MARCH 2024

U.S. Congressional Action Needed to Accelerate Ocean-Based Carbon Dioxide Removal Solutions

Science, Need, Opportunity, and Investments
for oCDR RD&D in the United States

CarbonToSea.org

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Our ocean plays a big role in helping to stabilize our climate.

Covering more than 70 percent of the planet and holding about 50 times more carbon than the atmosphere, our ocean plays a big role in helping to stabilize our climate. But this natural process comes at a cost. Too much greenhouse gas pollution in the air, blunted by the ocean, has cascading effects, making the ocean more acidic, increasingly starved of oxygen, less productive, and less habitable for fish and marine wildlife. Today's climate challenges require urgent solutions.

To this end, scientists around the world are evaluating whether and which ocean-based carbon dioxide removal (oCDR) approaches can safely and permanently reduce atmospheric CO_2. While philanthropy is bringing important resources to this effort, the government also has a critical role to play. Across technology sectors, such as medicine, renewable energy, or climate mitigation, government funding has long provided vital support for early innovation, advancement toward commercial viability, and development of the knowledge needed to ensure technologies are safe, effective, and properly regulated.

The federal government is already spending billions[1] to advance the technological readiness of carbon dioxide removal (CDR) necessary for commercial deployment yet has invested only modestly in developing the ocean-based forms of these technologies. As the critical role our ocean plays in stabilizing the climate becomes more widely understood alongside the growing recognition that CDR must play a big role in meeting our climate goals, the U.S. must right size investments in oCDR.

> The scale of the problem, the scale of the oceans, and the scale of the decarbonization options necessary to meet our climate goals demand commensurate resources to rigorously evaluate the promise of oCDR solutions.

> There is strong scientific consensus that a substantial effort to remove carbon dioxide directly from the atmosphere or upper ocean will be required to avert the worst effects of climate change.

According to the IPCC[2], CDR "is required to achieve global and national targets of net zero CO_2 and greenhouse gas (GHG) 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 current concentration of greenhouse gasses in the atmosphere is already causing severe climate effects. Worse, climate pollution continues to rise and remains in the atmosphere for decades to centuries.

CDR can contribute to climate change mitigation by removing CO_2 already in the atmosphere. If carried out at sufficient scale over time, it may also begin to draw down overall greenhouse gas levels in the atmosphere.

Nature-based solutions, such as locking up atmospheric carbon in woody matter by encouraging forest growth, can remove and store carbon over decades to centuries. However, such efforts are at risk of loss from fire and drought, which are themselves likely to be exacerbated by climate change. CDR only reduces net emissions if the removal is accurately quantified and permanent.

A broad suite of technology-based approaches is emerging that has the potential to deliver the kind of durable CDR needed to supplement efforts to reduce emissions. One group of technologies that shows great promise is based on ocean chemistry and biology. These technologies, collectively known as oCDR are illustrated in Figure 1.

Some encourage the growth of algae, which would be harvested or sunk in the deep sea for long-term storage of its carbon content. Another process, called ocean alkalinity enhancement, utilizes the natural chemistry of seawater to transform CO_2 that is already dissolved in seawater into inert components, making room for the ocean to absorb even more CO_2. Alkalinity is a measure of seawater's ability to neutralize acid. In other words, if the alkalinity of seawater is raised slightly, a portion of the CO_2 that is dissolved in it will be transformed into a stable pool of dissolved inorganic carbon, of which the ocean already contains 38 trillion tons. Another method uses electricity to strip dissolved carbon dioxide from seawater, and capture and store or utilize it. In addition to removing carbon dioxide, oCDR approaches may offer the benefit of locally reducing ocean acidification, which is harmful to marine life. These approaches could store carbon in seawater for centuries or longer.

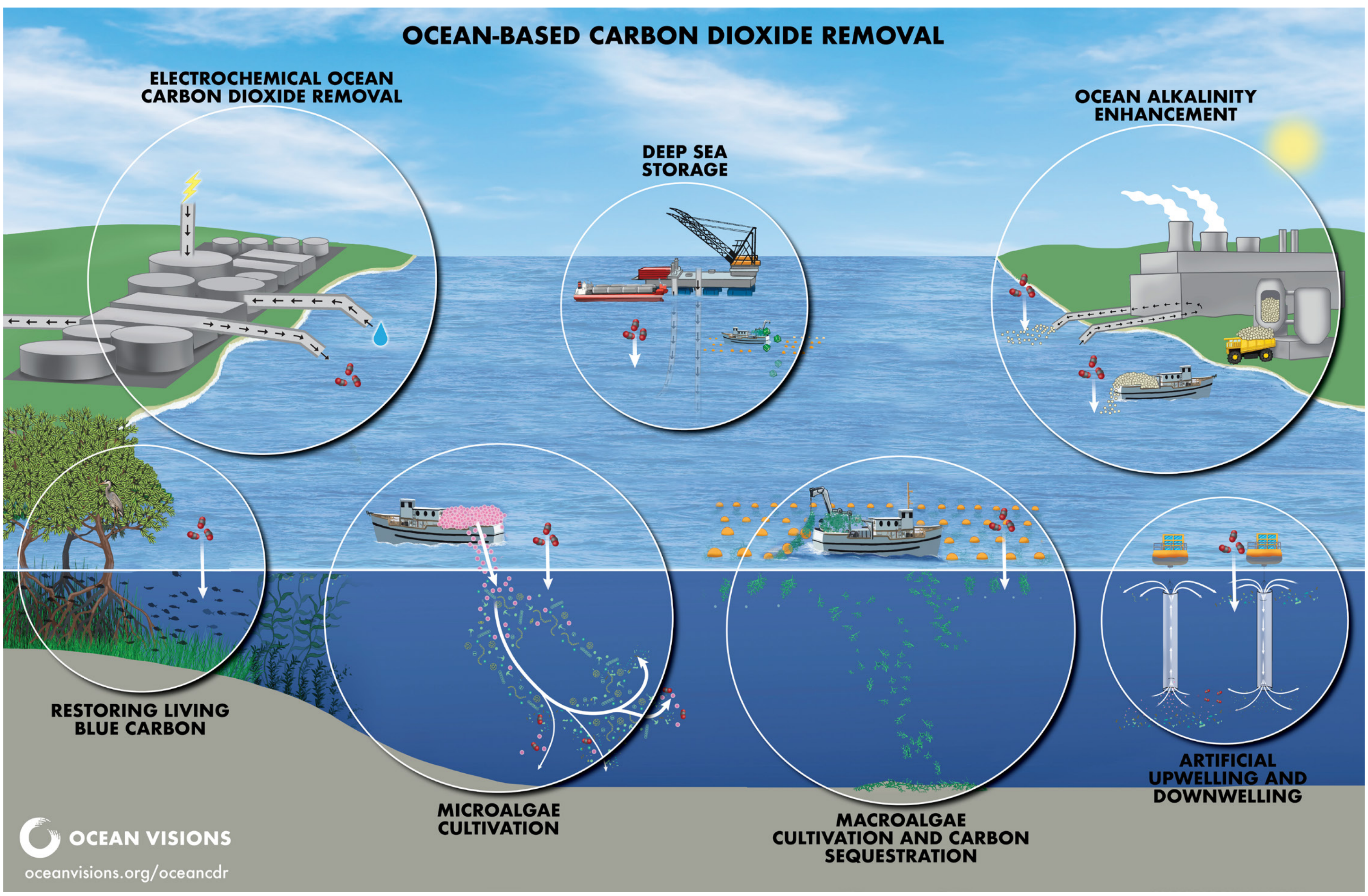
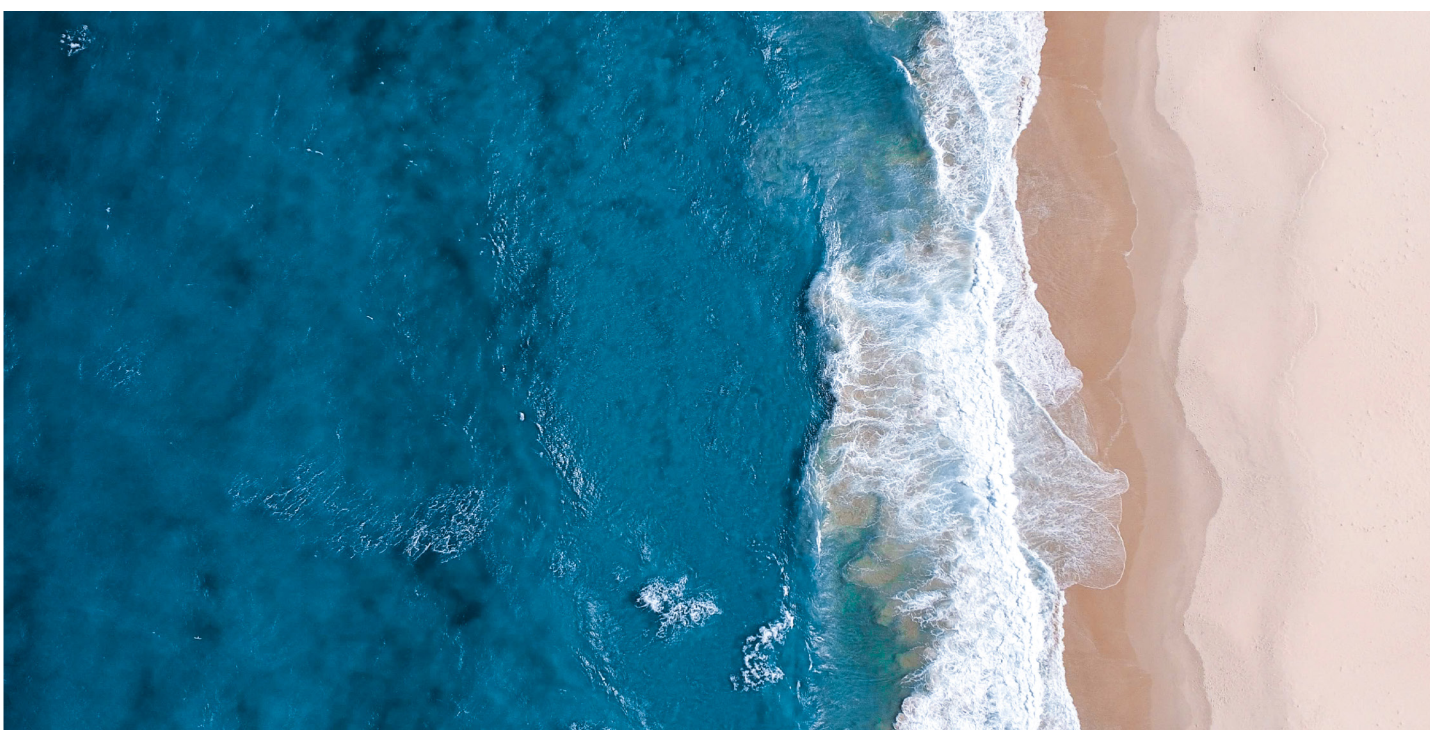


Figure 1: Ocean-Based Carbon Dioxide Removal © 2023 by Ocean Visions is licensed under CC BY-NC-ND 4.0. To view a copy of this license, visit https://creativecommons.org/licenses/by-nc-nd/4.0/

A report from Oxford University's Smith School of Enterprise and the Environment[3] predicts that six to ten billion metric tons per year of CDR would likely be needed to meet the widely agreed international goal of net zero greenhouse emissions by 2050. Based on these estimates, McKinsey and Company[4] predict that the CDR market could be worth up to $1.2 trillion by 2050. To stay on track to meet this demand, they estimate that CDR capacity would have to reach 0.8 to 2.9 billion metric tons per year by 2030. This capacity is 3-10 times the capacity that major industry players expect by that time, based on current levels of investment and technology development.

> That is why additional public investment is critical to supplement private and philanthropic funding.



> Given the environmental need and the business opportunity, substantial capital is flowing into CDR technologies.

$1 Billion

A recent analysis by the Boston Consulting Group (BCG)[5] estimates that over $1 billion in private capital was invested in direct air capture, biomass with CDR and storage, enhanced weathering/ CO_2 mineralization, and ocean alkalinity enhancement in 2022, with investment on track to meet or exceed that amount in 2023.

$400 Billion

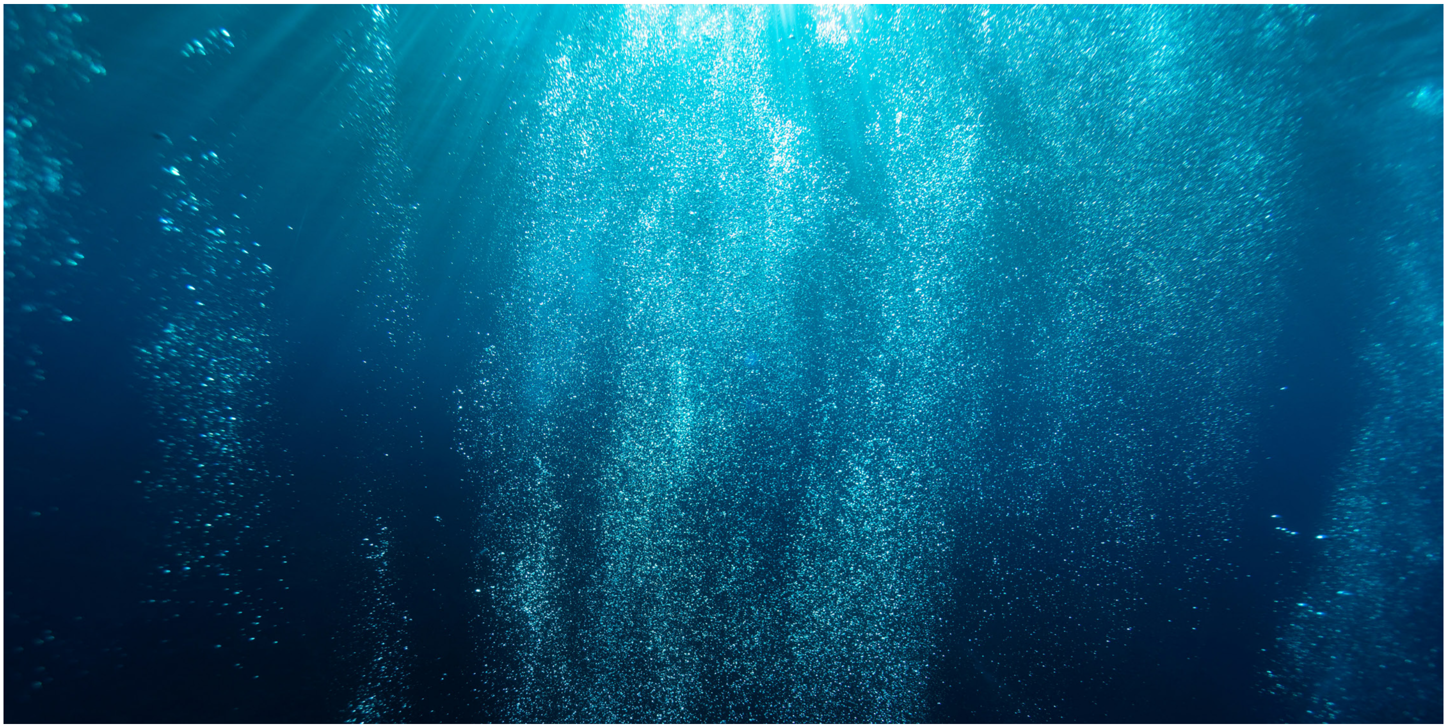
Despite strong projected demand, the current level of investment is less than 10 percent of investment in other climate-related technologies at a similar early stage, according to BCG. McKinsey and Company assessed that an investment of between $400 billion and $1.6 trillion is needed by 2030 to put CDR on track to meet 2050 climate targets.

It is hoped that business and philanthropic investors will continue to increase their support for CDR, and oCDR specifically. But philanthropy only has the capacity to initiate the massive investments necessary. To reach the scale and ensure the oversight needed, governments have an essential role in providing funding strategically to support advancement of safe and effective approaches through comprehensive research, development, and demonstration (RD&D). programs.

< $62 Million

While the U.S. government is investing billions in CDR, it has invested less than $62 million to date in oCDR RD&D (Table 2). In addition, the Department of Energy has also provided the opportunity for oCDR technologies to compete to win a portion of $30 million in government CDR offset procurement contracts.

Many oCDR technologies are in the early demonstration stage of efficacy and technological readiness and thus require federal funding assistance, as well as cooperation and governance from federal science and regulatory agencies, to potentially advance through demonstration to the commercially deployable stage. According to a buyer survey conducted by BCG[6], the top two indicators of quality for CDR buyers on the voluntary market are strong monitoring, reporting, and verification (MRV) of carbon offtake and permanence of storage. Federal research funding is vital to de-risk these indicators for oCDR, thereby providing buyers with more options for durable CDR offsets across a broader range of prices and technology. Federal funding also presents an opportunity to incentivize public engagement best practices and support researchers in achieving net positive environmental and social outcomes.



Key Benefits of government funding include:

Maintaining and enhancing U.S. leadership in the development of climate mitigation technologies.

Not only are these technologies vital for addressing the global climate crisis, but they represent a major business opportunity.

Responsible regulation and strategic research funding will help the U.S. benefit from jobs and investment resulting from a strong and sustainable domestic industry, and to strengthen its role as a global leader in developing and exporting technologies to address the climate crisis.

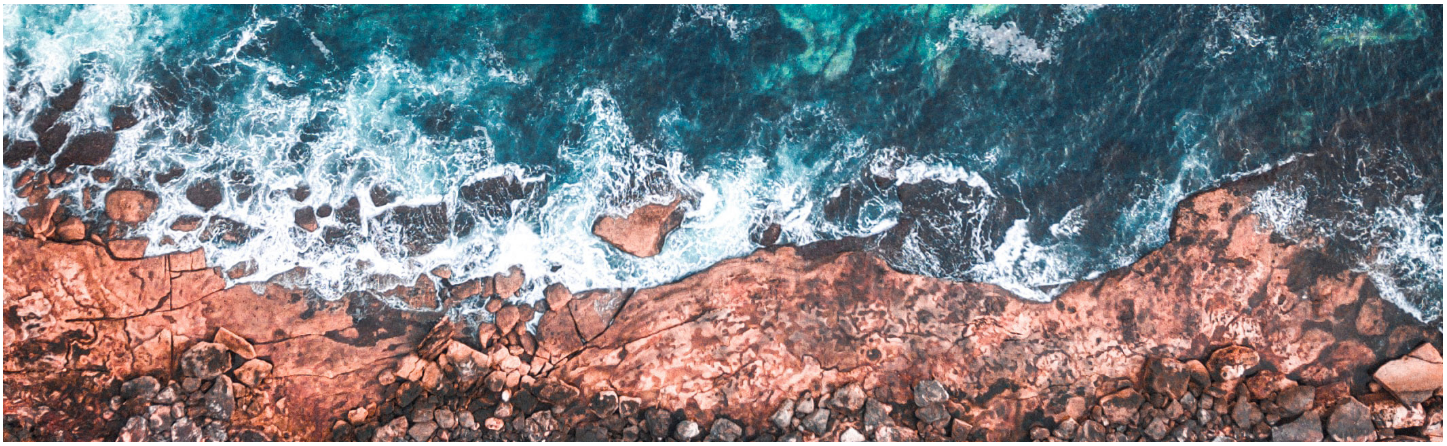
Strategically guiding research to identify and develop oCDR technologies that are safe for the environment and effective.

Field trials with rigorous MRV are required to evaluate environmental safety, quantify CDR, and assess the durability of carbon dioxide removals in open ocean systems.

These results will be needed for oCDR to earn public trust necessary to operate at scale in the public ocean space.

Building consumer confidence in, and ensuring a strong domestic "supply" of durable CDR capacity to assist governments at all levels and the private sector in meeting their climate goals and commitments.

Incentivizing project developers to pursue the highest levels of safety, environmental stewardship, accountability, community engagement, and societal benefits.



A DOWN PAYMENT

For a mature and responsible oCDR sector to materialize at the scale and pace required to meet climate goals, substantial and increasing government support for RD&D is required because privately funded efforts will be insufficient on their own. While the private sector can play an important role in accelerating innovation and reducing costs, a lack of government support may suppress private sector interest and be interpreted as a reason not to invest. Government investment will be required to ensure public and market confidence in the scientific rigor and environmental safety of oCDR pathways, so that they can be deployed at the scale required to meaningfully reduce legacy emissions.

According to a 2022 report by National Academies of Science, Engineering and Medicine[7] (NASEM), funding for oCDR RD&D needs to rise to about $301.5 million annually, for a ten-year investment of $2.41 billion, to ready oCDR technologies to deliver safe and effective CDR at scale. Additionally, a 2020 analysis by the Energy Futures Initiative[8] (EFI) called for a similar investment of $995 million in federal funding over five years and $2.1 billion over ten years to advance oCDR. The detailed funding recommendations from these reports are shown in Table 3.

> To date, funding continues to lag substantially behind the annual investment in the hundreds of millions projected to be needed to satisfy scientific requirements for oCDR.

More recently, the government has increased spending to advance the technological readiness of oCDR, which rose to nearly $61.5 million in FY23. (Table 2.)

Key federal oCDR investments in FY23 included:

$23.7 Million

$23.7 million in grants from the interagency National Oceanographic Partnership Program

Supporting 17 projects representing academic and government researchers and private industry, this is the first large-scale public investment of research specifically focused on a suite of marine carbon dioxide removal approaches to assess their potential as climate mitigation solutions

This research will enhance understanding of their risks and co-benefits, and provide science needed to build regulatory frameworks for further testing and scaling.

$35.8 Million

$35.8 million in grants for development of technology and modeling for MRV awarded by DOE's ARPA-E program

This funding supports 11 projects across 8 states to develop novel efforts to measure, report and validate oCDR and identify cost-effective and energy-efficient CDR solutions.

$2 Million

Nearly $2 million in small grants from DOE's Office of Fossil Energy and Carbon Management for design, modeling and field validation of various oCDR technologies

Support for conceptual design studies followed by field validations of cost-effective processes for ocean-based carbon capture and for direct air capture of CO_2 coupled with carbon-free hydrogen and captured CO_2 to create carbon-neutral methanol, a chemical building block for many valuable products.

Selected projects will support the cost and performance goals of DOE's Carbon Negative Shot initiative, which calls for innovation in CDR pathways that will capture CO_2 from the atmosphere and permanently store it at meaningful scales for less than $100/net metric ton of CO_2-equivalent.

$35 Million

The launch of what appears to be the world's first government CDR offset procurement project, with an initial investment of $35 million ($5 million for project development and $30 million for CDR offtake contracts)

The Carbon Dioxide Removal Purchase Pilot Prize will enable companies to compete for the opportunity to sell CDR credits directly to DOE. This will help build standards for successful CDR programs and create a market to encourage technology innovation and the growth of the industry.

This prize initiates a first-of-a-kind effort for the U.S. government to serve as the customer for carbon dioxide removal credits, supporting commercial carbon dioxide removal companies over several phases for delivery of the highest quality carbon dioxide removal technology offerings.

Appropriations for FY24 were completed in March 2024, over five months into the fiscal year, because of disputes in Congress over funding as well as policy provisions included in the appropriation bills.

Major provisions related to oCDR in the final FY24 appropriations legislation included:

$118 Million

$118 million (a $22 million decrease from FY23) for DOE's cross-cutting CDR initiative, which includes oCDR.

$20 Million

$20 million to continue DOE's competitive CDR purchasing pilot program.

$250,000

$250,000 for DOE to work with other agencies and industry partners toward a clear regulatory process to develop, test, and evaluate oCDR.

Report language encouraging NOAA to use previously appropriated funds to assess the carbon sequestration potential of various coastal habitats. (No dollar amount specified.)

Veterans of the federal appropriations process that we have consulted are not surprised that federal funding for FY24 decreased relative to FY23. An analysis by the nonpartisan Committee for a Responsible Federal Budget[9] shows that while defense spending rose a modest 3 percent, nondefense spending decreased by up to 9 percent. Experts anticipate that overall federal spending may dip even lower for FY25 as disputes over spending and policy priorities are exacerbated heading into the national elections in November.

The funding to date is a good start, but it represents only a fraction of the investment needed to determine whether and how an oCDR sector can play a meaningful role in drawing down greenhouse gasses in the atmosphere.

Congress can take three significant steps to reduce the investment gap:

1. Increase funding for DOE's cross-cutting carbon dioxide removal initiative to $353 million, of which not less than $100 million should be dedicated to advancing oCDR.

2. Provide not less than $30 million to NOAA for external oCDR research, development, and demonstration grants.

3. Maintain funding for DOE's ARPA-E program, which should allocate funds commensurate with the need for ongoing improvements in modeling and technology development for monitoring and verifying the effects and efficacy of oCDR.

(details provided in Table 1):

Building on the foundation set over the last two fiscal years, the funding requested by Carbon to Sea for FY25 will enable oCDR to contribute substantially to the goal of gigaton-scale capacity for safe and effective CDR by the end of the decade. The requested funding levels are consistent with the necessary annual investments in research priorities recommended by NASEM as well as the year-over-year ramp up of oCDR research funding proposed by EFI.

TABLE 1:

Appropriations History and FY25 Carbon to Sea appropriations request for oCDR.

Subcommittee	Commerce, Justice, Science	Energy and Water Development	Energy and Water Development
Department/ Agency	Commerce/NOAA	Department of Energy	Department of Energy
Account	Operations, Research, and Facilities (ORF)	Crosscutting Initiatives	
Program	Oceanic and Atmospheric Research (OAR): Ocean Acidification Program	Carbon Dioxide Removal (Offices of Science, Energy Efficiency and Renewable Energy, and Fossil Energy and Carbon Management)	ARPA-E
FY24 Enacted Appropriations (millions)	$0	$118 $70 FECM $25 Science $23 EERE	$460
FY25 President's Budget Request Appropriations (millions)	The President's FY25 Budget includes $212 million for NOAA's climate research programs. It is unclear what portion of that is specific to ocean CDR.	$70 FECM (Dedicated funds for CDR for Office of Science and EERE not requested)	$450
FY25 CTS Request Appropriations (millions)	$30	$353	$460

TABLE 1: CONTINUED

Appropriations History and FY25 Carbon to Sea appropriations request for oCDR.

Subcommittee	Commerce, Justice, Science	Energy and Water Development	Energy and Water Development
Report Language Request	The Committee provides not less than $30,000,000 to the National Oceanic and Atmospheric Administration (NOAA) to support research and development of diverse ocean-based carbon dioxide removal (CDR) approaches. The Committee recommends that NOAA continue to coordinate ocean CDR research activities within its office and with other agencies, as appropriate. The Committee supports research on ocean CDR approaches to expand the knowledge base around their efficacy and impacts; adoption of a research code of conduct, based on existing code of conduct efforts, for recipients of federal funding; and transparency and timely data sharing with regard to data collected as part of this research effort, including to the extent possible, data gathered through public-private partnership research efforts.	The Committee provides not less than $353,000,000 for research, development, and demonstration of diverse carbon dioxide removal technologies and approaches, to be appropriately coordinated between the Office of Fossil Energy and Carbon Management, the Office of Science, the Office of Energy Efficiency and Renewable Energy and any other relevant program offices or agencies. Within the amount provided, the Committee provides not less than $100 million to support research, development, and demonstration of ocean-based carbon dioxide removal and not less than $30,000,000 to support the continuation of the competitive carbon dioxide removal pilot prize that the Secretary was directed to establish in the FY23 Energy and Water joint explanatory statement, consistent with Division D of Public Law 117-328. In carrying out the pilot prize, the Committee recommends that the Secretary prioritize no fewer than four different carbon removal technology pathways, including ocean alkalinity enhancement, and emphasize methods that minimize removal reversibility and maximize storage duration. The Committee supports the Department's efforts to improve measurement, monitoring, reporting, and verification, including to inform the pilot prize, offtake agreements, and other federal incentives.	The committee is encouraged by the progress ARPA-E has made in the advancement of cutting-edge energy technology projects that have put the United States at the forefront of solving the nation's most challenging obstacles, including climate change. To further this important work, the committee recommends ARPA-E give full consideration to the funding of ocean-based carbon dioxide removal research and development needs..

TABLE 2:

FY23 Federal grants for oCDR RD&D.

Agency	Program	mCDR Project	Lead Institution	Location	Amount
NOAA-NOPP	Investments to Advance mCDR Research	Carbon capture and ocean acidification mitigation potential by seaweed farms in tropical and subtropical coastal environments	Scripps Institution of Oceanography	San Diego, CA	$1,451,575
NOAA-NOPP	Investments to Advance mCDR Research	Assessing chemical and biological implications of alkalinity enhancement using carbonate salts obtained from captured CO_2 to mitigate negative effects of ocean acidification and enable mCDR	Scripps Institution of Oceanography	San Diego, CA	$995,891
NOAA-NOPP	Investments to Advance mCDR Research	Electrolysis-driven weathering of basic minerals for long-term ocean buffering and CO_2 reduction	Oregon State University	Corvallis, OR	$2,000,000
NOAA-NOPP	Investments to Advance mCDR Research	Multiscale observing system simulation experiments for iron fertilization in the Southern Ocean, Equatorial Pacific, and Northeast Pacific	Woods Hole Oceanographic Institute	Woods Hole, MA	$1,983,731
NOAA-NOPP	Investments to Advance mCDR Research	An opportunity to study Ocean Alkalinity Enhancement, CDR, and ecosystem impacts through coastal liming	University of Rhode Island	Kingston, RI	$1,538,452
NOAA-NOPP	Investments to Advance mCDR Research	Tidal wetlands as a low pH environment for accelerated and scalable olivine dissolution	United States Geological Survey	Reston, VA	$1,895,531
NOAA-NOPP	Investments to Advance mCDR Research	Assessing the laboratory and field responses of diatoms and coccolithophores to ocean alkalinity enhancement	Woods Hole Oceanographic Institution	Woods Hole, MA	$1,026,045

TABLE 2: CONTINUED

FY23 Federal grants for oCDR RD&D.

Agency	Program	mCDR Project	Lead Institution	Location	Amount
NOAA-NOPP	Investments to Advance mCDR Research	Determining the Influence of Ocean Alkalinity Enhancement on Foraminifera Calcification, Distribution, and CaCO3 Production	Vassar College	Poughkeepsie, NY	$510,359
NOAA-NOPP*	Investments to Advance mCDR Research	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	University of Hawai'i, Manoa	Honolulu, HI	$1,999,835
NOAA-NOPP	Investments to Advance mCDR Research	Assessing Carbon Dioxide Removal and Ecosystem Response for an Ocean Alkalinity Enhancement Field Trial	Woods Hole Oceanographic Institution	Woods Hole, MA	$1,877,644
NOAA-NOPP	Investments to Advance mCDR Research	Assessing efficacy of electrochemical ocean alkalinity enhancement at an existing outfall using tracer release experiments and oceanographic models	University of Hawaii	Honolulu, HI	$1,915,600
NOAA-NOPP	Investments to Advance mCDR Research	Quantifying the Efficacy of Wastewater Alkalinity Enhancement on mCDR and Acidification Mitigation in a Large Estuary	University of Maryland Center for Environmental Science	College Park, MD	$1,864,561
NOAA-NOPP	Investments to Advance mCDR Research	Biotic calcification impacts on marine carbon dioxide removal additionality	University of Washington (CICOES)	Seattle, WA	$1,250,482

TABLE 2: CONTINUED

FY23 Federal grants for oCDR RD&D.

Agency	Program	mCDR Project	Lead Institution	Location	Amount
NOAA-NOPP	Investments to Advance mCDR Research	Developing a coupled benthic-pelagic biogeochemical model to evaluate the effectiveness of mCDR interventions	Northeastern University	Boston, MA	$1,258,967
NOAA-NOPP	Investments to Advance mCDR Research	Engaging U.S. Commercial Fishing Community to Develop Recommendations for Fishery-Sensitive mCDR Governance, Collaborative Research and Monitoring, and Outreach to Fishing Communities	Responsible Offshore Development Alliance	Washington, DC	$99,591
NOAA-NOPP	Investments to Advance mCDR Research	Coupling Desalination with Novel mCDR Membranes	University of Pittsburgh	Pittsburgh, PA	$1,403,802
NOAA-NOPP	Investments to Advance mCDR Research	Data requirements for quantifying natural variability and the background ocean carbon sink in mCDR models	Columbia University	New York, NY	$589,464
TOTAL NOAA-NOPP					**$23,661,530**
DOE-FECM	Investments for Carbon Management R&D Projects	Ocean-Based Carbon Capture, Storage, and Alkalinity Improvement by a Seawater-Regenerated Metal-Polymer Hybrid Sorbent	Advanced Cooling Technologies, Inc	Lancaster, PA	$249,999
DOE-FECM	Investments for Carbon Management R&D Projects	Atmospheric CO_2 Removal via Direct Ocean Capture on an Offshore Platform	Captura Corporation	Pasadena, CA	$249,919

TABLE 2: CONTINUED

FY23 Federal grants for oCDR RD&D.

Agency	Program	mCDR Project	Lead Institution	Location	Amount
DOE-FECM	Investments for Carbon Management R&D Projects	Optimizing the integration of aquaculture and ocean alkalinity enhancement for low-cost carbon removal and maximum ecosystem benefit	Ebb Carbon, Inc.	San Carlos, CA	$250,000
DOE-FECM	Investments for Carbon Management R&D Projects	Ocean Energy Carbon Removal	Ocean Energy USA LLC	Sacramento, CA	$250,000
DOE-FECM	Investments for Carbon Management R&D Projects	Development of Modular Electrochemical Tubes to Remove Dissolved Inorganic Carbon from Ocean	University of Houston	Houston, TX	$250,043
DOE-FECM	Investments for Carbon Management R&D Projects	Depolarized Electrochemical Reactor for Ocean Alkalinity Enhancement and Facile Recovery of High Purity Carbon	University of Kentucky Research Foundation	Lexington, KY	$249,998
DOE-FECM	Investments for Carbon Management R&D Projects	Hydrolytic Softening for Ocean Carbon Dioxide Removal	University of North Dakota Energy & Environmental Research Center (EERC)	Grand Forks, ND	$235,935
DOE-FECM	Investments for Carbon Management R&D Projects	TRACER: Electrochemical Removal of Carbon Dioxide from Oceanwater: Field Validation	University of Texas at Arlington	Arlington, TX	$250,000
DOE-FECM TOTAL					**$1,985,894**
DOE-ARPA-E	Sensing Exports of Anthropogenic Carbon through Ocean Observation (SEA-CO_2)	Scalable, Multiparameter Chip-Size Carbon Sensors	Woods Hole Oceanographic Institution	Woods Hole, MA	$3,738,960

TABLE 2: CONTINUED

FY23 Federal grants for oCDR RD&D.

Agency	Program	mCDR Project	Lead Institution	Location	Amount
DOE-ARPA-E	SEA- CO_2	Acoustic Methods for mCDR based on Blue Carbon Burial in Seagrass Meadows	University of Texas at Austin	Austin, TX	$2,034,903
DOE-ARPA-E	SEA- CO_2	Monitoring, Reporting and Verification of Zooplankton-Mediated Export Pathways for Carbon Sequestration	Bigelow Laboratory for Ocean Sciences	East Boothbay, ME	$2,279,867
DOE-ARPA-E	SEA- CO_2	SLEUTH: Spectroscopy of Oceanic Liquid Environments Using Towed Optical Sensor Heads	University of Colorado, Boulder	Boulder, CO	$5,904,233
DOE-ARPA-E	SEA- CO_2	A Scalable, Integrated, Real-Time, GPU-Based Modeling System to Enable MRV for mCDR	atdepth MRV	Cambridge, MA	$2,524,964
DOE-ARPA-E	SEA- CO_2	SEAfloor Self-sustaining CO_2 Assessment Probe Edge (SEASCAPE)	University of Utah	Salt Lake City, UT	$2,004,554
DOE-ARPA-E	SEA- CO_2	Spatially Resolved Multi-Parameter Sensing Of Ocean Carbon Dynamics Utilizing Fiber Optic Time-Of-Flight Sensors	General Electric (GE) Research	Niskayuna, NY	$4,274,658
DOE-ARPA-E	SEA- CO_2	Computational Systems for Tracking Ocean Carbon (C-Star)	[C]Worthy	Boulder, CO	$3,884,825
DOE-ARPA-E	SEA- CO_2	Hybrid Distributed pH, CO_2, Temperature, and Acoustic Sensing for Monitoring and Verification of Marine Carbon Dioxide Removal Applications	University of Pittsburgh	Pittsburgh, PA	$2,274,859

TABLE 2: CONTINUED

FY23 Federal grants for oCDR RD&D.

Agency	Program	mCDR Project	Lead Institution	Location	Amount
DOE-ARPA-E	SEA- CO_2	Quantification of Atmospheric Carbon Dioxide Removal Using an Autonomous Ocean Sensor that Measures Sinking Particulate Carbon Flux	Woods Hole Oceanographic Institution	Woods Hole, MA	$4,802,245
DOE-ARPA-E	SEA- CO_2	Integrated Experimental and Modeling Assessment of Ocean Alkalinity Enhancement for Scalable Marine Carbon Dioxide Removal	Pacific Northwest National Laboratory	Seattle, WA	$2,080,715
TOTAL ARPA-E					**$35,804,783**
FY 23 TOTAL					**$61,452,207**

TABLE 3:

Comparison of oCDR funding recommendations by the Energy Futures Initiative (2019, 2020) and the National Academies of Science, Engineering and Medicine (2022).

	Cumulative funding allocation (million US$)				Comparable NASEM Research Categories				
	Year 1	Year 5	Year 10	2019 EFI 10-yr Allocation	2020 v. 2019 est	Annual	Priority	Cumulattive Spending	Duration (years)
1. Biological Methods	$34	$465	$950	$1,282	-$332				5-10
a. Microalgae Fertilization	$2	$40	$100	$328	-$228	$48	$33	$290-440	
b. Microalgae Cultivation	$10	$100	$200	$38	$162				5-10
c. Macroalgae Cultivation	$10	$100	$200	$40	$160	$41	$26	$235-385	
d. Biomass Utilization RD&D	$5	$100	$200	$107	$93				5-10
e.Upwelling/Downwelling	$2	$25	$50	$0	$50	$54	$5	$25-466	5-10
f. Blue Carbon	$5	$10	$200	$769	-$569	$41	$26	$220-295	
2. Non-biological Methods	$100	$325	$800	$374	$426				5-10
a. Seawater Alkalinity Addition	$50	$200	$500	$374	$126	$45	$25	$125-350	5-10
b. Seawater CO_2 extraction, utilization, and storage	$50	$125	$300	$0	$300	$73	$55	$350-475	
3. New/Emerging Marine CDR methods	$5	$50	$100	$0	$100				2-4
4. Modeling, Measuring and Planning Tools	$20	$105	$125	$94	$31	$9	N/A	$30	1-10
5. Governance, and Stakeholder and Public Engagement	$5	$50	$100	$0	$100	$13	N/A	61	
TOTAL	**$164**	**$995**	**$2,075**	**$1,750**	**$325**	**$324**	**$170**	**$1,336-2,502**	

FY23 Funding Authorizations and Sources.

$23.7 million in grants from the interagency National Oceanographic Partnership Program

- Authorizations: 1) Public Law 102-567, §201(c), Coastal Ocean Program; 33 U.S.C. Chapter 50, Sec. 3701-3708; 2) Federal Ocean Acidification Research and Monitoring Act (FOARAM); Public Law 116-283, §1055, Reauthorization of National Oceanographic Partnership Program; and 3) Inflation Reduction Act of 2022 sec 40001.
- Appropriations[10]: 1) $14.36 million from the Inflation Reduction Act as part of the Investing in Coastal Communities and Climate Resilience provision under NOAA's U.S. Integrated Ocean Observing System Office IRA priorities; and 2) $10M provided by NOAA's Ocean Acidification Program and Global Ocean Monitoring and Observing Program and NOAA's appropriations for the NOAA's National Oceanographic Partnership Program, the Department of Energy's Office of Fossil Energy and Carbon Management and Water Power Technologies Office, Office of Naval Research, U.S National Science Foundation, and the ClimateWorks Foundation support seven more marine carbon dioxide removal research projects.

$35.8 million in grants for development of technology and modeling for MRV awarded by DOE's ARPA-E program

- Authorization[11]: Title 42, Chapter 149, Subchapter XVII of the United States Code as amended by Sec. 5012 of P.L. 110-69 (H.R. 2272), Sec. 904 of P.L. 111-358 (H.R. 5116), and Sec. 10001 of P.L. 116-260 (H.R. 133)
- Appropriation: Consolidated Appropriations Act, 2023 (Public Law 117–328). Joint Explanatory Statement, Book 1 (Divisions A-F)[12], page 800.

Nearly $2 million in small grants from DOE's Office of Fossil Energy and Carbon Management for design, modeling and field validation of various oCDR technologies

- Authorization: DOE Organization Act, 42 U.S.C. § 7101., et seq. (Public Law 95-91), as amended; and Energy Policy Act of 2005, 42 U.S.C. § 15801., et seq. (Public Law 109-58) as amended, TITLE IX, Subtitle F, Sec. 962.
- Appropriation: Consolidated Appropriations Act, 2023 (Public Law 117–328). Joint Explanatory Statement, Book 1 (Divisions A-F), pp. 897, 928.

$35 million for government procurement of CDR

- Authorization: DOE Organization Act, 42 U.S.C. § 7101., et seq. (Public Law 95-91), as amended and; 42 U.S.C. § 16292.
- Appropriation: Bipartisan Infrastructure Law[13], section 41005(b).

ENDNOTES

1 https://www.reuters.com/business/sustainable-business/us-energy-department-spend-37-billion-carbon-removal-2022-12-13/

2 https://www.ipcc.ch/report/ar6/wg3/downloads/outreach/IPCC_AR6_WGIII_Factsheet_CDR.pdf

3 https://www.stateofcdr.org/

4 https://www.mckinsey.com/capabilities/sustainability/our-insights/carbon-removals-how-to-scale-a-new-gigaton-industry#/

5 https://www.bcg.com/publications/2023/the-need-and-market-demand-for-carbon-dioxide-removal

6 https://web-assets.bcg.com/67/f7/0f41cd074a66b49cdb8baf5e59c0/bcg-the-time-for-carbon-removal- has-come-sep-2023-r.pdf

7 https://nap.nationalacademies.org/catalog/26278/a-research-strategy-for-ocean-based-carbon-dioxide-removal-and-sequestration

8 https://efifoundation.org/reports/uncharted-waters/

https://bipartisanpolicy.org/download/?file=/wp-content/uploads/2019/06/Carbon-Removal-Comparing-Historical-Investments-with-the-National-Academies-Recommendations.pdf

9 https://www.crfb.org/blogs/appropriations-watch-fy-2024#:~:text=The%20FRA%20caps%20total%20base,on%20how%20it%20is%20 measured).

10 https://oceanacidification.noaa.gov/fy23-nopp-mcdr-awards/#:~:text=The%20NOPP%20marine%20carbon%20dioxide,enhanced%20weathering%2C%20and%20electrochemical%20approaches.

11 https://arpa-e.energy.gov/about/authorization

12 https://www.congress.gov/117/cprt/HPRT50347/CPRT-117HPRT50347.pdf

13 https://www.whitehouse.gov/build/guidebook/

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Carbon to Sea Initiative