Problem solving in Marine Carbon Dioxide Removal (mCDR):
Identifying important questions and capabilities for studying new human perturbations to the Ocean Carbon System

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A paired proposal for an OCB Scoping Workshop and associated Working Group

Summary

We seek funding in the amount of $67,356 to support an OCB workshop to accelerate marine carbon dioxide removal (mCDR) research paired with $28,446 for a working group to rapidly pursue priorities set at the workshop. The goal of the workshop is to bring communities interested in conducting mCDR research together to assess key knowledge gaps, investigate the potential for best practices, and consider strategies for federal investment in mCDR research. This request follows guidance for interdisciplinary consensus building among the scientific community suggested by the National Academies (2019 and 2021), the Energy Futures Initiative (2019 and 2020a, b), the World Resources Institute (2018 and 2020a, b), and the Ocean Visions program (2021). The urgency of providing scientific input to burgeoning mCDR interest groups, further outlined below, suggests that any priorities identified at the workshop should be immediately evaluated and documented. Thus, this is the motivation for submitting a paired workshop/working group proposal.

Limiting warming to levels that avoid extreme risk (1.5 - 2°C) will require removing multiple gigatons of carbon dioxide from the atmosphere each year, on top of immediate and substantial reductions of greenhouse emissions (SR1.5: IPCC, 2018). While emissions-reduction approaches are the primary component for addressing this challenge, the delay in implementing these strategies over the previous decades means that negative emissions strategies are now integral to keeping global temperatures at or below target levels. Anticipating carbon markets and spurred on by massive nonprofit investments from Stripe, ClimateWorks, the Bezos Earth Fund, and the $100M Carbon Removal X-Prize, the private sector is already implementing carbon removal strategies. Offsets already have deep market penetration: for example, consumers can purchase carbon offsets with airline flights or monthly utilities. However, despite the fact that carbon offsets and negative emissions shares are currently for sale, the effectiveness and verification of these programs are highly questionable (Joppa et al., 2021). In some cases, it may not be clear if the strategies are safe or equitable (e.g., Mawonde and Togo, 2019; Samaniego et al., 2021), let alone effective.

Given the urgency of this problem, here we propose two linked OCB activities to marshall the ocean biogeochemistry community to set priorities in marine carbon dioxide removal (mCDR): a workshop designed to both educate and challenge our colleagues to engage mCDR research and and a working group to begin setting benchmarks for problem-solving. The workshop will first build community engagement and consensus around defining key mCDR research questions. Then, a representative, interdisciplinary, diverse small group will transparently work towards action plans for necessary mCDR research. We will seek to stitch together networks of researchers with complementary skills/interests and reach out beyond our traditional community to connect more directly with applications-centric groups and potentially impacted stakeholders. Our end goal is to build on the work that defined unknowns and problems in mCDR research (e.g., NASEM, 2019 and 2021) and towards

problem-solving and meaningful scaling. CDR has already arrived as part of the ocean carbon system: it is past time for our community to confront it.

Scientific Background and Rationale

According to the recent IPCC AR6 WG1 report (IPCC, 2021), emissions strategies that limit climate warming to 1.5 - 2 °C require, by the middle of this century, approximately 10 - 15 GT C removal each year. To achieve that goal, it has been estimated that carbon removal projects will need to grow by 3 - 7 GT C per decade (See Minx et al., 2018 Figure 9). Worldwide, most operational projects are currently small (i.e., 10,000 times less than what is needed). In order to meet these targets, it will be necessary to not only increase the efficiency and number of these projects but also explore alternative technologies to achieve these ambitious goals by 2050 (Nemet et al., 2018). Some of these removal techniques rely on accelerating or leveraging the ocean's natural carbon cycle to remove carbon from the atmosphere and store it durably. However, there has been limited research conducted into most of these methods (NASEM, 2019), and many key unknowns regarding efficacy of removal and durability of storage remain.

Emerging mCDR pathways include:

- **Ocean Alkalinization Enhancement (OAE):** alkaline minerals are added to surface waters to increase the seawater carbon uptake capacity. Amendments under consideration: olivine, lime, other alkaline solutions.
- **Ocean Afforestation:** farmed seaweed is sunk or removed from the ocean for use or "burial" on land; possibly combined with artificial upwelling.
- **Direct Ocean Capture (DOC):** CO_2 is chemically or electro-chemically removed from seawater locally, thereby stimulating uptake via air-sea flux. Concentrated CO_2 is subsequently stored in the deep-ocean or under the sea-floor, for example in basaltic crust.
- **Artificial upwelling:** Nutrient and CO_2-rich waters from the deep ocean are pumped to the surface, seeking to enhance algal productivity and possibly organic carbon export to the extent that it overcompensates upwelled CO_2.
- **Artificial downwelling:** Following natural or enhanced CO_2 uptake, surface waters are sunk into the deep ocean.
- **Ocean fertilization:** add Fe, P, N, or Si to stimulate phytoplankton growth and organic carbon export from the surface ocean.
- **Terrestrial biomass dumping:** Drop terrestrial biomass into the deep ocean or bury it in ocean sediments.

In most cases, these approaches are in the very early phases of development and require testing for effectiveness, efficiency, and ecological risk. However, private-sector applications for these techniques may already outpace scientific confidence in some cases; for example, Bach et al. (2021) documented the rapid deployment of ocean afforestation techniques, despite questionable evidence that they could sequester carbon from the atmosphere. This is a challenge that the private sector itself acknowledges. Inconsistent definitions of carbon capture and poor measurement and tracking of carbon sequestration and storage limit the capacity of the private sector to completely decarbonize or offset emissions (Joppa et al., 2021).

At its most fundamental level, successful mCDR would both create and track another global carbon sink. By 2050 and especially by 2100, the magnitude of necessary carbon pulled from the atmosphere will rival the sizes of the global carbon sinks that we already measure (Figure 1). Accordingly, it seems possible that we would be able to use the same tools that are already available to track the new CDR sink.

However, initial CDR projects are likely to be small. There are currently 15 direct air capture plants operating worldwide; there are also multiple private companies pursuing mCDR techniques (e.g., Seafields; Southern Ocean Carbon Company; Running Tide; Project Vesta). However, all of these installations combined are still five orders of magnitude smaller than the current sinks defined by Friedlingstein et al., 2020, and much smaller than the sinks required to offset emissions defined in Minx et al. 2018 and updated via the IPCC AR6 WG1 report (IPCC, 2021). Tracking, measuring, and modeling mCDR efficiency at the small scale may even be more important, given it is the experimentation at the local level that will identify the techniques that may be able to achieve the gigaton-scale carbon sequestration that is so urgently needed.

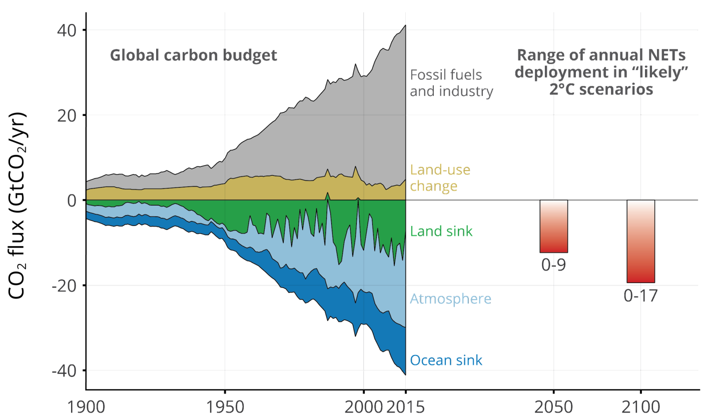

Figure 1: *CDR is a new carbon sink: The latest global carbon budget given for 2021 from Friedlingstein et al., 2020, compared to NET goals projected for 2050 and 2100, updated from Minx et al., 2018 using data from Friedlingstein et al., 2020*

Connections to OCB

Testing, discovering, tracking, observing, monitoring, and predicting local and regional changes in the marine carbon cycle is at the heart of the OCB community. These very basic tasks, so central to the success of CDR, comprise the top two research priorities for the OCB team, including "Climate- and human-driven changes in ocean chemistry (e.g., acidification, deoxygenation, nutrient loading, etc.) and associated impacts on marine ecosystems" and "Ocean carbon uptake and storage, including processes from the air-sea interface to the deep ocean." Multiple previous OCB activities have sought to resolve knowledge gaps in our understanding of the global carbon cycle and the role the ocean plays, including the Coastal Carbon Synthesis (CCarS) program, as well as the ongoing working group "Filling the gaps in observation-based estimates of air-sea carbon fluxes."

This history of the OCB community and connection to CDR research was profiled at he 2021 OCB summer workshop plenary session on ocean-based Negative Emissions Technologies, where the convenors joined a panel of experts on mCDR to explore the potential and sustainability of the most technically advanced mCDR approaches, to identify knowledge gaps and discuss future research activities that could close those gaps. As with many previous reports on marine carbon removal (e.g., NASEM, 2019; EFI 2019, 2020a, b; WRI 2018, 2020a, b), that session identified substantial gaps in our understanding of carbon removal (see orange panels in Figure 2).

Given these multiple calls for additional research, and consensus building around key unknowns, there is substantial energy in the scientific community to begin addressing these challenges. The Carbon Cycle Interagency Working Group (CC-IWG) subcommittee on CDR, the Interagency CDR Research Coordination workstream, has *specifically requested* an OCB output that documents potential pathways and best practices to researching these problems. The agencies are specifically seeking guidance on how existing and new programs could help resolve CDR knowledge gaps, and especially whether there are best practices that the agencies should consider for these proposals and governance of mCDR installations. Given OCB's long history of advising national and international science activities, as with the CCarS implementation plan (Benway et al. 2016), it is clear that the OCB community is uniquely suited to providing this guidance.

Figure 2. *Assessment of sequestration potential, economic feasibility, legal constraints, public acceptance, environmental, and social impacts of key marine CDR techniques. From David Keller, OCB 2021 Plenary "A few good reasons to consider ocean-based CDR."*

CDR approach	Physical CDR potential	Economic feasibility	Political / legal constraints	Public acceptance	Environmental impact	Social impact
Ocean alkalinization	High	Tech. specific; low-medium	Unclear	Unknown	Likely to be medium; impacts on biology not clear	Low, unless large mining operations are required
Direct CO_2 removal from seawater with CCS	Unknown; theoretically high	Unknown; likely low	Unknown	Unknown	Unknown	Unknown
Marine biomass for biochar, bioenergy, or to sink	Unknown; likely low-medium	Unknown; likely low	Low (in regards to seaweed farming)	Unknown; positive for biochar	Unknown; likely high	Unknown
Artificial downwelling	Unknown	Low	Unknown	Unknown	Unknown	Unknown
Blue carbon sink enhancement	Low	High	Low	Unknown	Low, likely many co-benefits	Likely beneficial
Terrestrial biomass dumping	Unknown	Unknown	High	Unknown	Unknown; theoretically high	Unknown
Artificial upwelling	Low	Unknown; likely low	Unknown	Unknown	High	Unknown; potentially high
Ocean fertilization	Low to medium	Tech. specific; low-high	High	Unclear	High	Unclear

Deliverables, Outputs and Benefits to the broader OCB community
These paired activities build on the efforts of the OCB O-NETs plenary, in response to the research needs demonstrated by from the CC-IWG's I-CDR-C vision. We propose using an initial workshop effort as a springboard for a follow-on OCB working group activity that will immediately set about documenting consensus points around emerging research needs and best practices, as well as developing an action plan for mCDR science.

This workshop will be the marine-based companion to a similar effort that may be convened by the U.S. Carbon Cycle Science Program / I-CDR-C and the North American Carbon Program (NACP) focused on terrestrial (including coastal) carbon removal practices and technologies, but addressing similar key topics, like which techniques may be able to verify the amount of carbon sequestered, measuring and monitoring the durability of storage, the certainty required for those measurements in a governance context, and how research activities in the science community can support those key outputs. Dr. Gyami Shrestha, Director of the U.S. Carbon Cycle Science Program at the U.S. Global Change Research Program, is willing to co-organize the companion NACP effort with Dr. Libby Larson, Coordinator of the NACP, pending availability of funds and resources.

Benefits and Outputs
We envision four key questions that could focus the expertise and potential of the OCB and NACP communities on construction of a CDR knowledge-to-action pipeline:

- What is the CO_2 removal potential for the various CDR approaches?

    - Multiple reviews have indicated that the existing literature may not be able to resolve questions of efficiency, scalability, durability, and cost. Identifying key studies that can help fill these gaps is essential to evaluating CDR.
- How can the efficiency of CDR deployments and measurements be optimized?
    - On the marine side, our knowledge of ocean biogeochemical systems at the heart of the OCB community's expertise help inform the design of effective, safe mCDR installations. Forging meaningful partnerships between scientists and industry leaders, including creating best practice guidance to preclude both real and perceived conflicts of interest, will improve the quality of mCDR method.
    - How can the science community help accelerate the pace of assessment and deployment such that we have the necessary knowledge available within the next 10 years, the pace necessary to scale CDR to reach climate goals? Our normally linear research process will need to be dramatically accelerated. What actions can parallelize basic research and quickly enable field assessments?
- What are the co-benefits/risks of CDR on ecosystems, including humans?
    - Considering marine applications, many of these methods could pose important risks for marine ecosystems-- for example, trace metal addition could occur with some forms of alkalinity addition. Conversely, some methods may have ecological benefits, such as the mitigation of ocean acidification. Understanding and projecting both risks and co-benefits-- and developing frameworks for evaluating those risks-- will be essential for CDR governance.
- What combination of observations and models will enable verification of carbon removal and sequestration timescales during actual deployments?
    - A carbon accounting reference model may become necessary to determine CO_2 equilibration and permanence as a "gold standard" for the international CDR economy. A toolkit that intercompares different installations and methods will be essential to scaling the CDR sector and deterring techniques that may be ineffective or pose high risks.
    - Models may also forecast when transitions to non-carbon based energy may relieve the need for CDR.

Overall, the aim of the paired workshop and working group is to move beyond calls for more research that identifies unknowns, and transition to solutions-based blueprints and best practices to resolve key issues. One benefit will be a networked international community of practice that can work together to address important interdisciplinary questions in CDR research. Second, this community should go beyond scientific researchers, to include agency and governance voices from the beginning. Ultimately, our research outputs should inform evidence-based decision making, so it will be essential to understand decision points and needs to scale research projects. Including those voices and needs from the outset will help the OCB community accelerate the transition of scientific research to public benefit, an especially important factor given the urgency of this problem.

Deliverables

- Opening workshop.
  - We will work with our colleagues at NACP to structure a companion workshop for terrestrial CDR techniques, and share insights across this disciplinary boundary.
  - We will work with our colleagues at the CC-IWG's I-CDR-C to identify and pursue key questions related to mCDR governance and implementation during both workshops.
  - The workshop will be designed to guide and inspire future OCB efforts, including input for the mCDR working group.
- Working group.
  - Based on the outcomes of the workshop, we will identify key players across disciplines, career levels, and life experience in the ocean biogeochemistry community as members of our small group. This group will include at least one representative from the NACP and U.S. Carbon Cycle Science Program to ensure effective cross-communication.
  - We will prepare a workshop report summarizing key outcomes of the OCB and NACP workshops, as defined above, synthesizing this knowledge into a roadmap for cross-disciplinary research for CDR. This report will be submitted to BAMS or EOS.
  - We will develop an action plan for addressing the four questions defined above. This action plan will be informed by the scientific literature, issues in governance, and environmental justice.
    - This action plan will be developed iteratively and transparently, including multiple opportunities for external feedback through town halls at major scientific meetings, live and recorded virtual information sessions, and written products.
    - Ultimately, the action plan, based on both OCB's marine expertise and NACP's terrestrial and atmospheric expertise, will be published as a community white paper, similar to the CCARS Science Plan, a previous OCB working group product.

Efforts to Enhance Participation of Underrepresented Groups

In the broader climate community, carbon removal and sequestration are rightfully considered with some skepticism as methods that can enable or prolong continued emissions and the lifetime of polluting industries (e.g., Batres et al., 2021). This could be a serious roadblock to achieving sufficient emissions reductions. Carbon removal and sequestration also do not account for other pollutants that are emitted alongside carbon dioxide, short-lived climate pollutants like methane, or particulate matter and other air and water pollutants hazardous to health and human safety. One of the best things we can do as a part of this project to ensure environmental justice is to acknowledge these challenges, and include strategies to empower communities historically impacted by the climate crisis as a part of any roadmap, toolkit, or action plan we develop.

Beyond acknowledging these principles, we can also work to ensure that both the workshop and the working group have specific strategies in place to get underrepresented voices into the conversation during both the workshop and the working group.

Workshop.

- **Invited environmental justice experts and local stakeholders.** We plan to invite 5 environmental justice and social science experts to our opening workshop, and have included in our budget both full travel support and modest honoraria for these attendees. Given financial restrictions, we note specifically that these honoraria can be completely covered by the cost of registration. Plenary time will be devoted to these perspectives at the top of the agenda, and findings of these breakout groups will be given equal weight to science breakout groups.
- **Recruitment.** We will seek participation in the workshop through multiple venues, including direct outreach to HBCUs, MSIs, and associated professional societies, with clearly referenced travel support options.
- **Early career support.** We also acknowledge that there are those within our own community that are historically overlooked. We plan to offset the costs of 15 early career or underrepresented participants, and will seek participation specifically from HBCUs and MSIs.

Working group.

- **Working Group members**. The working group members will be composed of diversity in scientific expertise, career level, and life experience (see below). We commit to at least 3 members at the early-career stage and 3 members from underrepresented backgrounds or MSIs. We will also consider place-based experience to ensure broad geographic scope of experts.
- **Workshop locations.** For the two in-person meetings of the working group, we will seek venue opportunities at HBCUs or MSI institutions. Ideally, these will be communities who have connections to CDR installations or environmental justice initiatives that could represent information exchange.

Timeline

Below, we present a Gantt chart showing the projected distribution of effort and deliverables defined above. For ease of comparison, workshop funded activities are marked in green, while working group activities are marked in blue. Engagement with the broader community is marked by an X: note that transparent presentation of working group findings is conducted almost quarterly. In-person meetings are marked with a bold outline. Note that in-person activities are conducted approximately every 6 months and immediately followed by external reporting. The pace of outputs outlined by this working group is relatively fast: this accelerated schedule is intentional, matching the urgency of the problem outlined.

Activity	**Target Date**	**2022**				**2023**			
		Q1	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**
Workshop planning	March - April 2022								
Speaker Invitations	May - June 2022								
Workshop registration	July - Aug 2022								
Workshop	September 2022			X					
Workshop follow-up	October 2022								

Virtual Monthlies	Aug 2022 - Dec 2023									
Workshop report	Nov - Dec 2022									
AGU Town Hall	December 2022				X					
In-person 1 planning	Dec 2022 - Jan 2023									
In-person 1	February 2023									
Virtual Town Hall	March 2023							X		
In-person 2 planning	July 2023									
In-person 2	September 2023									
Virtual Town Hall	October 2023								X	
AGU Town Hall 2023	December 2023									X
Final Report	December 2023									

Steering Committee

Below, we outline the preliminary members of our steering committee that will both plan the workshop and who plan to participate in the working group. Note that there are multiple positions deliberately held open to recruit traditionally underrepresented members and social science experts.

Preliminary Steering Committee					
Name	**Institution**	**Region**	**Expertise**	**Career Level**	**Pronouns**
Jessica Cross	NOAA-PMEL	Pacific / Arctic	Observations	Mid career	she/her
Lennart Bach	UTas	Southern Ocean	Obs / stats / Geoengineering	Early career	he/him
Jaime Palter	URI	North Atlantic	Obs / modeling	Mid career	she/her
Clare Reimers	OSU	NE Pacific	Benthic fluxes	Late career	she/her
Matt Long	NCAR	Global/Southern Oc.	Ocean and bgc modeling	Mid career	he/him
Patrick Rafter	UC-Irvine	Global / Eq Pacific	Paleoclimate / isotopes	Mid career	he/him
EJ Pos 1					
EJ Pos 2					
EJ Pos 3					
MSI 1					
MSI 2					
MSI 3					

Budget and Budget Justification

Below, we present budgets for both the workshop and working group as separate efforts for ease of consideration of the SSC. For the timeline of support required, we encourage our reviewers to reference the Gantt chart given above.

Workshop

In planning the venue and dates for the workshop, we cross-compared the cost of hosting the meeting at the home institutions of each member of this proposal. According to federal per-diem rates, the most cost effective site for the meeting is the University of Rhode Island, despite costs for necessary buses for transit between area hotels and URI's Narragansett Bay Campus ($10,000). Total workshop participation is estimated at 80 people. Full travel support is provided for 11 members of the working group ($16,115). Current federal employees (e.g., Cross) will seek travel support from other sources. Additional full travel support is provided for 5 science experts ($7,295) and 5 environmental justice experts and stakeholders ($7295). An additional $1000 is budgeted for 5 $200 honoraria for our stakeholder participants. Full travel support is also included for 15 early career or underrepresented participants ($13,785). 40 unsupported participants paying a $250 registration fee offset the overall costs of the workshop ($10,000), including full coverage of the costs of the honoraria listed above, the participation of 4 international participants ($7,616), and extended catering which may be subject to U.S. grant restrictions. Additional meeting support, including $3,000 to offset the costs of meeting supplies and processing registration fees, as well as $3,000 to support webcasting, is also included. The total cost for the workshop is estimated to be $67,356.

	Flights	**Lodging**	**Food**	**Honoraria**	**Persons**	**Registration**	**Total**
Full travel support, 11 SC	750	384	320	--	11	--	16115
Full travel support, 5 experts	750	384	320	--	5	--	7295
Stakeholder Honoraria, 5 experts	750	384	320	200	5	--	8295
Full Travel support, Early Career	750	384	320	--	15	--	22035
International participants	1200	384	320	--	4	--	7616
Unsupported participants	--	--	--	--	40	250	-10000
Total Participants					*80*		
Buses							10000
Supplies and Processing							3000
Webcasting							3000
Total							**67356**

Working Group

In order to scale the costs of the two in-person working group meetings, we also used the per diem rates for the University of Rhode Island, although note that we intend to hold these meetings at MSIs. Per diem, including meals, and incidental expenses are estimated for 11 people at $1947. Air travel support for 9 U.S. travelers totals $5400, while international air travel costs are listed for 2 people ($2400). Hotel accommodations are listed at the federal per-diem rate of $96 / night for 3 nights ($3168) for 11 people. Vehicle travel is also requested for carpooling ($1308). Note that federal employees (e.g., Cross) will seek travel support from other sources. The total cost for the two workshops is estimated to be $28,446. We will request support for participation in national meetings such as AGU from other sources. No publication costs are included as we intend to publish our findings as an OCB white paper, per discussions with the CC-IWG I-CDR-C.

Item	**Notes**	**Total**
Per Diem, M&IE	$59 / day * 11 people * 3 days	1947
International Flights	$1200 * 2 people	2400
Air Travel	$600 / person * 9 people	5400
Hotel Rooms	$96 / night * 11 people * 3 nights	3168
Vehicle Travel	$109 / day * 3 days * 4 cars	1308
	Subtotal for 2 workshops	28446
	Total Request	**28446**

References

Benway, H., Alin, S., Boyer, E., Cai, W.-J., Coble, P., Cross, J., Friedrichs, M., Goñi, M., Griffith, P., Herrmann, M., Lohrenz, S., Mathis, J., McKinley, G., Najjar, R., Pilskaln, C., Siedlecki, S., Smith, R., 2016. A Science Plan for Carbon Cycle Research in North American Coastal Waters. Report of the Coastal CARbon Synthesis (CCARS) community workshop, August 19-21, 2014, Ocean Carbon and Biogeochemistry Program and North American Carbon Program, 84 pp., doi: 10.1575/1912/7777.

Bach, L.T., Tamsitt, V., Gower, J., Hurt, C.L., Raven, J.A., and Boyd, P.W., 2021. Testing the climate intervention potential of ocean afforestation using the Great Atlantic *Sargassum* Belt. Natuer Communications, 12, 2556, doi: 10.1038/s41467-021-22837-2

Batres, M., Wang, F.M., Buck, H., Kapila, R., Kosar, Y., Licker, R., Nahabhushan, D., Rekhleman, E., and Suarez, V., 2021. Environmental and climate justice and technological carbon removal. The Electricity Journal, 34(7), 107002, doi: 10.1016/j.tej.2021.107002

EFI, 2019. Clearing the Air: A federal RD&D initiative and management plan for carbon dioxide removal technologies. Available at: https://www.dropbox.com/s/x0880okedchb18p/EFI%20Clearing%20the%20Air%20Full%20Report.pdf?dl=0.

EFI, 2020a. Uncharted Waters: expanding the options of carbon dioxide removal ain coastal and ocean environments. Available at: https://energyfuturesinitiative.org/s/Uncharted-Waterspdf.pdf

EFI, 2020b. From the Ground Up: cutting-edge approaches for land-based carbon dioxide removal. Available at: https://energyfuturesinitiative.org/s/From-the-Ground-Up.pdf.

Friedlingstein et al., 2020. Global Carbon Budget 2020. Earth System Science Data, 12, 3269-3340, doi: 10.5194/essd-12-3269-2020.

IPCC, 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press. In Press.

IPCC, 2018: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors,

J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. In Press.
Joppa, L., Luers, A., Willmott, E., Friedman, S.J., Hamburg, S.P., and Broze, R., 2021. Microsoft's million-tonne CO2-removal purchase: lessons for net zero. Nature, 597, 629-632, doi: 10.1038/d41586-021-02606-3.
Mawonde, A., and Togo, M., 2019. Implementation of SDGs at the University of South Africa. International Journal of Sustainability in Higher Education, 20(5), 932-950, doi: 10.1108/IJSHE-04-2019-0156
Minx, J.C., Lamb, W.F., Callaghan, M.W., Fuss, S., Hillarie, J., Creutzeg, F., Amann, T., Beringer, T., de Oliveira Garcia, W., and Hartmann, J., 2018. Negative emissions-- Part 1: Research landscape and synthesis. Environmental Research Letter, 13(6), 063001, doi: 10.1088/1748-9326/aabf9b
National Academies of Sciences, Engineering, and Medicine. 2019. Negative Emissions Technologies and Reliable Sequestration: A Research Agenda. Washington, DC: The National Academies Press doi: 10.17226/25259.
National Academies of Sciences, Engineering, and Medicine. 2021. A research strategy for ocean carbon dioxide removal and sequestration, in prep. Information available at https://www.nationalacademies.org/our-work/a-research-strategy-for-ocean-carbon-dioxide-removal-and-sequestration.
Nemet, G.F., Callaghan, M.W., Creutzig, F., Fuss, S., Hartmann, J., Hilarie, J., Lamb, W.F., Minx, J.C., Rogers, S., and Smith, P., 2018. Negative emissions-- Part 3: Innovation and upscaling. Environmental Research Letters, 13(6), 063003, doi: 10.1088/1748-9326/aabff4
Ocean Visions, 2021. Harnessing the power of the ocean to restore the climate and the ocean: ocean-based carbon dioxide cleanup. Available at: https://oceanvisions.org/wp-content/uploads/2021/10/Ocean-Based-CDR-factsheet_FINAL.pdf and https://oceanvisions.org/work/ocean-based-carbon-dioxide-removal/.
Samaniego, J., Schmidt, K.-U., Carlino, H., Caratori, L., Carlino, M., Ggorza, A., Rodriquez Vagaria, A., and Vazquez Amabile, G., 2021. Current understanding of the potential impacts of Carbon Dioxide Removal approaches on the SDGs in selected countries in Latin America and the Caribbean. Final Report. Available at: https://repositorio.cepal.org/handle/11362/47072.
WRI, 2018. Technological Carbon Removal in the United States. Working Paper. Mulligan, J., Ellison, G., Levin, K., and McCormick, C., Eds. Washington, DC: World Resources Institute. Available online at https://www.wri.org/publication/ tech-carbon-removal-usa.
WRI, 2020a. Foundational questions in carbon removal in the United States. Working Paper. Mulligan, J., Ellison, G., and Levin, K., eds. Washington, DC: World Resources Institute. Available online at https://www.wri.org/research/foundational-questions-carbon-removal-united-states.
WRI, 2020b. Carbon Shot: Federal policy options for carbon removal in the United States. Working Paper. Mulligan, J., Rudee, A., Lebling, K., Levin, K., Anderson, J., and Christensen, B., Eds. Washington, DC: World Resources Institute. Available online at https://www.wri.org/research/carbonshot-federal-policy-options-carbon-removal-united-states.

U.S. Carbon Cycle Science Program
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October 22, 2021

Dr. Heather Benway
Ocean Carbon Biogeochemistry Program
Woods Hole Oceanographic Institution

Dear Heather and OCB Scientific Steering Committee,

I am reaching out to the OCB Project Office and Scientific Steering Committee in support of a proposal submitted to the 2022 OCB Activity Solicitation by Drs. Jessica Cross, Lennert Bach, Jaime Palter, Clare Reimers, Matt Long, and Patrick Rafter concerning a marine Carbon Dioxide Removal (mCDR) workshop and working group.

Given the potential economic and climate benefits of carbon management for the U.S., the Biden Administration has set a goal of Net Zero emissions from the United States by 2050 (White House, 2021a and b). Most U.S. emissions reductions can be achieved through development of renewable and non-carbon energy to replace fossil fuel use, but meeting the target of 1.5 to 2 °C will require significant net negative emissions as well. While some of this carbon can be captured at the smokestack level, use and storage techniques are already emphasized by recent Executive Orders, the recent infrastructure omnibus bill in Congress, and additional pending legislation. Net negative techniques that actively remove carbon dioxide from the atmosphere– that is to say, pushing beyond Net Zero– is necessary for any viable mitigation scenario implemented at this late stage.

Given this context, the U.S. Carbon Cycle Science Program Office/Carbon Cycle Interagency Working Group (CCIWG) has recently been coordinating activities to facilitate strategic interagency Carbon Dioxide removal (CDR) research deliberations and actions via a newly established CCIWG work stream, the Interagency CDR Research Coordination (I-CDR-C) group. We follow the IPCC (2018) CDR definition - any process, practice or technology that removes CO_2 from the atmosphere by either enhancing existing natural processes that remove carbon from the atmosphere or using chemical processes to, for example, capture CO_2 directly from the ambient air and store it elsewhere. Co-benefits of CDR include biodiversity enhancement and flooding or storm hazard mitigation, while trade-offs could include consequences for sustainable development if the use of land competes with producing food to support a growing population, biodiversity conservation or land rights.

Accordingly, in my role as the U.S. Carbon Cycle Science Program Director coordinating the I-CDR-C, I would welcome the opportunity to explore how we can leverage the expertise of both OCB and North American Carbon Program (NACP) scientists to brainstorm research actions for multidisciplinary CDR science planning. We are working both with this team and with the North American Carbon Program (NACP) to encourage scoping activities, with OCB members focusing on marine CDR methods and NACP members focusing on approaches spanning atmospheric and terrestrial systems, including wetlands, inland waters, coastal and land-ocean interfaces.

Given our mutual interests and intersecting plans as detailed in the proposal submitted to you, I am pleased to provide this letter in support. I plan to work with the PIs listed on this proposal directly to contribute to the development of both workshop and working group outcomes that benefit the agencies participating in the CCIWG's I-CDR-C work stream, in the event that this proposal is funded, as well as to contribute to the coordination, facilitation and planning efforts between the parallel marine and terrestrial/atmospheric workshops and science communities, pending the availability of funds.

I would be happy to field any questions from the OCB Science Steering Committee in support of this review process concerning either this effort or the nascent NACP and CCIWG I-CDR-C effort, and it is my hope that we will continue to work closely together in the event that this excellent proposal receives support.

Best regards,

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