The FY23 National Oceanographic Partnership Program (NOPP) Marine Carbon Dioxide Removal funding opportunity supports 17 projects that advance marine carbon dioxide removal research.

Project PI: Andreas Andersson, Scripps Institution of Oceanography

Satoshi Mitarai, Okinawa Institute of Science and Technology (OIST)
Loretta Roberson, Marine Biological Laboratory (MBL)
Reggie Spaulding, Sunburst Sensors
Adrienne Sutton, NOAA Pacific Marine Environmental Lab

Carbon capture and ocean acidification mitigation potential by seaweed farms in tropical and subtropical coastal environments

Award amount: $1,451,575

Project duration: 3 years

Funding source(s): NOAA Ocean Acidification Program and NOPP
IRA funding? No

Why we care
Growing seaweed in the ocean could be one way to alleviate some of the impacts by climate change and ocean acidification. We need to know how much carbon can be captured by cultivated seaweed and the potential benefits and risks to species and communities such as shellfish and corals that are susceptible to acidification.

What we will do
This project will explore the carbon capture capacity and ocean acidification mitigation in three operational seaweed farms in Florida and Okinawa, Japan. At the two smaller study sites, co-culturing of seaweed with shellfish and corals offers opportunities to assess the additive co-benefits of these combined activities, which could strengthen ecosystem resilience. The study sites in Japan are larger than any seaweed farms in the US, and studies here will help identify the risks and benefits of seaweed farming at scale. Researchers will use a state-of-the-art monitoring program with ocean sensors as well as reference-quality measurements. Drifting ocean sensors will measure water flow across the seaweed farms, which affects the productivity and the amount of carbon absorbed. Numerical modeling will elucidate the capacity of seaweed to absorb carbon under a range of different conditions. By

comparing these estimates based on seawater chemistry and physics to the amount of seaweed harvested and exported each year, we can identify carbon capture efficiency to different aspects of the seaweed cultivation.

Benefits of our work
"*Learning more about its carbon uptake capacity and ocean acidification mitigation potential is an important endeavor in the context of marine carbon dioxide removal*", says principal investigator Dr. Andreas Andersson of Scripps Institution of Oceanography. "*Seaweed cultivation offers many potential benefits to both marine and human communities. It has a rich history in many Asian countries with an extensive knowledge base of best practices and potential environmental impacts.*" This project tests how well carbon capture and ocean acidification mitigation can be measured in seaweed farms and if these operations capture carbon and mitigate ocean acidification on different scales. Counteracting ocean acidification is one benefit of seaweed cultivation. This is especially good news for marine ecosystems and species that are sensitive to acidification, like coral reefs and shellfish. Additionally, when seaweed is grown alongside other aquatic activities like fish farming or coral restoration, it can create a positive environment for those activities because the seaweed helps keep the water less acidic and more suitable for marine life. The scale of the larger seaweed farms from Japan in this study exceeds any current farms in the U.S and provides a realistic and rigorous perspective of what is required in terms of space and infrastructure to meet certain carbon capture or local mitigation of ocean acidification goals. Since seaweed farming has a long history in Japan, lessons learned by Japanese seaweed cultivators will be invaluable to U.S. counterparts for adaptation, expansion, and advancement of seaweed cultivation in the U.S. This also can help support the development and implementation of permitting and regulatory frameworks in the U.S.
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Project PI: Andrew Dickson, Scripps Institution of Oceanography

Dr. Robert Richardson, Pacific Rim Design & Development
Dr. Nina Bednaršek, Oregon State University Cooperative Institute for Marine Resources Studies
Dr. Richard A. Feely, NOAA Pacific Marine Environmental Laboratory

Assessing chemical and biological implications of alkalinity enhancement using carbonate salts obtained from captured CO2 to mitigate negative effects of ocean acidification and enable mCDR

Award amount: $995,891

Funding source(s): NOAA

IRA funding? Yes

Project duration: 3 year

Why we care

Energy, manufacturing and deployment costs are critical to the viability of any carbon dioxide removal approach. This research project focuses on a new strategy that promises low energy burden and low manufacturing costs to capture carbon and achieve ocean alkalinity enhancement, essential features for scaling any future efforts of this technology to capture carbon and assuage ocean acidification.

What we will do

Researchers will develop and test a pilot-scale system that captures carbon dioxide from the air and converts it into a mixture of salts that can be used for marine carbon dioxide removal (sodium carbonate, sodium bicarbonate). To understand the chemical constraints of this method, the project examines the precipitation of different minerals in seawater and the best rate of adding the critical components. Marine species may differ in their response to the changes caused by ocean alkalinity enhancement. Part of this project synthesizes published data to assess how different species with varying calcification behaviors may respond to changes in seawater. Researchers will then evaluate the potential effects of ocean alkalinity enhancement on different habitats along the United States West Coast that incorporate both experimental data and field data. Lastly, the project emphasizes maintaining quality control and chemical validation throughout the research to ensure accurate and reliable results.

Benefits of our work

This work builds and tests a pilot-scale system for carbon dioxide removal from a gas stream and investigates how the chemicals produced can be used to enable marine carbon dioxide removal. It evaluates the chemical and biological impacts of ocean alkalinity enhancement, contributing to the knowledge and implementation of sustainable strategies for carbon dioxide removal. “*For marine carbon dioxide removal to be successful, it needs to happen soon, be environmentally safe, and to be economically viable. We hope to show all can be true together*” says the project principal investigator Dr. Andrew Dickson of the University of California San Diego Scripps Oceanography.

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Project PI: Burke Hales, Oregon State University

Yvette Spitz, Oregon State University
Kelsey Stoerzinger, Oregon State University
George Waldbusser, Oregon State University
Dick Feely, NOAA Pacific Marine Environmental Laboratory
Simone Alin, NOAA Pacific Marine Environmental Laboratory

Electrolysis-driven weathering of basic minerals for long-term ocean buffering and CO2 reduction

Award amount: $2,000,000

IRA funding? No

Funding source(s):
Department of Energy Office of Fossil Energy and Carbon Management, Water Power Technologies Office

Project duration: 3 years

Why we care
Ocean alkalinity enhancement has the potential to capture carbon and mitigate ocean acidification. While ocean alkalinity enhancement is a promising approach for removing carbon from the atmosphere, there are important questions about its impacts on the marine environment. A strategic roadmap identifying and addressing concerns about deployment of ocean alkalinity enhancement is an important step for developing this marine carbon dioxide removal approach. This project will use laboratory studies and ocean models to investigate the risks, limitations, and benefits of ocean alkalinity enhancement to inform a Regulatory Strategic Roadmap.

What we will do
Environmental risks could result from releasing too much alkalinity into ocean waters, as well as releasing harmful byproducts. In order for this method to successfully remove carbon from the atmosphere, it will also need to be powered almost exclusively by renewable energy. To address these risks, the team will develop an alkalinization system for seawater that is simple to control, limits the simultaneous release of harmful byproducts like chlorine, and operates on wave energy. Researchers will design components and procedures that minimize the generation and release of these byproducts while carefully controlling the alkalinity of the effluent. To address sustainably powering the system, the team will test how much power the alkalinization system requires and build a wave-energy power system that can support its operation. Once the technical specifications are established, the team will use circulation and ecosystem models to simulate the addition of alkalinity across a variety of seawater conditions representing real-life Oregon coastal waters where this type of system may be deployed. Modeling will identify the best local conditions for alkalinity enhancement and identify local ecosystem sensitivities to alkalinization actions. Subsequent laboratory experiments will help identify ways to limit impacts of alkalinity enhancement on sensitive life stages of commercially and culturally sensitive species, including California mussels, Olympia oysters, Dungeness crab, and eelgrass.

Benefits of our work
Overall, the project will demonstrate proof-of-concept alkalinity addition and wave power systems that could be used in tandem. This project also informs a regulatory roadmap to highlight existing research gaps needed for the regulatory decision making process. Specifically, it addresses This project will use laboratory studies and ocean models to investigate the risks,

limitations, and benefits of ocean alkalinity enhancement to inform a Regulatory Strategic Roadmap.
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Project PI: Dennis McGillicuddy, Woods Hole Oceanographic Institute

Ken Buesseler, Woods Hole Oceanographic Institute
John Dunne, NOAA Geophysical Fluid Dynamics Laboratory
Kristen Krumhardt, National Center For Atmospheric Research
Matthew Long, National Center For Atmospheric Research
Weifeng (Gordon) Zhang, Woods Hole Oceanographic Institute
Charles Stock, NOAA Geophysical Fluid Dynamics Laboratory

Multiscale observing system simulation experiments for iron fertilization in the Southern Ocean, Equatorial Pacific, and Northeast Pacific

Award amount: $1,983,731
IRA funding? No

Funding source(s): NOAA Global Ocean Monitoring and Observing (GOMO), NOAA Ocean Acidification Program (OAP), National Science Foundation

Project duration: 3 years

Why we care
Iron is a critical limiting nutrient for phytoplankton in the ocean. Iron fertilization adds this limiting nutrient to promote phytoplankton blooms as a way to take up carbon dioxide and store carbon when they sink. Unknowns on the effectiveness, measurement and monitoring, and need to be addressed. This project uses larger and longer iron fertilization experiments needed to address these unknowns.

What we will do
This project studies the effectiveness of iron enrichment for carbon capture at different scales and the long-term effects of regional iron fertilization. Researchers will use Observing System Simulation Experiments run by ocean biogeochemical models to assess the potential impacts of new observing systems, instrumentation, or data assimilation, prior to implementation. The Observing System Simulation Experiments will target field trials in three regions: the Southern Ocean, the Equatorial Pacific, and the Subarctic Pacific. High resolution models will examine the extent of carbon sequestration and potential effects on local and remote ecosystems on a small scale. Global biogeochemical models will explore the long-term effects of regional iron fertilization, including carbon sequestration and monitoring of ecosystem perturbations.

Benefits of our work
This project will address the effectiveness of ocean iron fertilization as a carbon dioxide removal technique, identify potential unintended ecological consequences, and determine the necessary systems for monitoring carbon and ecosystem changes. The study addresses questions regarding the magnitude, duration, observing systems, time scales, and impacts on ecosystem services of iron fertilization. The broader scientific community will have input to improve the Observing System Simulation Experiments. These global models, when run over many years, will also investigate the ocean's capacity to absorb atmospheric carbon dioxide by means of iron fertilization and the fundamental changes that the method may cause to ocean ecosystems.
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Project PI: Jaime Palter, University of Rhode Island
Jason Grear, Environmental Protection Agency
David Ho, University of Hawai'i, Manoa
Robert Pockalny, University of Rhode Island
Rebecca Robinson, University of Rhode Island
Samantha Siedlecki, University of Connecticut
Hongjie Wang, University of Rhode Island

An opportunity to study Ocean Alkalinity Enhancement, CDR, and ecosystem impacts through coastal liming

Award amount: $1,538,452
IRA funding? Yes

Funding source(s): NOAA

Project duration: 3 years

Why we care
Terrestrial liming, or the addition of a basic (alkaline) material like calcium carbonate to crops and lawns is a common agricultural soil treatment. When applied on land in the coastal zone, this alkalinity likely influences neighboring bodies of water and may foster carbon dioxide removal and mitigate local ocean acidification. This project will study the effectiveness of carbon dioxide removal and impacts of resulting alkalinity from the common practice of terrestrial liming in a coastal setting.

What we will do
Dr. Jaime Palter of the University of Rhode Island says *"a golf course's routine lawn care includes the spreading of large quantities of limestone – nearly 20 tons for 9 holes. With that fact in mind, we realized that using a golf course's lime deployment as our release experiment could provide an ideal, permit-free opportunity to study the effect of coastal alkalinity enhancement."* This project takes advantage of a routine lawn care technique of golf course liming. The team will monitor the carbon chemistry of a small coastal lagoon before and after the application of

the limestone on a nearby golf course. The team will measure dissolved inorganic carbon, or the total amount of inorganic carbon in the water using sensors continuously measuring water properties and in weekly field sampling. They will also measure total alkalinity, the water's buffering capacity that may increase with liming and enhance the lagoon's ability to take in carbon dioxide. These essential observations help track the sources and sinks of carbon in a system. More specifically, they will allow the team to calculate the balance of dissolved inorganic carbon and total alkalinity in the lagoon to understand if the lagoon can further absorb carbon after the liming process. The research will also study the impact on the ecosystem and mitigation of local ocean acidification on clams. Finally, the project employs modeling simulations to understand the fate of alkalinity and dissolved inorganic carbon as it leaves the coastal zone, estimate the carbon dioxide removal achieved through observed lime application, and explore the scalability of terrestrial liming along the U.S. east coast.

Benefits of our work

The work aims to address the unknowns associated with the practice of coastal liming as a carbon dioxide removal pathway. Specifically, the team will learn more about *"how this coastal liming could mitigate local acidification, promote measurable carbon dioxide removal in the coastal zone, or export alkalinity to the open ocean, and how these practices might scale along the US East Coast"* says Palter. Furthermore, the work also evaluates impacts on shellfish using this approach.

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Project PI: Kevin Kroeger, United States Geological Survey

Grace Andrews, Vesta Corporation
Sophia Fox, National Park Service
Shannon Meseck, NOAA National Marine Fisheries Service
Timothy Smith, National Park Service
Robert Sohn, Woods Hole Oceanographic Institute
Nathaniel Walworth, Vesta Corporation
Aleck Wang, Woods Hole Oceanographic Institute

Tidal wetlands as a low pH environment for accelerated and scalable olivine dissolution

Award amount: $1,895,531

IRA funding? Yes

Funding source(s): NOAA

Project duration: 4 years

Why we care
Enhanced weathering is a carbon capture technology that increases ocean alkalinity by adding rocks with ultrabasic minerals, particularly in ecosystems like wetlands and mangroves. This project examines the safety, efficacy, and potential for large-scale implementation of enhanced weathering in tidal wetlands to enhance weathering as a method of carbon dioxide removal and local-scale ocean acidification mitigation.

What we will do
Researchers will test that enhanced weathering, particularly with the rock-forming mineral olivine, leads to a decrease in carbon dioxide released into the atmosphere. Additionally, the study tests that this method increases dissolved inorganic carbon and alkalinity in the porewater and adjacent estuary, and creates a chemical range beneficial for oyster larval recruitment, survival, and growth. The team will conduct experiments at various scales, from the laboratory to field macrocosm, to develop models for olivine dissolution. Laboratory experiments will optimize olivine dissolution rates and assess impacts on various impacts such as the chemistry of soil and coastal seawater and ecosystem health. This small-scale experimentation will inform the design and execution of a field trial where olivine will be applied to a 0.5-hectare salt marsh plot in collaboration with the Herring River Restoration, a salt marsh ecosystem project in the U.S. National Park Service land. The field trial provides an opportunity for the research and regulatory communities to evaluate environmental safety as well as compare measurement, monitoring, reporting and verification technologies. Other outcomes of the field trial include understanding the impact of olivine on soil chemistry, microbial communities, vegetation, and invertebrates.

Benefits of our work
This project evaluates the safety, efficacy, and potential for large-scale implementation of enhanced weathering in tidal wetlands. This while generating wide interaction and training in the array of fields that need to engage with coastal marine carbon dioxide removal.
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Project PI: Adam Subhas, Woods Hole Oceanographic Institution
Kay Bidle, Rutgers University
Kimberlee Thamatrakoln, Rutgers University

Assessing the laboratory and field responses of diatoms and coccolithophores to ocean alkalinity enhancement

Award amount: $1,026,045

IRA funding? Yes

Funding source(s): NOAA

Project duration: 3 years

Why we care
Ocean alkalinity enhancement relies on modifying the acid-base properties of seawater to remove carbon dioxide, however the effect of this strategy on primary productivity, cell physiology, and carbon export remain unknown. These impacts are not only potential ecosystem effects, but may influence the efficiency of carbon dioxide removal. This research focuses on understanding the impacts of ocean alkalinity enhancement as a method of removing carbon dioxide from the ocean on phytoplankton, specifically diatoms and coccolithophores.

What we will do
This project aims to address potential impacts of ocean alkalinity enhancement on phytoplankton by conducting laboratory and field experiments. Laboratory experiments will assess the effects of ocean alkalinity enhancement on representative diatom and coccolithophore species. Next, the team will study the response of natural diatom and coccolithophore communities to ocean alkalinity enhancement during research cruises. They hypothesize that the impact of ocean alkalinity enhancement will depend on the dominant phytoplankton species in the community. Lastly, this study will evaluate the response of a natural microbial community to a dispersing plume of dissolved alkalinity during a field trial. The research team anticipates that the differences in the community response inside and outside the plume will be measurable but insignificant. The project also evaluates the effect of biomass loading during a bloom progression, assessing community composition, mineral production, particle dynamics, and carbon export.

Benefits of our work
This work will provide valuable insights for ocean alkalinity enhancement practitioners, modelers, and stakeholders, and to generate important measurements of ocean alkalinity enhancement biological responses in the field.
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Project PI: Laura Haynes, Vassar College

Jennifer Fehrenbacher, Oregon State University
Emily Osborne, NOAA Atlantic Meteorological Laboratory

Determining the Influence of Ocean Alkalinity Enhancement on Foraminifera Calcification, Distribution, and CaCO3 Production

Award amount: $510,359

IRA funding? Yes

Funding source(s): NOAA

Project duration: 3 years

Why we care
Foraminifera, or forams, are single-celled organisms that produce calcium carbonate shells and play a crucial role in the ocean's carbon cycle. Ocean alkalinity enhancement aims to increase the ocean's ability to absorb carbon dioxide by enhancing its buffering capacity. However, the impact of the addition of alkalinity on foraminifera is not well understood. *"Our work seeks to understand how a key group of marine organisms- plankton called foraminifera that make shells- would respond to ocean alkalinity enhancement. When these plankton make their shells, they actually take up alkalinity, which could make ocean alkalinity enhancement less efficient"* says principal investigator Dr. Laura Haynes from Vassar College. This project investigates the effects of ocean alkalinity enhancement on these important calcifiers and how forams may impact the effectiveness of this carbon dioxide removal approach.

What we will do
To examine the effects of different materials used in ocean alkalinity enhancement on foraminifera, researchers will grow foraminifera in culture experiments and use advanced imaging techniques to examine the impact on calcification (shell building). They will test three materials: calcium carbonate, calcium hydroxide, and olivine. The research team anticipates that adding calcium-bearing minerals will increase foraminiferal calcification, reducing the effectiveness of ocean alkalinity enhancement, whereas adding magnesium-iron silicates will decrease calcification. The team will also investigate how respiration and shell chemistry of foraminifera respond to ocean alkalinity enhancement to understand changes in their physiology. The project will capture young tropical surface foraminifera as well as mid-latitude sediment-dwelling foraminifera to grow in the laboratory under different ocean alkalinity conditions. Results will help estimate global changes in the ocean's calcium carbonate budget and its carbon dioxide absorption capacity under global ocean alkalinity enhancement scenarios.

Benefits of our work
"We need to understand how marine organisms would respond to these proposed climate solutions -not only to evaluate how well they would work, but also to understand the ramifications for global ecosystems" says Dr. Haynes.This research provides valuable insights into the potential impacts of ocean alkalinity enhancement on foraminifera and contribute to understanding of the effectiveness and consequences of this approach on a primary carbonate producer in the open ocean. The research will also contribute to increasing the diversity of the group of scientists involved in marine carbon dioxide removal research by engaging a group of undergraduate researchers from various backgrounds. The project emphasizes creating inclusive and supportive environments for students and making scientific data available for outreach and educational activities.
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Project PI: Melissa Meléndez, University of Hawai'i, Manoa
Keisha Bahr, Texas A&M Corpus Christi
Hannah Barkley, NOAA Pacific Islands Fisheries Science Center
Nick Hawco, University of Hawai'i, Manoa
Conall McNicholl, University of Hawai'i, Manoa
Lisa McManus, University of Hawai'i, Manoa
Christopher Sabine, University of Hawai'i, Manoa

Assessing the effects and risks of ocean alkalinity enhancement on the physiology, functionality, calcification, and mineralogy of corals and crustose coralline algae in the Pacific

Award amount: $1,999,835

IRA funding? No

Funding source(s): Department of Energy Office of Fossil Energy and Carbon Management

Project duration: 4 years

Why we care
One potential benefit of ocean alkalinity enhancement is reversing ocean acidification, which can impact marine life like corals, clams, and crabs. This project investigates the potential benefits and risks of ocean alkalinity enhancement on Pacific tropical and subtropical corals and crustose coralline algae. The project's goal is to understand if ocean alkalinity enhancement can help counteract the effects of ocean acidification on coral reefs, which are important ecosystems for marine biodiversity and human communities.

What we will do
The main objectives of the research are to identify how corals and crustose coralline algae respond to immediate alkalinity additions and to determine the effects of chronic and acute exposure to ocean alkalinity enhancement. The study will explore whether biological limitations are primarily attributed to alkalinity or other factors like potential trace metal toxicity from the minerals used in ocean alkalinity enhancement. Laboratory experiments using different alkalinity enhancement agents (quicklime, sodium hydroxide, and olivine) conducted in chambers and mesocosms will establish safe operating conditions and understand the mechanisms of calcification in corals and crustose coralline algae under different ocean alkalinity enhancement scenarios. The team will support inclusivity and equity in the field of marine carbon dioxide removal by offering paid internships for underrepresented groups.

Benefits of our work
"Understanding the intricate balance between alkalinity additions and coral response will contribute to developing effective and informed strategies for mitigating the impacts of climate change and ocean acidification" says Dr. Melissa Meléndez of the University of Hawai'i. It is

especially important to assess *“potential benefits and limitations of ocean alkalinity enhancement, particularly in the context of safeguarding the health of corals.”* The findings will provide valuable insights into the effects of ocean alkalinity enhancement on coastal ecosystems and guide the development of strategies that combine coral restoration and ocean alkalinity enhancement activities. The project team will provide training and educational opportunities for Pacific Islanders, community members, early-career researchers, underrepresented students, and stakeholders to learn about ocean alkalinity enhancement approaches and their potential impacts on coral reefs. Ultimately, the research contributes to the development of sustainable carbon dioxide removal methods and ocean acidification mitigation on coral reef ecosystems.
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Project PI: David Nicholson, Woods Hole Oceanographic Institution

Adam Subhas, Woods Hole Oceanographic Institution (WHOI)
Yui Takeshita, Monterey Bay Aquarium Research Institute (MBARI)
Robert Todd, Woods Hole Oceanographic Institution (WHOI)
Katherine Zaba, MRV Systems, LLC

Assessing Carbon Dioxide Removal and Ecosystem Response for an Ocean Alkalinity Enhancement Field Trial

Award amount: $1,877,644

IRA funding? Yes

Funding source(s): NOAA

Project duration: 3 years

Why we care
Tracking how ocean alkalinity enhancement reduces acidity, resulting in carbon dioxide removal from the atmosphere is important for knowing how, where and when to deploy this approach as well as its potential impacts to marine life. Capitalizing on an ocean alkalinization field trial in the Gulf of Maine already underway, this project will measure additional carbon uptake and ecosystem responses to the alkalinity enhancement.

What we will do
Researchers will use five ocean gliders to track the alkalinity released by a field trial in the Gulf of Maine. The gliders will track a patch of seawater with elevated alkalinity and ‘tagged’ with an inert dye and monitor changes in pH (measure of how alkaline or acidic the water is). The gliders can identify these changes from baseline data collected several weeks prior to the start of the trial as well as other measurements and modeled data collected as part of the larger experiment. In order to make these measurements, the team will add specialized sensors to the gliders.This engineering phase will include housing modifications and electrical integration of the

pH and dye sensors into the glider body, as well as the development of firmware that controls the glider and the incorporated sensors. Researchers will test integration of these components on short deployments the year before the main alkalinity addition experiment. In addition to these sensors, the glider will also measure temperature, salinity, current speeds and direction, dissolved oxygen, chlorophyll, and ocean sound. The gliders equipped with these sensors will first help identify a suitable location within the bounds of a permitted patch for the alkalinity release. The gliders will then hone in on a particular location or feature. Parts of the fleet will stay close to the original site of release while others will track the outer edges of the patch. During the data analysis phase, reference-quality measurements will be made as part of the parallel alkalinity addition project. These simultaneous measurements allow for the calibration of the glider data, as well as calculation of an overall carbon budget. Data from the glider and from these calculations will also be integrated into a model to characterize how well the gliders were able to monitor the evolution of the patch of added alkalinity over time.

Benefits of our work
Overall, this research contributes to simultaneous estimates of the efficiency, additionality, and possible leakage of the carbon removed by ocean alkalinity enhancement under development. Accordingly, the results may be used to help establish important monitoring, reporting, and verification practices for future carbon removal experiments.
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Project PI: David Ho, University of Hawaii

Danielle Bianchi, University of California Los Angeles
Matthew Eisaman, Ebb Carbon, Inc.
Alicia Karspeck, Convergent Research, LLC
Matthew Long, Convergent Research, LLC
James McWilliams, University of California Los Angeles
Sara Nawaz, American University
Mallory Ringham, Ebb Carbon, Inc.

Assessing efficacy of electrochemical ocean alkalinity enhancement at an existing outfall using tracer release experiments and oceanographic models

Award amount: $1,915,600

IRA funding? Yes

Funding source(s): NOAA, ClimateWorks Foundation

Project duration: 3 years

Why we care

Adding alkalinity to the ocean may provide a safe and effective approach to removing carbon dioxide from the atmosphere. Assessing the efficacy and efficiency of ocean alkalinity enhancement are essential steps to ensuring that this method of carbon dioxide removal can contribute to mitigating climate change and ocean acidification.

What we will do

Through partnership with a local wastewater treatment plant in San Francisco Bay, this project will conduct an experiment that adds alkalinity to ocean water to test its effect on removing carbon dioxide from the atmosphere. Researchers will first use a numerical modeling framework to design the experiment, including the release strategy and a sampling plan that will track effects in the environment. Following the experiment, the team will conduct a retrospective analysis that combines models and observations to estimate the efficacy of the alkalinity release in removing carbon from the atmosphere. Further, they will apply the modeling framework to estimate the efficiency of removal. The technical work will be accompanied by public engagement to introduce local groups and communities like Tribes, NGOs, civil society organizations to the project. Engagement will explore how the project aligns with their views and priorities, and what associated risks and co-benefits these groups perceive.

Benefits of this work

This work provides an evaluation of alkalinization efficacy in a specific coastal ocean system. Dr. David Ho of the University of Hawai'i and principal investigator of the project says it *"represents the first time an alkalinity release is conducted with the $^{3}He/SF_6$ dual tracers and allows us the opportunity to determine air-sea CO_2 fluxes and track the evolution of an ocean alkalinity enhancement"* over this time scale. Also delivered is a *"demonstration of how we develop tools for a monitoring, reporting, and verification (MRV) of ocean carbon dioxide removal."* The project also provides recommendations on methods and best practices for conducting public engagement alongside future pilot field trials of ocean alkalinity enhancement and related marine carbon dioxide approaches.

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Project PI: Jeremy Testa, University of Maryland Center for Environmental Science

Wei-Jun Cai, University of Delaware
Ming Li, University of Maryland Center for Environmental Sciences (UMCES)
Yuanyuan Xu, Planetary Technologies, Inc.

Quantifying the Efficacy of Wastewater Alkalinity Enhancement on mCDR and Acidification Mitigation in a Large Estuary

Award amount: $1,864,561

IRA funding? Yes

Funding source(s): NOAA

Project duration: 3 years

Why we care

Manipulating wastewater treatment plant procedures and discharge to enhance carbon removal is practical because of the current readiness of infrastructure to deliver alkalinity to the coastal ocean. Many wastewater facilities already treat wastewater with alkalinity, permits to allow alkalinity discharge already exist, and there are several known technologies that can increase alkalinity in wastewater streams. *"This method of carbon removal is attractive because existing wastewater streams provide an opportunity to leverage existing infrastructure and to provide several co-benefits to the facility and the adjacent tidal waters"* states Dr. Jeremy Testa of the University of Maryland Center for Environmental Science. Despite the existence of this "shovel-ready" carbon removal technology, there is still much uncertainty. These uncertainties center around costs, the efficacy of the process at a scale that can meaningfully impact coastal waters, and the environmental and biological impacts of various alkalinity-rich materials. *"Our research will help quantify the feasibility of this approach"* says Testa, and evaluate carbon removal and ocean acidification mitigation via alkalinity enhancement at a wastewater treatment plant in Chesapeake Bay.

What we will do

This project will add alkalinity at a single wastewater treatment plan in the Hampton Roads Sanitation District in Virginia. In the first year, a 1-week test will ensure the safety and rigor of the dosing method. The team will closely monitor and control alkalinity dosing rates within the facility and then concurrently monitor the receiving tidal waters for carbon removal and environmental impacts. During the second year, the researchers will perform a 4-week test. This longer test will help identify other natural factors that modify the potential effect of carbon removal, such as the phase of the tide, the amount of algal growth in the water, and weather. During both tests, the team will monitor oyster growth and other environmental parameters like total suspended solids, nutrient concentrations, metals, and carbon chemistry variables. The results of these two tests will inform an ocean model to better understand the benefits and impacts of a scaled-up version of these small field tests.

Benefits of our work

This project will evaluate the feasibility, cost, and potential for carbon dioxide removal by alkalinity addition via existing wastewater treatment discharges. It will also provide a well-refined protocol for measuring and monitoring the amount of carbon removed in this context that can be applied to future efforts.

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Project PI: Kelly Kearney, University of Washington (CICOES)

Brendan Carter, University of Washington

Kristen Krumhardt, National Center For Atmospheric Research
Darren Pilcher, University of Washington

Biotic calcification impacts on marine carbon dioxide removal additionality

Award amount: $1,250,482

IRA funding? Yes

Funding source(s): NOAA

Project duration: 4 years

Why we care
There are several challenges that can limit the efficiency and effectiveness of marine carbon dioxide removal methods. One potential consequence of some methods is increased growth of organisms that build shells out of calcium carbonate, or calcification (shell building). Calcification releases carbon dioxide into seawater, which may reduce the efficiency of carbon removal projects. This project will explore the potential impacts of increased calcification using ocean model simulations.

What we will do
The team will use simulations from two different model frameworks to identify a range of efficiency reductions that could come from calcification. Simulations will be based on proposed real-world applications of marine carbon removal. Accurate estimation of efficiency and the uncertainty of efficiency will be important to determine the value of carbon removal credits in market settings. In addition to testing this important feedback, researchers will also explore natural processes that mimic this calcification feedback with existing ocean carbon data.

Benefit of our work
This project may inform carbon markets and carbon prices/discounts for ocean carbon dioxide removal projects. These results could provide an important way of setting the price – or discount rate. Models like the one produced here are important because the long time scales and large spatial scales involved in this process make it very difficult to measure in a laboratory or at sea.
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Project PI: Cristina Schultz (Northeastern University) & Jessica Luo (NOAA GFDL)
Damien Brady, University of Maine, Walpole
Enrique Curchister, Rutgers University
Samantha Siedlecki, University of Connecticut

Charles Stock, NOAA Geophysical Fluid Dynamics Laboratory
Jeremy Testa, University of Maryland Center for Environmental Sciences (UMCES)

Developing a coupled benthic-pelagic biogeochemical model to evaluate the effectiveness of mCDR interventions

Award amount: $1,258,967

IRA funding? Yes

Funding source(s): NOAA

Project duration: 4 years

Why we care
The ocean seafloor, or benthos, serves as the only long-term storage of oceanic carbon on geologic timescales. However, the interaction between ocean water and sediments and its role in carbon storage is a major knowledge gap. Understanding this feedback is important for assessing the duration of carbon storage for ocean carbon dioxide removal methods that store it in seafloor sediments.

What we will do
This project will develop a model to represent the exchange, transformations, and storage of carbon and nutrients in the sediments. The model will also simulate ecosystem interactions in sediments and assess the efficiency of seaweed aquaculture and benthic ecosystem restoration. Both methods may result in either carbon storage or production under different conditions.

Benefits of the work
Ultimately, this project will develop a modeling framework capable of resolving a range of marine carbon dioxide removal concerns related to durability, additionality, verifiability, and other aspects of sediment processes in ocean models.
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Project PI: Fiona Hogan, Responsible Offshore Development Alliance
Roger Griffis, NOAA Office of Science and Technology (OST)
Sarah Schumann, Shining Sea Fisheries Consulting, LLC

Engaging U.S. Commercial Fishing Community to Develop Recommendations for Fishery-Sensitive mCDR Governance, Collaborative Research and Monitoring, and Outreach to Fishing Communities

Award amount: $99,591

IRA funding? No

Funding source(s): Office of Naval Research, ClimateWorks Foundation

Project duration: 2 years

Why we care
Marine carbon dioxide removal strategies will interact with fishery ecosystems, resources, and activities. It is important to engage with commercial fisheries early to develop an accurate understanding of governance concerns to build trust and fishery-sensitive governance.

What we will do
The project will leverage existing networks of fishermen from the Northeast, Alaska, and the West Coast to create marine carbon dioxide removal literacy within the community. The project will form a fisherman's marine carbon dioxide learning learning committee and will produce informational sheets, webinars and articles. Next, the partners will work with this committee, experts within NOAA, and coastal acidification networks to develop three documents to offer guidance on: 1) best practices for siting including recommendations of criteria for project evaluation and permitting, 2) methods to engage commercial fisherman as co-producers of necessary data from observing system and ecosystem impact studies, and 3) ways to engage with the fishman community in culturally appropriate ways.

Benefits of our work
The project aims to engage and build trust with commercial fishermen. This work provides guidance on engagement, co-production of information, and fishery-responsive criteria for marine carbon dioxide removal development. The three guidance documents will allow for enhanced collaboration and understanding between the different ocean users, particularly the fishery communities.
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Project PI: Katherine Hornbostel, University of Pittsburgh

Matthew Green, Arizona State University
Mou Paul, National Renewable Energy Laboratory
Abhishek Roy, National Renewable Energy Laboratory
Jennifer Yang, University of California, Irvine

Coupling Desalination with Novel mCDR Membranes

Award amount: $1,403,802

IRA funding? No

Funding source(s): Office of Naval Research

Project duration: 2 years

Why we care
Large-scale marine carbon dioxide removal methods will require lots of infrastructure to move and process seawater, which could make them prohibitively expensive. This project examines a novel approach that leverages existing desalination infrastructure to minimize the cost of removing CO2 from seawater. This could make marine carbon dioxide removal a more cost-competitive and energy-efficient option to complement direct air capture approaches for large-scale CO2 removal from the environment.

What we will do
The research team will work with existing desalination membranes to enable them to remove CO2 from seawater while producing fresh drinking water. The team will investigate two different promising chemical groups that can be attached to the surface of desalination membranes to make CO2 bubble out of the seawater when it reaches the membrane. The team will perform a combination of experiments, prototyping, modeling, and technoeconomic assessment to determine which types of membranes and surface groups will result in the most cost-effective system.

Benefits of our work
This work will lay the foundation for an approach to couple marine carbon dioxide removal with desalination for large-scale, cost-effective marine carbon dioxide removal. It's an approach *"that could potentially be scaled up quickly in the near future by leveraging existing desalination infrastructure"* says Dr. Katherine Hornbostel, principal investigator at the University of Pittsburgh.
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Project PI: Galen McKinley, Columbia University

Thea Hatlen Heimdal, Columbia University
Adrienne Sutton, NOAA Pacific Marine Environmental Laboratory

Data requirements for quantifying natural variability and the background ocean carbon sink in mCDR models

Award amount: $589,464
IRA funding? No
Funding source(s): National Science Foundation, NOAA Ocean Acidification Program
Project duration: 3 years

Why we care
Ocean uptake of carbon has great natural variability that accompanies rising atmospheric carbon dioxide. A major challenge for marine carbon dioxide removal will be to quantify its additional carbon removal from the atmosphere. Ocean models can quantify carbon uptake attributed to marine carbon dioxide removal will likely be the basis for carbon credit calculations for carbon markets.

What we will do
Better quantification of air-sea CO2 fluxes at regional scales is required before mCDR additionality can be quantified.

"*Marine carbon dioxide removal presents exciting new challenges for scientists who have been working for decades to measure the ocean carbon sink that naturally removes 25% of humanity's carbon dioxide emissions from the atmosphere each year*" says Dr. Galen McKinley of Columbia University. "*In this project, we will apply state-of-the-art methods we've developed for ocean carbon sink studies to the challenge of marine carbon dioxide removal monitoring, reporting and verification.*" To validate the models that will be required to estimate carbon credits for marine carbon dioxide, the team will determine the natural background carbon uptake, its variability, and the degree of certainty with which it is known in areas where marine carbon dioxide removal deployments are likely to occur. The project will also determine the requirements for additional sampling of pCO2, a measure of the carbon dioxide in seawater, needed to quantify the baseline ocean carbon sink in models. This work will develop machine learning approaches for use in marine carbon dioxide removal monitoring, reporting and verification. It will also support future observing system development, both critical for future development of observation-based benchmarks for evaluation of proposed marine carbon dioxide removal models.

Benefits of our work
This work will inform future investments in ocean observing required prior to implementing future research or marine carbon dioxide removal. It will also identify regions that might already have sufficient background data that may be poised for next steps. The project supports workforce development in the area of ocean carbon cycling and machine learning, critical skills for this growing field.
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