a sufficient knowledge base to support future decisions on whether or not to deploy specific marine carbon dioxide removal technologies." A concern within parts of the ocean research community is that the rate at which we are improving understanding about marine carbon removal efficacy and environmental impacts is not keeping pace with the rollout of new technologies by industry. This knowledge gap will make it more difficult for regulators, government leaders, and communities to make informed decisions on when, where, and even if some form of marine CDR can serve as a safe, effective, and scalable climate solution. Federally supported research investments are likely warranted because they typically are rigorous, independent, and transparent, providing a unique external perspective on proposed industrial approaches and projects. Federal research will be especially valuable if it includes adequate support for in-depth measurement, monitoring, reporting, and verification (MMRV) and environmental impact assessment.

NASEM (Natl. Acad. Sci. Eng. Med.). 2022. A research strategy for ocean-based carbon dioxide removal and sequestration. Report from NASEM, Washington, DC. https://doi.org/10.17226/26278

2. What specific resources, including updated programmatic funding levels, would be most useful to conduct this work?

The research recommendations in the 2022 National Academies report (NASEM, 2022) could be used to guide prioritization for targeted marine carbon dioxide removal research investments. While the total recommended funding levels in the report are quite large over a decade time horizon (Tables S.2 and S.3 in the report Summary), the report does provide options for a more focused and smaller funding portfolio focused on high priority topics. This prioritization includes foundational, cross-cutting research topics common to all marine CDR such as governance and MMRV frameworks (NASEM, 2022; Table S.2) as well as priority research needs for specific biotic and abiotic approaches (NASEM, 2022; Table S.3). The rapidly growing interest in alkalinity enhancement and electrochemical approaches by industry could be one factor used to guide decisions on allocating research resources to specific CDR technologies.

NASEM (Natl. Acad. Sci. Eng. Med.). 2022. A research strategy for ocean-based carbon dioxide removal and sequestration. Report from NASEM, Washington, DC. https://doi.org/10.17226/26278

Questions submitted by Representative Kevin Mullin, Committee on Science, Space, and Technology

1. What permit requirements exist for mCDR pilot projects and what are the expected timelines related to each? How do these requirements impact businesses in their decisions to conduct research in the United States versus international locations?

The permitting process for marine CDR field experiments is governed by federal regulatory agencies including the EPA, US Army Corps of Engineers, and NOAA under existing statues such as the Marine Protection, Research and Sanctuaries Act (MPRSA) or Clean Water Act - National Pollutant Discharge Elimination System (https://www.epa.gov/ocean-dumping/permitting-mcdr-and-msrm). As a university professor and researcher, I am not involved in permitting processes or decisions. The regulatory federal agencies are better placed to answer specific questions related to the permitting processes, timelines, or possible impacts on businesses.

Questions submitted by Representative Maxwell Frost, Committee on Science, Space, and Technology

1. In the table you provided with your testimony, only one carbon removal technique had a low environmental risk. That is ecosystem conservation. Ecosystem conservation is also well understood and provides many other benefits. Is work being done to maximize the role of conservation and ecosystem restoration in CO2 removal?

A number of research efforts are directed at better understanding the potential for conservation and carbon removal win-win situations for coastal blue carbon ecosystems that include marshes, mangroves, and seagrass. The National Academies of Sciences, Engineering, and Medicine recently conducted a review on land-based carbon removal approaches with a detailed chapter on coastal blue carbon

(NASEM, 2019), and the 5th National Climate Assessment included a specific, though brief focus on blue carbon (May et al., 2023). The Congressional Research Service (CRS) recently released a report on coastal blue carbon including sections on "*Federal Agency Policy and Authorities Related to Coastal Blue Carbon Science*" and "*Federal Agency Research Coordination and Collaboration on Coastal Blue Carbon Ecosystems*". The CRS report sections are comprehensive and up to date.

Congressional Research Service, 2024. Coastal Blue Carbon as a Carbon Dioxide Removal Approach: Selected Issues for Congress, https://crsreports.congress.gov/product/pdf/R/R48148/5

May, C.L., A.R. Crimmins, S.R. Cooley, E. Fleishman, E.E. Grossman, B. Helmuth, R.A. MacKenzie, D.R. Ramirez Lopez, and E. Wasley, 2023: Focus on blue carbon. In: Fifth National Climate Assessment. Crimmins, A.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, B.C. Stewart, and T.K. Maycock, Eds. U.S. Global Change Research Program, Washington, DC, USA. https://doi.org/10.7930/NCA5.2023.F5

NASEM (Natl. Acad. Sci. Eng. Med.). 2019. Negative emissions technologies and reliable sequestration: a research agenda. Report from NASEM, Washington, DC. https://doi.org/10.17226/25259

Measurement, monitoring, reporting, and verification (MMRV) protocols are under development or already in use to quantify carbon storage and greenhouse gas emissions for coastal blue carbon habitats for carbon accounting and national emissions inventory reporting (Crooks et al. 2018, Oreska et al. 2020), though with substantial uncertainties (Holmquist et al. 2018). The extent to which blue-carbon restoration can serve as a cost-effective climate mitigation option is also open to debate (Williamson & Gattuso 2022).

Crooks S, Sutton-Grier AE, Troxler TG, Herold N, Bernal B, et al. 2018. Coastal wetland management as a contribution to the US National Greenhouse Gas Inventory. Nat. Clim. Change 8:1109–12. https://doi.org/10.1038/s41558-018-0345-0

Holmquist JR,Windham-Myers L, Bliss N, Crooks S, Morris JT, et al. 2018. Accuracy and precision of tidal wetland soil carbon mapping in the conterminous United States. Sci. Rep. 8:9478. https://doi.org/10.1038/s41598-018-26948-7

Oreska MPJ, McGlathery KJ, Aoki LR, Berger AC, Berg P, Mullins L. 2020. The greenhouse gas offset potential from seagrass restoration. Sci. Rep. 10:7325. https://doi.org/10.1038/s41598-020-64094-1

Williamson P, Gattuso J. 2022. Carbon removal using coastal blue carbon ecosystems is uncertain and unreliable, with questionable climatic cost-effectiveness. Front. Clim. 4:853666. https://doi.org/10.3389/fclim.2022.853666

Recent research expands beyond coastal blue carbon to the potential of conservation-based CDR approaches for benthic, pelagic, and offshore ocean ecosystems, including macroalgae and marine animals (Christianson et al. 2022). However, the knowledge base and research investments on the efficacy of these approaches for pelagic ecosystems is considerably less mature than for coastal blue carbon, and some current claims for the potential of pelagic conservation-based CDR approaches are not yet supported by systematic scientific assessments.

Christianson A, Cabre A, Bernal B, Baez SK,Leung S, et al. 2022. The promise of blue carbon climate solutions: where the science supports ocean-climate policy. Front. Mar. Sci. 9:851448. https://doi.org/10.3389/fmars.2022.851448

2. You have a low confidence in the efficacy of artificial upswelling and downswelling. Is mCDR research evaluated on a regular basis for both its practicality and environmental impact?

I am not aware of a recurring, systematic assessment of marine CDR research within the U.S research community, though it's possible that the upcoming Marine CDR Fast Track Action Committee report will include such a recommendation. The National Academies of Sciences, Engineering, and Medicine recently released a comprehensive, one-time review on the topic (NASEM, 2022). NOAA recently released a white paper on a strategy for carbon dioxide removal that included marine approaches (https://sciencecouncil.noaa.gov/wp-content/uploads/2023/06/mCDR-glossy-final.pdf), and the agencies typically track their current and recently funded projects (e.g., NOAA Ocean Acidification Program, https://oceanacidification.noaa.gov/carbon-dioxide-removal/). An international review was released by GESMAP (2019) – a group of independent scientific experts that provides advice to the UN system on scientific aspects of marine environmental protection. I also anticipate that marine CDR research will be reviewed in some depth in the next round of scientific assessments from the Intergovernmental Panel on Climate Change (IPCC).

GESAMP (Joint Group Experts on the Scientific Aspects of Marine Environmental Protection). 2019. High level review of a wide range of proposed marine geoengineering techniques. Rep. Stud. 98, International Maritime Organization, London. http://www.gesamp.org/publications/high-level-review-of-a-wide-range-of-proposed-marine-geoengineering-techniques

NASEM (Natl. Acad. Sci. Eng. Med.). 2022. A research strategy for ocean-based carbon dioxide removal and sequestration. Report from NASEM, Washington, DC. https://doi.org/10.17226/26278

Questions submitted by Representative Paul Tonko, Committee on Science, Space, and Technology

1. How should the federal government help guarantee that local communities are meaningfully included in decision-making processes for marine carbon dioxide removal trials and projects?

While the federal regulatory permitting process provides one avenue for community and general-public input on marine carbon dioxide removal research, additional steps both before and after permitting are likely needed for full transparency, public engagement, and development of social license for marine carbon dioxide removal. Typically, field research projects are fully designed by the time they reach the step of requesting public comments for a permit. This can lead to a confrontational atmosphere where communities and the public are asked to either support or not an existing research plan. An alternate approach could involve requirements for closer community collaboration and two-way discussions during the project planning and development phases where the perspectives and priorities of the community are factored in from the beginning of the process and in the experimental design. Further, community engagement is needed while the research is being conducted, particularly in the evaluation of environmental impacts, reversibility or recovery of any identified damages, and discussions on experimental continuance or termination. After the completion of the field work, engagement can help transmit scientific findings as they coming into focus. The recent National Academies of Sciences, Engineering, and Medicine report (NASEM, 2022) and a review article by Cooley et al. (2023) provide discussion on engagement approaches. The 2023 federal Ocean Justice Strategy (https://www.whitehouse.gov/wp-content/uploads/2023/12/Ocean-Justice-Strategy.pdf) also provides recommendations on approaches for effective, open and equitable community engagement.

Cooley SR, Klinsky S, Morrow DR, Satterfield T. 2023. Sociotechnical considerations about ocean carbon dioxide removal. Annu. Rev. Mar. Sci. 15:41–66. https://doi.org/10.1146/annurev-marine-032122-113850

NASEM (Natl. Acad. Sci. Eng. Med.). 2022. A research strategy for ocean-based carbon dioxide removal and sequestration. Report from NASEM, Washington, DC. https://doi.org/10.17226/26278

2. How should we craft comprehensive research codes of conduct to ensure that mCDR projects both protect marine ecosystems and safeguard the livelihoods of those dependent on them?

Loomis et al. (2022) provide a useful framing for the rationale and elements of a research code of conduct:

"By encouraging researchers to assess, minimize, and publicize the impacts of their experiments, a code of conduct could reduce the harm done by field experiments. And by promoting principles that would encourage the growth of a rigorous body of research—such as rules requiring the disclosure of funding or the peer review and publication of results—a code of conduct could help researchers transparently and honestly determine the efficacy of ocean-based CDR technologies, which they must do if those technologies are to play a meaningful role in climate mitigation."

Some groups, including the Aspen Institute (2023), have released codes of conduct that could be adopted either in whole or in part by the U.S. academic, federal and industrial ocean research sectors. The Aspen Institute's code was developed from eight interconnected foundational principles – awareness of power imbalances, inclusiveness, consent, reciprocity, reflexivity, responsiveness and trust, accountability, anticipation and precaution – broadly similar to code frameworks suggested by several other groups. Next steps should include much broader discussions with academia, federal science, industry, environmental stakeholder groups, and the general public to develop wide buy-in for an agreed upon code of conduct. Any research code of conduct needs to be consistent with regulatory and permitting requirements, and therefore federal and state regulatory agencies need to be involved throughout the development process.

Aspen Institute, 2023. A Code of Conduct for Marine Carbon Dioxide Removal Research, Aspen Institute Energy and Environment Program, https://www.aspeninstitute.org/publications/a-code-of-conduct-for-marine-carbon-dioxide-removal-research/ and https://www.aspeninstitute.org/wp-content/uploads/2023/11/110223_Code-of-Conduct_FINAL2.pdf

Loomis R, Cooley SR, Collins JR, Engler S and Suatoni L (2022) A Code of Conduct Is Imperative for Ocean Carbon Dioxide Removal Research. Front. Mar. Sci. 9:872800. https://doi.org/10.1146/10.3389/fmars.2022.872800

Questions submitted by Representative Derek Kilmer

My district is home to the Pacific Northwest National Laboratory in Sequim, which houses the only marine research facility in the Department of Energy complex, and a unique and thriving maritime sector.

I'm proud to have introduced legislation that will supercharge marine energy research, including marine carbon dioxide removal (mCDR), the Blue Ocean Energy Innovation Act. I am excited to see these technologies advance to keep our oceans healthy and our coastal communities strong.

1. What research infrastructures can support progress on mCDR? Additionally, how can we ensure that this research infrastructure is established in the locations that it can be most impactful, whether through access to resources or through colocation of the power source and sensing technologies?

Most ocean carbon removal research areas follow a similar pathway from early small-scale laboratory experiments to later pilot-scale field perturbation experiments, often with an intermediate scale of experiments in large-volume enclosures or mesocosms. Studying the biological and ecological impacts of marine carbon dioxide removal, such as adding alkalinity to seawater, will likely require substantial laboratory and possibly mesocosm infrastructure to conduct systematic and controlled perturbations of seawater conditions. One possible pathway would be to leverage and expand on the knowledge gained from the laboratory systems used for studying the biological effects of ocean acidification. For example, there are a number of excellent facilities that combine multiple aquaria or mesocosms with high-quality controls on seawater acid-base chemistry in the Pacific Northwest including at University of Washington's Friday Harbor Laboratory (https://fhl.uw.edu/facilities-resources/other-research-facilities-resources/ocean-acidification-environmental-laboratory/) and NOAA Fisheries Northwest Science Center (https://www.fisheries.noaa.gov/west-coast/science-data/ocean-acidification-research-pacific-northwest).

Pilot field perturbation experiments will also require substantial research infrastructure, some to conduct the carbon dioxide removal perturbations themselves (e.g., adding alkalinity) and likely even larger investments in measurement, monitoring, reporting, and verification (MMRV) to track the effectiveness of the marine CDR in removing atmosphere CDR as well as evaluating the environmental impacts on marine life and ecosystems. One possible path would be to invest in targeted marine carbon dioxide removal experimental sites that could be shore-based, mooring/off-shore platform-based or ship-based. These sites could provide a common pool of monitoring instrumentation, scientific expertise, and site-based numerical models to facilitate MMRV and environmental assessment of marine CDR experiments by different groups of researchers or companies. A clear protocol for permitting for these sites could be constructed to speed research while also enhancing transparency and community engagement. One model could be DOE's PacWave sites (https://pacwaveenergy.org/) for evaluating wave energy technologies, though marine CDR would require more extensive environmental monitoring and MMRV for carbon dioxide removal.

Appendix II

ADDITIONAL MATERIAL FOR THE RECORD

LETTERS SUBMITTED BY REPRESENTATIVE MAX MILLER

*** American University, Institute for Responsible Carbon Removal * California Ocean Science Trust * Carbon to Sea Initiative * Environmental Defense Fund * Ocean Conservancy * Ocean Defense Initiative * Ocean Visions * Scripps Institution of Oceanography * Woods Hole Oceanographic Institution ***

The Honorable Mike Johnson
Speaker
United States House of Representatives
Washington, DC 20515

The Honorable Chuck Schumer
Majority Leader
United States Senate
Washington, DC 20515

The Honorable Hakeem Jeffries
Minority Leader
United States House of Representatives
Washington, DC 20515

The Honorable Mitch McConnell
Minority Leader
United States Senate
Washington, DC 20515

August 20, 2024

Dear: Speaker Johnson, Minority Leader Jeffries, Majority Leader Schumer, and Minority Leader McConnell:

We write in support of legislation and funding for research and development to evaluate the efficacy and impacts of marine carbon dioxide removal (mCDR) approaches, and to determine whether these approaches can provide safe and permanent atmospheric CO_2 removal which must occur alongside needed emissions reductions.

Scientists around the world support research to evaluate whether and which mCDR approaches can safely and permanently reduce atmospheric CO_2 while minimizing risks and equitably distributing benefits to those disproportionately impacted, such as Tribal and Indigenous groups and fishing communities. Philanthropy and the private sector are bringing important resources to this effort, but the government has a critical role to play. To conduct the needed research, testing, and community engagement to ensure that technologies are safe, effective, and properly regulated, congressional authorization and appropriations are required. Federal funding will help ensure transparency and provide vital support for innovation, knowledge development, and community engagement while at the same time providing new opportunities for public-private partnerships.

mCDR technologies that are proven safe, equitable, and effective have the potential to play a vital role in the broader effort to address the global climate challenge and represent a major economic opportunity. McKinsey and Company predicts that the CDR market could be worth up to $1.2 trillion by 2050. Legislation, regulation, and strategic research funding will benefit U.S. jobs and investments, resulting in a strong and sustainable domestic industry, and strengthen the U.S. as a global leader in developing and exporting technologies to address the climate challenge.

According to a 2022 report by National Academies of Science, Engineering and Medicine (NASEM), funding for mCDR RD&D needs to rise to about $300 million annually, for a ten-year investment of $2.41 billion. This level of investment is necessary to ensure that mCDR technologies can be evaluated at scale, while prioritizing safety and effectiveness. Similarly, a 2020 analysis by the Energy Futures Initiative (EFI) recommends a similar investment of $1 billion in federal funding over five years and $2.1 billion over ten years to advance mCDR. This level of federal research investment is required prior to consideration of any initiative to pursue mCDR at large scales and will provide critical data and insight to guide legislative and regulatory frameworks.

We urge Congress to support legislation and appropriations to evaluate and advance effective and safe strategies to remove carbon dioxide from the atmosphere. We must address the climate challenge through emissions reductions, preservation and restoration of ecosystems' natural carbon cycling capacity and by exploring equity-focused and innovative CDR approaches, including those leveraging the ocean's natural capacity to sequester carbon dioxide.

Sincerely,
American University, Institute for Responsible Carbon Removal
California Ocean Science Trust
Carbon to Sea Initiative
Environmental Defense Fund
Ocean Conservancy
Ocean Defense Initiative
Ocean Visions
Scripps Institution of Oceanography
Woods Hole Oceanographic Institution

Carbon to Sea Initiative

September 19, 2024

Congressman Frank Lucas
Chair
House Committee on Science Space
Technology
2321 Rayburn House Office Building
Washington, DC 20515

Congresswoman Zoe Lofgren
Ranking Member
House Committee on Science Space and
and Technology
2321 Rayburn House Office Building
Washington, DC 20515

Re: *Navigating the Blue Frontier: Evaluating the Potential of Marine Carbon Dioxide Removal Approaches*

Dear Chairman Lucas and Ranking Member Lofgren:

Thank you for the opportunity to submit written testimony. My name is Dr. Julie Pullen and I am a founding partner and chief scientist of Propeller Ventures, an early-stage venture fund focused on ocean climate technology. I am also a member of the Science Advisory Board for Carbon to Sea, the leading nonprofit effort to evaluate the promise of one high-potential marine carbon dioxide removal (mCDR) pathway called ocean alkalinity enhancement (OAE). I serve on the boards of several other ocean science and climate organizations, including Ocean Visions and Waterfront Alliance.

I earned my Ph.D. in physical oceanography from Oregon State University and am an adjunct research scientist at The Earth Institute at Columbia University. I am a member of the U.S. Climate Security Roundtable. I have also served on the leadership councils of the American Meteorological Society and The Oceanography Society.

OUR CLIMATE CHALLENGE

I appreciate the opportunity to discuss the need for increased investment in carbon dioxide removal technologies, particularly in mCDR, which is understudied and underfunded.

I'm grateful for this committee's leadership in building up a domestic green economy. Your support of the bipartisan Infrastructure Investment and Jobs Act and the Inflation

Reduction Act has strengthened America as a leader in climate technology and innovation, helping mitigate climate change while strengthening our economy.

Despite the progress made with those two pieces of legislation, we are still not on track to meet the emissions reduction targets set out in the Paris Agreement. We're also leaving good jobs and economic growth on the table if we don't double down on carbon dioxide removal.

Americans depend on the ocean and coastal waters for the jobs and economic contribution they generate. Unless we find solutions to the challenges that our ocean waters face, the $275 billion fishing and shellfish industry - and the nearly 2 million family-supporting jobs that rely on it - could suffer.

CDR IS A NECESSARY COMPLEMENT TO EMISSIONS REDUCTION

Scaling back fossil fuel use is the top priority to slow global warming and, at the same time, I strongly believe we must develop and responsibly scale CDR to draw down legacy carbon emissions from the atmosphere. According to the Intergovernmental Panel on Climate Change (IPCC), CDR "is required to achieve global and national targets of net zero CO_2 and greenhouse gas emissions. CDR cannot substitute for immediate and deep emissions reductions, but it is part of all modeled scenarios that limit global warming to 2° or lower by 2100." The International Energy Agency similarly reports that CDR must account for 8 percent of emission reductions in order to meet the goals outlined in the Paris Agreement.

CDR'S ECONOMIC POTENTIAL

Carbon dioxide removal is a burgeoning industry full of economic potential, which could eventually be worth anywhere from $259 billion by 2050 according to Rhodium Group, to $1 trillion by 2037 according to Bloomberg, to $1.2 trillion by 2050 according to McKinsey. The U.S. has the opportunity to lead the way on support for innovation, scientific study, and regulation for this emerging industry, in order to reap the economic rewards over the coming years. Already, investment in carbon capture facilities from the American Jobs Plan is expected to create up to 78,600 jobs by 2035, with the National Oceanic and Atmospheric Administration (NOAA) predicting a total of 300,000 new CDR jobs by 2050.

Major companies such as Microsoft and Stripe have begun investing in this technology. This year, Microsoft announced that they will be purchasing 500,000 tons of carbon removal credits over the next six years, in addition to the company's previous $200 million investment in CDR. Stripe has similarly invested $15 million into CDR, helping companies purchase carbon dioxide removal and bring emerging technologies to the market.

Those numbers signal the market's interest — and they understate it if anything. But the overall focus so far has been disproportionately weighted towards land-based methods of CDR, like DAC, reforestation, and soil regeneration efforts. They're further along, so it makes sense. But we must recognize that these are not our only options and there is more work to be done.

OCEAN-BASED CDR IS AN UNDEREXPLORED OPTION

One promising solution scientists are exploring leverages an existing natural resource: the ocean. The ocean is already the world's largest carbon sink, covering more than 70 percent of the planet and holding about 50 times more carbon than the atmosphere. Through a natural geological process, alkaline rocks like limestone wash into the ocean and alter the water to make it more alkaline than freshwater sources. This increase in alkalinity causes a chemical reaction that converts dissolved carbon dioxide into carbonates and bicarbonates, which safely remain locked away for thousands of years. That chemical reaction in turn allows the ocean to absorb more carbon dioxide from the atmosphere. The carbon is stored in the ocean for tens of thousands of years, making this geological process effectively permanent.

If we accelerate this process without creating adverse effects on the larger ecosystem, we could remove billions of tons of atmospheric carbon dioxide. It's important to say that the concept of adding alkalinity to water has been used for decades by shellfish hatcheries and to reduce acidification in rivers.

Recent laboratory[1 2 3 4] studies and controlled outdoor environmental experiments,[5 6] which simulate real-world conditions[7] on a smaller scale, show that while there are upper limits as to how much OAE should be done in any particular place,[8 9] OAE can theoretically be done in effective,[10 11 12] safe,[13 14 15] and responsible[16 17 18] ways.

GREATER PUBLIC INVESTMENT IS NEEDED

This early interest and investment in CDR and mCDR from philanthropic, public and private sectors is a strong start to build a nascent field. To support further high-quality research, attract new private sector funders, and encourage greater collaboration and professionalization within the field, greater public investment is needed. The U.S. government must play a catalytic role in strengthening investments and developing a responsible regulatory framework for the mCDR field if we hope to tap into its true market potential.

The U.S. government has already made historic investments, nearly $61.5 million, in mCDR technologies and the ocean-climate space over the last year or so. This includes $24.3 million in grants from the interagency National Oceanographic Partnership Program to advance mCDR research, which funded 17 projects with partners from 47 institutions. The DOE's ARPA-E program also awarded $35.8 million in grants to accelerate the development of mCDR technology. As just one example of this funding at work, the University of Pittsburgh was awarded $1.4 million from the Office of Naval Research to explore how desalination membranes (special filters used to separate salt and minerals from water) can support mCDR. That's just a part of overall government funding for CDR, which is more than a billion dollars so far.

In addition to funding, the White House has taken steps to build systemic, whole-of-government support for the emerging CDR market. The Ocean Climate Action Plan and Fast-Track Action Committee are specifically designed to support mCDR research and advance mCDR technologies, like OAE. Last month, the Department of Energy (DOE) and National Oceanic and Atmospheric Administration (NOAA) announced a memorandum of agreement to advance mCDR research and development, promote coordination and collaboration between agencies, and create ethical guidelines for this technology. This is an encouraging example of interagency collaboration, bringing together NOAA's ocean science expertise and the DOE's capacity to scale and advance the commercialization of technologies.

These are exciting and necessary announcements, but the U.S. must ramp up funding for mCDR research to help inform decisions about which approaches are most effective and safe for large-scale development. In order for mCDR technologies to deliver safe and effective CDR at scale, NASEM estimates that funding for R&D needs to rise to about $301.5 million annually, for a ten-year investment of $2.41 billion. Already, more than 400 scientists from around the world have called for increased R&D of mCDR to determine its efficacy and safety.

OAE IS A HIGH-POTENTIAL PATHWAY

Given the urgency of the climate crisis and the need for further research into mCDR, the U.S. should invest in a portfolio of marine CDR approaches. There are multiple mCDR pathways that could be used — for example adding alkaline-rich types of sand to the ocean, nutrient fertilization, and other biotic pathways. Each of these methods require different amounts of time, money, and resources and may have varying degrees of success at scale. But there is broad agreement among the ocean-climate scientific community that it's worth exploring these methods to determine their effectiveness, safety, and long-term potential to help mitigate climate change.

Leading research organizations like the IPCC and U.S. National Academies of Sciences, Engineering, and Medicine (NASEM) have specifically identified ocean alkalinity enhancement (OAE) as one high-potential approach that demands further exploration. In theory, OAE is a scalable, permanent, and effective way to remove carbon from the atmosphere. Researchers and scientists from academic institutions, private companies, philanthropies, and government agencies are already working to answer questions around OAE's efficiency, safety, environmental impacts, and costs. Notably, NASEM published research in 2021 advocating for the development of OAE technologies and recently, Isometric (a network of scientists) developed the world's first MRV protocol for OAE.

In order to meet global emission reduction goals and strengthen the U.S. economy, greater federal investment into marine carbon dioxide removal technology is needed. Doing so will address the worsening climate crisis and allow the U.S. to emerge as a global environmental leader.

I appreciate the opportunity to submit this testimony. Please do not hesitate to contact me should you have any questions or need any further information.

Sincerely,
Dr. Julie Pullen
Science Advisory Board Member
Carbon to Sea Initiative

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[DISCUSSION DRAFT]

118TH CONGRESS
2D SESSION

H. R. ____

To require the Administrator of the National Oceanic and Atmospheric Administration, in coordination with the Secretary of Energy, to establish a marine carbon dioxide removal and verification, research and development, and demonstration program, and for other purposes.

IN THE HOUSE OF REPRESENTATIVES

M__. ________ introduced the following bill; which was referred to the Committee on ____________

A BILL

To require the Administrator of the National Oceanic and Atmospheric Administration, in coordination with the Secretary of Energy, to establish a marine carbon dioxide removal and verification, research and development, and demonstration program, and for other purposes.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled,

SECTION 1. SHORT TITLE.

This Act may be cited as the "Marine Carbon Dioxide Removal Research and Development Act of 2024".

SEC. 2. DEFINITIONS.

In this Act:

(1) ADMINISTRATOR.—The term "Administrator" means the Administrator of the National Oceanic and Atmospheric Administration.

(2) APPROPRIATE COMMITTEES OF CONGRESS.—The term "appropriate committees of Congress" means the following:

(A) The Committee on Science, Space, and Technology of the House of Representatives.

(B) The Committee on Natural Resources of the House of Representatives.

(C) The Committee on Commerce, Science, and Transportation of the Senate.

(D) The Committee on Energy and Natural Resources of the Senate.

(3) DIRECTOR.—The term "Director" means the Director of the Office of Science and Technology Policy.

(4) MARINE CARBON DIOXIDE REMOVAL.—The term "marine carbon dioxide removal" (commonly referred to as "ocean-based carbon dioxide removal") means the deliberate enhancement of oceanic uptake of carbon dioxide from the atmosphere, combined with the durable and long-lived storage of such carbon dioxide, which results in a net removal

of carbon dioxide from the atmosphere, as measured on a lifecycle basis.

(5) NATIVE HAWAIIAN.—The term "Native Hawaiian" has the meaning given such term in section 6207 of the Elementary and Secondary Education Act of 1965 (20 U.S.C. 7517).

(6) SECRETARY.—The term "Secretary" means the Secretary of Energy.

(7) INDIAN TRIBE.—The term "Indian Tribe" has the meaning given such term in section 4 of the Indian Self-Determination and Education Assistance Act (25 U.S.C. 5304).

SEC. 3. MARINE CARBON DIOXIDE REMOVAL AND VERIFICATION RESEARCH AND DEVELOPMENT PROGRAM.

(a) AGENCY AUTHORITY.—The Administrator, in collaboration with the Secretary, shall establish the Marine Carbon Dioxide Removal and Verification Research and Development Program (in this Act referred to as the "Program").

(b) REQUIREMENTS.—

(1) NOAA.—In carrying out the Program, the Administrator shall collaborate with the Secretary to carry out the following:

(A) Establish the goals, priorities, and metrics for a plan to accelerate research, development, and short-, medium-, and long-term demonstration of marine carbon dioxide removal in the United States.

(B) Support Federal marine carbon dioxide removal research, development, demonstration, and commercial application activities, to achieve the goals, priorities, and metrics established pursuant to subparagraph (A).

(C) Partner with industry, universities, and other entities as the Administrator determines appropriate to leverage knowledge and resources.

(D) Support activities to develop a marine carbon dioxide removal and measurement, monitoring, reporting, and verification science, technology, and engineering workforce pipeline.

(E) Develop ecosystem impact assessments to understand the effects on marine ecosystems, including culturally and economically significant species, of marine carbon dioxide removal.

(F) Oversee measurement, monitoring, reporting, and verification of marine carbon dioxide removal approaches undertaken by researchers or other entities pursuant to this Act.

(G) Assess the ability of marine carbon dioxide removal approaches to durably remove carbon dioxide from the atmosphere.

(H) Research and develop tools, sensors, and models to collect and represent baseline information on metocean, geotechnical, geophysical, and biological conditions in marine environments that can effectively demonstrate permanent carbon dioxide storage.

(I) Conduct lifecycle assessments of carbon dioxide emissions removed by a marine carbon dioxide removal approach specified in subsection (c).

(J) Conduct research to establish potential environmental responses to marine carbon dioxide removal projects, and provide a detailed risk assessment of potential harms.

(K) Develop advanced materials capable of enduring harsh environmental conditions.

(L) Develop tools or mechanisms to avoid or minimize conflicts or create synergies between marine carbon dioxide removal research, development, demonstration, and commercial application activities and other ocean uses.

(M) Avoid conflicts with or harm to existing marine protected areas.

(N) Avoid or minimize any adverse impacts of marine carbon dioxide removal research, development, demonstration, and commercial application activities on coastal communities, Indian Tribes, and Native Hawaiian communities, and maximize the participation of such communities and Indian Tribes in such activities with co-design principles.

(O) Develop education and outreach materials to engage with the public on the benefits and risks of marine carbon dioxide removal.

(P) Require each recipient of Program funding to certify such recipient understands and will follow the research and development Code of Conduct developed under section 4(d).

(Q) Establish a unified marine carbon dioxide removal data management strategy to ensure data collected pursuant to this Act are safeguarded and made findable and accessible for subsequent research and decision-making pursuant to subchapter II of chapter 3 of part

I of title 5, United States Code, and preserve and curate such data and metadata in accordance with chapter 31 of title 44, United States Code.

(2) DOE.—In carrying out the Program, the Secretary shall carry out the following:

(A) Designate the Office of Fossil Energy and Carbon Management of the Department of Energy to coordinate with the Biological and Environmental Research Program of the Office of Science of the Department, and other offices of the Department, to ensure the efficient exchange of information, research, and resources regarding marine carbon dioxide removal.

(B) Support, coordinate with, and augment the ability of the Administrator to carry out the activities described in paragraph (1).

(C) Leverage existing Department investments efficiently to advance Program goals and priorities established under paragraph (1).

(c) MARINE CARBON DIOXIDE REMOVAL APPROACHES SPECIFIED.—Marine carbon dioxide removal approaches specified in this subsection include the following:

(1) Nutrient fertilization.

(2) Ocean alkalinity enhancement.

(3) Electrochemical engineering methods, such as direct ocean capture.

(4) Artificial upwelling and downwelling.

(d) INTERAGENCY COORDINATION.—In carrying out the Program, the Administrator and the Secretary shall coordinate with the heads or appropriate designees of the following Federal departments and agencies:

(1) The Department of Defense.

(2) The Department of Interior.

(3) The Department of State.

(4) The Environmental Protection Agency.

(5) The National Aeronautics and Space Administration.

(6) The National Institute of Standards and Technology.

(7) The National Science Foundation.

(8) The White House Council on Environmental Quality.

(9) The White House Office of Science and Technology Policy.

(10) Any other Federal department or agency the Administrator determines appropriate.

(e) FUNDING.—

(1) IN GENERAL.—To carry out the Program, there are authorized to be appropriated to the Administrator the following:

(A) $24,000,000 for fiscal year 2025.

(B) $30,000,000 for fiscal year 2026.

(C) $35,000,000 for fiscal year 2027.

(D) $40,000,000 for fiscal year 2028.

(E) $50,000,000 for fiscal year 2029.

(2) SOURCES.—Funds necessary to carry out the activities of the Program shall be made available each fiscal year from existing funds for—

(A) the National Oceanic and Atmospheric Administration, as determined by the Administrator; and

(B) the Department of Energy, as determined by the Secretary.

SEC. 4. MARINE CARBON DIOXIDE REMOVAL AND VERIFICATION STEERING COMMITTEE.

(a) DESIGNATION.—Not later than 180 days after the date of the enactment of this Act, the Director shall establish a Steering Committee on marine carbon dioxide removal and verification research and development (in this section referred to as the "Steering Committee") in accordance with chapter 10 of title 5, United States Code (commonly referred to as the "Federal Advisory Committee Act''). The Steering Committee shall be responsible for advising the Program.

(b) COMPOSITION AND STAFF.—

(1) IN GENERAL.—The Director may appoint, and assign duties to, a Chair and such other full- and part-time administrative employees of the Steering Committee as the Director determines necessary to the performance of the Steering Committee's functions.

(2) MEMBERSHIP.—The Steering Committee shall consist of not more than 15 members appointed by the Director—

(A) who are representatives of industry, universities, Federal laboratories, or nonprofit organizations, and who are qualified to provide advice and information on marine carbon dioxide removal;

(B) from Indian Tribes or Native Hawaiian communities with expertise on coastal community concerns and needs related to marine carbon dioxide removal; and

(C) with expertise in relevant social disciplines related to marine carbon dioxide removal.

(3) GEOGRAPHIC REPRESENTATION.—To the maximum extent practicable, the Director shall ensure Steering Committee members represent an appropriate balance of geographic interests.

(c) TRANSACTION OF BUSINESS.—

(1) QUORUM.—A majority of members of the Steering Committee shall constitute a quorum, but one or more such members may hold hearings.

(2) DECISION-MAKING.—All decisions of the Steering Committee shall be by majority vote of members present, in person or via live video participation.

(3) MEETINGS.—The Steering Committee shall meet at appropriate times and at the call of the Chair or upon the request of a majority of its members.

(d) ESTABLISHMENT OF NATIONAL RESEARCH PLAN.—

(1) IN GENERAL.—The Steering Committee, in consultation with a Marine Carbon Dioxide Removal and Verification Research Center established pursuant to section 5, shall develop and periodically update a National Research Plan for research, development, testing, evaluation, and demonstration of ma-

rine carbon dioxide removal, and shall carry out the following:

(A) Assess the current understanding of marine carbon dioxide removal, the role such activities could play in reducing carbon dioxide concentrations, reducing pressures on land-based carbon capture approaches, and any environmental, social, economic, or other benefits or risks resulting from the advancement and scale-up of such activities.

(B) Develop a comprehensive Code of Conduct to ensure the impacts of research activities are understood and accounted for as such activities progress.

(C) Describe research pathways that progress from theory to field testing, including laboratory, mesocosm, and modeling research that describes when field tests are appropriate.

(D) Establish a working definition of the threshold mass of carbon dioxide removal that delineates between demonstration and deployment of marine carbon dioxide removal.

(E) Assess freshwater environments, including the Great Lakes, for the suitability and scalability of marine carbon dioxide removal.

(F) Establish performance-based criteria for prioritizing resources to support marine carbon dioxide removal activities that show the most promise in terms of efficacy, scalability, and safety, among other relevant factors.

(G) Report on the most current state of knowledge for any marine carbon dioxide removal approach investigated under the Program, including relating to the following:

(i) Lifecycle net carbon dioxide removal from the atmosphere and expected duration of storage.

(ii) The scalability and cost per ton of carbon dioxide removed from the atmosphere.

(iii) The potential co-benefits.

(iv) The potential environmental, ecological, or societal impacts.

(H) Include an updated summary of federally funded marine carbon dioxide removal, research, and development, demonstration, and commercial application activities.

(2) ENVIRONMENTAL ASSESSMENTS.—The National Research Plan under paragraph (1) shall include environmental assessments of the following lo-

cations to serve as potential marine carbon dioxide removal research zones for specific approaches:

(A) Any network of existing regional marine research facilities suitable for marine carbon dioxide removal research and development.

(B) Naval test ranges and other military installations and facilities of the Department of Defense.

(C) Wind energy areas and decommissioned oil platforms designated by the Department of the Interior.

(D) Desalination plants, hydropower plants, and waterpower areas designated by the Department of Energy or other Federal departments or agencies.

(E) Wave energy sources, ocean thermal energy sources, floating solar energy sources, and other relevant energy sources, to meet the energy needs of marine carbon dioxide removal.

(F) Farms for bivalves, crustaceans, or other shell builders, as well as coral reefs, that could biologically benefit from increased ocean alkalinity.

(G) Such other locations the Steering Committee considers appropriate.

(3) CONSIDERATION.—In assessing the suitability of locations for marine carbon dioxide removal research zones under paragraph (2) for the National Research Plan under paragraph (1), the Steering Committee shall consider the following factors:

(A) The potential for research projects in the location proposed to enhance scientific understanding of carbon dioxide removal.

(B) The environmental effects of designating such location as a marine carbon dioxide removal research zone.

(C) The potential impact on nearby marine protected areas.

(D) The extent to which any effects identified by subparagraph (B) could impact Federal, State, local, Tribal, and territorial goals with respect to environmental protection or ecological restoration.

(E) The potential impact on United States military operations and readiness.

(F) Such other factors the Steering Committee considers appropriate.

(e) COLLABORATION.—

(1) IN GENERAL.—The Steering Committee shall collaborate with the following entities in developing the National Research Plan under subsection (d):

(A) A Marine Carbon Dioxide Removal and Verification Research Center established pursuant to section 5.

(B) The Program and all Federal departments and agencies associated with the Program, including the Federal departments and agencies specified in section 3(d).

(2) INCORPORATION.—To the greatest extent practicable, the Steering Committee shall incorporate findings from relevant interagency working groups, task forces, research programs, or similar bodies into the National Research Plan under subsection (d).

(f) REPORT TO CONGRESS.—Not later than one year after the date of the enactment of this Act and every five years thereafter until 2035, the Steering Committee shall submit the National Research Plan and subsequent updates to the Committee on Science, Space, and Technology of the House of Representatives and the Committee on Commerce, Justice, and Science and the Committee on Energy and Natural Resources of the Senate.

SEC. 5. MARINE CARBON DIOXIDE REMOVAL AND VERIFICATION RESEARCH CENTER.

(a) ESTABLISHMENT.—The Secretary, in collaboration with the Administrator, shall, through a competitive, merit-reviewed process, establish at least one, but not more than five, Centers, each to be known as a "Marine Carbon Dioxide Removal Research and Verification Center" (in this section referred to as a "Center"), to accelerate research, development, demonstration, and commercial application activities of marine carbon dioxide removal that best advance the priorities of the Program.

(b) CONSIDERATION.—In consideration of establishment of a Center, the Secretary—

(1) shall consider applications from institutions of higher education, research centers, multi-institutional collaborations, and any other entity the Secretary determines appropriate; and

(2) may consider applications from entities co-located with marine energy test centers while avoiding duplication.

(c) COORDINATION.—The Secretary shall avoid unnecessary duplication of existing marine carbon dioxide removal research and development activities of the Department of Energy, the National Oceanic and Atmospheric Administration, the Environmental Protection Agency, and other related programs, as appropriate.

(d) DURATION.—The Secretary shall establish each Center to carry out activities for a period of five years. The Secretary may renew each center for an additional subsequent period of five years following a successful, merit-based review.

(e) REQUIREMENTS.—A Center shall carry out the following:

(1) Attract and pool funding, infrastructure, knowledge, and multidisciplinary expertise to make efficient use of resources.

(2) Promote the discovery of synergies, such as with desalination, ocean energy, and wastewater treatment, among other relevant factors.

(3) Establish relationships with communities and organizations located near research zones, to enable such communities and organizations to benefit from innovation, workforce capacity building efforts, and job creation resulting from marine carbon dioxide removal.

(4) Integrate social science into marine carbon dioxide removal.

(5) Oversee any other activities under the Program that promote the advancement of marine carbon dioxide removal.

(f) FUNDING.—

(1) IN GENERAL.—There are authorized to be appropriated to the Secretary up to $5,000,000 for each of fiscal years 2025 through 2029 to carry out this section.

(2) SOURCE.—Amounts made available to carry out this section shall be derived from amounts appropriated or otherwise made available to the Department of Energy.

SEC. 6. INTERNATIONAL COOPERATION.

(a) IN GENERAL.—The Administrator, in consultation with the Secretary of State, shall seek effective international action and cooperation to facilitate global measurement, monitoring, reporting, and verification of marine carbon dioxide removal and ensure scientifically sound, safe, and responsible research.

(b) RESEARCH AND DEVELOPMENT.—The Administrator, in consultation with the Secretary of State, may, in carrying out subsection (a), formulate, present, or support specific proposals in the United Nations or international organizations for the development of appropriate international research and development programs in support of this Act.