Exploring the Viability of Ocean-Based Carbon Dioxide Removal (CDR) Solutions

Meshing science and early-stage impact investing

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Executive Summary

Scientists, investors, and others interested in removing carbon dioxide from the atmosphere are increasingly turning to land-based carbon offsets as a viable strategy, but questions remain about the long-term efficacy of such a prospect. At the same time, ocean-based solutions for removing carbon from the atmosphere are still very new and represent an emerging market space for capital investment. While ocean-based CDR initiatives are gaining momentum, each proposed approach raises important risk management considerations. Leveraging Earth's natural carbon sequestration capabilities — whether on land or in the ocean — can create opportunities to generate revenue (and realize ROI) through the sale of carbon credits, a market-based mechanism to offset difficult-to-eliminate greenhouse gas (GHG) emissions.

Dr. Dave Reidmiller, Climate Center Director at Gulf of Maine Research Institute ("GMRI"), and Brady Bohrmann, Managing General Partner at GMRI's partner investment fund, Bold Ocean Ventures Fund, outline both the risks and potential opportunities of this new field by responding to some of the major questions related to ocean-based CDR. Their answers to these questions attempt to address issues such as the accuracy and permanence of carbon removal, the overall market opportunity and its scalability, the potential positive and negative environmental and social impacts, and managing overall risk.

What's the difference between carbon reduction and carbon removal — and what opportunities are offered by each?

Dr. Reidmiller: Climate change is driven by the accumulation of GHG in the atmosphere — like a bathtub filling with water. To limit the amount of future warming, we can: (1) reduce the amount of additional GHG emissions (turn off the faucet to the tub), or (2) remove those harmful gases from the atmosphere after they're emitted (widen the drain to the tub).

Decades of insufficient action on the global scale have resulted in sustained annual growth in global emissions. We would need extraordinary rates of decarbonization to avoid the worst impacts from climate change. Coupling that with the advances across a range of approaches for directly removing CO_2 from the atmosphere in recent years means we must consider both traditional emissions mitigation measures and innovative CDR techniques if we are to avoid the worst impacts from climate change.

Bohrmann: Dave does an excellent job using the bathtub analogy to explain the urgent need for both carbon reduction and carbon removal. From my perspective as an early-stage investor, this vast unmet need demands fresh thinking and creative solutions, ranging from top-down, large scale, and often policy-driven approaches, to those arising from the creative class of inventors, tinkerers, and entrepreneurs. We need to use every tool in the toolbox.

The urgency of the problem combined with growing awareness among the stakeholders is attracting entrepreneurs and investors. Already, we are seeing new approaches to reducing carbon including restoring natural ecosystems, fertilizing the ocean, modifying ocean chemistry, and methods to store carbon dioxide. I believe that many of these solutions will benefit from the support from venture capital.

What is the role of kelp aquaculture as a potential carbon removal solution? How does it work and what other ocean-based CDR solutions exist?

Dr. Reidmiller: Kelp aquaculture is one of several ways to remove CO_2 from the atmosphere by relying on natural Earth system processes — in this case, photosynthesis. Like trees on land, kelp in the ocean absorbs CO_2 from the atmosphere (and ocean water) and converts that into biomass. Some kelp species grow remarkably fast — to the tune of a foot or more per month(!) under the right conditions — meaning, they can "capture" a large amount of carbon in a short amount of time.

The key for this as a long-term carbon removal solution, however, is making sure that the kelp sinks to the bottom of the ocean — and stays there — so the carbon is permanently sequestered and is not at risk of being re-emitted into the atmosphere. Recognizing these criteria for successful CDR, the Integrity Council for the Voluntary Carbon Market (ICVCM) recently proposed a list of Core Carbon Principles with the goal of addressing challenges related to the unregulated nature of the existing market.

In addition to kelp aquaculture, a range of other ocean-based CDR solutions are surfacing, including nutrient fertilization, artificial upwelling and downwelling, recovery of marine ecosystems, ocean alkalinity enhancement, and electrochemical engineering approaches (National Academies of Sciences, Engineering, and Medicine, 2022).

Bohrmann: At Bold Ocean Ventures we are looking for solutions backed by sound science that can be engineered into a scalable product or service that addresses a large enough market opportunity to create a meaningful environmental and social impact, as well as a sustainable economic opportunity. We look to strong unit economics in the business model as indicators of potential success and seek teams that can successfully execute against the impact and growth opportunity.

As one example, we closely track the developments and companies in kelp aquaculture, both as a source of new products and opportunities for climate mitigation and adaptation strategies including its potential to sequester carbon. We are bullish about kelp aquaculture as a growing industry, where we see clear climate and economic benefits to our region (as does GMRI, as demonstrated by its decision to provide verification for kelp harvested in the Gulf of Maine under their Gulf of Maine Responsibly Harvested® label). However, we have observed that there remain some open questions regarding the efficacy of kelp as a means of permanently removing carbon and we are excited about the robust body of ongoing research to gain clarity. We consider this active, if not spirited debate, a positive, as it draws attention and critical thinking to the marketspace, thereby helping investors assess risk and opportunity, while advancing this nascent climate solution.

What is the feasibility of this solution at scale?

Dr. Reidmiller: For any of these ocean-based CDR approaches, we need to be mindful of the magnitude of potential sequestration against the magnitude of carbon reductions needed to achieve internationally-agreed upon goals. Globally, we emitted ~55 billion tons of CO_2-equivalent ($GtCO_2e$) in 2021. To be on an emissions pathway consistent with the 2°C global goal, the UN Environment Programme states (through its annual Emissions Gap report), that global emissions need to total ~39 $GtCO_2e$ by 2030. This 16 Gt CO_2e "emissions gap" is nearly equivalent to the current annual emissions of China, the U.S., and India combined (the top 3 emitters in the world). In contrast, scientists have suggested that a reasonably successful CDR goal for kelp aquaculture would be to remove ~0.1 Gt CO_2/yr (equivalent to the annual CO_2 emissions for the state of Virginia). **So, in the grand scheme, kelp aquaculture has the potential to be a contributor to the solution, but it will by no means be the silver bullet solution to climate change.** To realize CO_2 sequestration of this magnitude, you would need a kelp farm approximately 73,000 km^2 —or half the state of Iowa. Stated differently, if one considers a 100-meter-wide continuous belt of seaweed farms along all coastlines, it'd require 730,000 km of coastline (or 63% of the global coastline). [*Stats from Chapter 5 of NASEM report linked above*].

Farms of such a scale create many regulatory, logistical, and cost considerations. In addition, nutrient availability, the durability of sequestration, and seasonality will limit optimal site locations. For example, optimal growth requires precise nutrient concentrations and light levels. Achieving both presents challenges because, throughout most of the world's oceans, vertical regions with enough solar radiation to drive photosynthesis (the process by which CO_2 gets locked into biomass) are often depleted in macronutrients, while depths where adequate nutrients are available are often too deep to support growth because of the lack of available sunlight. Moreover, there are issues of social acceptance, unintended environmental consequences from such large-scale cultivation, and cross-jurisdictional governance issues that remain unresolved. Another potential challenge for growing seaweed at scale is building farms that can withstand the intensity of open-ocean storms. In addition, siting these farms in areas that not only meet these criteria, but also provide access to nearby ports would be essential to help reduce costs and increase efficiencies for farm operations.

Complicating this approach further, permanent sequestration of the absorbed CO_2 (minimal re-emission back to the atmosphere) would require the seaweed to be sunk to depths of >1000 meters (many kelp species have air bladders that make it difficult to sink to even close to these depths). See Figure 5.3 from the 2022 NASEM report, which illustrates the fraction of CO_2 sequestered for 100 years at various sinking depths:

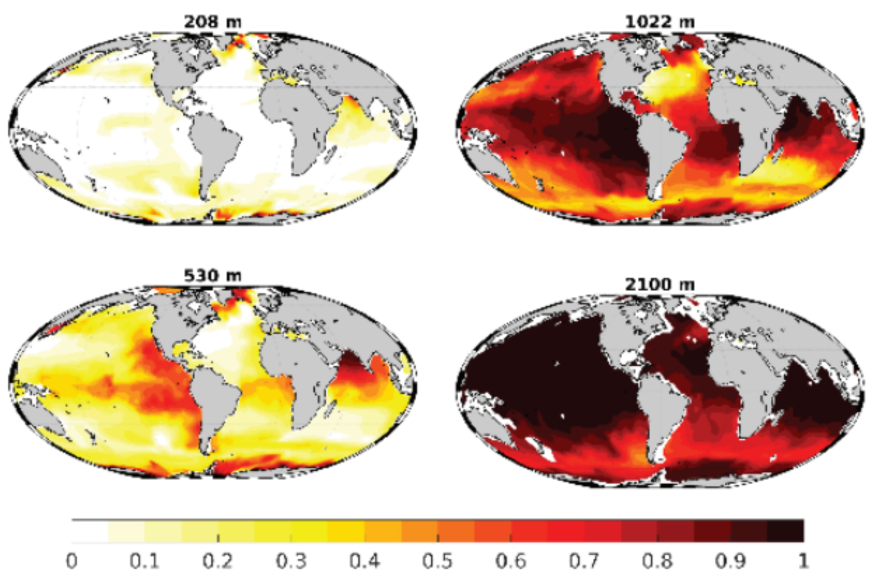

Figure 5.3 Maps of the fraction of CO_2 retained after 100 years for injection depths of 208, 530, 1,022, and 2,100 meters in the purposeful sequestration metrics modeling of Siegel et al. (2021b).

Bohrmann: When making an investment decision we look for both a net positive impact consistent with GMRI's mission and the potential for return on capital invested. Both are essential components of an investment decision and they are evaluated independently. In evaluating the benefits of a kelp aquaculture project, we would consider not just the science on the CDR impact, but also other factors such as kelp as a sustainable source of food, the creation of new value-added products, growing and diversifying our marine economy, and applications in other industries. If the CDR benefit is minimal or the science is uncertain, that factor alone may not be enough to meet the Bold Ocean Ventures impact requirements. However, when we consider carbon reduction as one of a number of criteria important to our broader definition of impact, a kelp aquaculture project can become an attractive investment candidate. In addition, our assessment on the question of CDR impact is likely to evolve over time as new science emerges and new technologies and/or experimental designs are tested and more data becomes available.

How do you measure the impact of ocean-based CDR, including the positive and negative impacts on both the natural ecosystem and society?

Bohrmann: The United Nations has declared 2021-2030 as the "Decade of Ocean Science for Sustainable Development." The goals include sustainably feeding the global population, developing the ocean economy, restoring ecosystems and biodiversity, and unlocking ocean-based solutions to climate change. Achieving these goals requires new ways of using ocean resources so that they can be both productive and regenerative. The health of the ocean and the economies that depend on it are inextricably linked. The combination of sound science and investment capital need to be applied in innovative ways to reduce, modify, or adapt traditional practices to sustain both people and the natural environment in the context of climate change.

We seek companies that are providing or supporting solutions for carbon removal, mitigation, or adaptation to climate change. We measure these solutions both by direct impact on carbon and/or the adoption of enabling technologies that assist in the movement toward limiting warming or adapting to its impacts. Additionally, we screen each prospective portfolio company to ensure it has the appropriate environmental, social, and governance operations and policies in place to avoid unintended consequences that run counter to their (and our) goals.

Dr. Reidmiller: The magnitude of the carbon reduction challenge before us (whether through emissions reduction or atmospheric drawdown) is such that **we have to seriously explore and consider all options**. No single ocean-based CDR approach can solve our carbon problem, but each can be an important tool in the global arsenal for tackling the problem. Moreover, we could realize valuable co-benefits in the process of scaling up kelp farming as a climate solution. Even if the magnitude of atmospheric CO_2 reduction is relatively small, innovations in marine equipment durability, genetic advances in kelp cultivars that can withstand certain (potentially more extreme) environmental conditions, or improved understanding of the carbon cycle over the entire water column are all potential ancillary benefits of investing in kelp aquaculture as a climate solution. In that sense, a more holistic assessment of the ***value*** that can be derived for not just kelp cultivation, but all ocean-based CDR approaches, would provide a more accurate characterization of "impact".

At the same time, there are a range of other impacts — both positive and negative — on both natural ecosystems and human systems to consider as we think about scaling kelp aquaculture for carbon sequestration purposes. We need to be cognizant of and forthcoming about issues such as the potential unintended ecosystem impacts (and the requisite environmental monitoring and associated costs), as well as the challenges associated with carbon accounting like permanence, to say nothing of the challenges that would be involved in finding appropriate sites for farms of this scale.

On the ecological side:

- Kelp aquaculture would have impact in the surface ocean environment as the seaweed would likely deplete the upper levels of the ocean of nutrients that would otherwise drive other ecosystem processes in that zone. In addition, such dense seaweed cultivation at the surface would also limit the amount of sunlight available to the other organisms that thrive in this zone as a result of photosynthesis. These combined effects would likely result in reduced rates of primary productivity from phytoplankton and, as a result, a reduction in the amount of carbon exported from the surface ocean to the depths of the ocean. Such an effect would likely have negative consequences for higher trophic levels that support fisheries and other valued marine resources, at least on a local to regional scale.

- Seaweed cultivation will likely introduce non-native species to ecosystems where the farming occurs because nearshore species will need to be farmed in offshore biomes. It is also likely that cultivars will need to be selected that can maximize biomass production in low-nutrient environments. The introduction of non-native species may have detrimental ecological impacts and legal implications that could complicate the permitting processes.

- The sequestering of large amounts of organic matter at depth is likely to have detrimental effects on the ecology of the deep sea. The anthropogenic addition of such vast amounts of organic matter will alter the chemical and, subsequently, biological conditions of the surrounding benthic environment. Consequences could include deoxygenation, acidification, and eutrophication.

On the societal side:

- If deployed at scale, seaweed aquaculture could grow the blue economy in certain regions of the world, with consequential benefits to both coastal communities and the many marine industries involved in farm development, maintenance, and operations.

- Co-benefits may also be realized if seaweed farms are sited adjacent to other uses (e.g., finfish or shellfish aquaculture), through localized buffering of acidified waters or lush habitat for larval species.

- Farms at scale could, however, pose navigational hazards and/or displace fishing and other historical uses of that ocean space.

Final Thoughts: As Dr. Reidmiller and Bohrmann both address in their responses, and Mr. Goldberg of Carbon Direct reinforces in the *New York Times* article linked above,

… "where we need to be for climate and carbon removal, none of the verticals on their own will be sufficient. We don't have enough forests, and we don't have enough ability to change soils. All of them need to work, and they all have different trade-offs."

This logic holds true for ocean-based CDR. There are some important concerns to consider, including permanence, broader ecological impacts, and social acceptance, yet all options must be on the table in order to substantially close the emissions gap. Investing in this nascent space is still very risky, and at the same time, carbon credits are the mechanism that allows companies and individuals to pay to offset their GHG emissions – which is particularly necessary for the several global corporations that have pledged net-zero carbon emissions in the next 10-20 years (a recent report shows only 3 out of 55 major corporations received an "A" grade on their net-zero carbon targets). These opportunities warrant continued monitoring and exploration as the hard science and various proposed innovative approaches begin to coalesce.

Gulf of Maine Research Institute

The Gulf of Maine Research Institute develops and delivers collaborative solutions to global ocean challenges. We are an independent, objective nonprofit organization dedicated to the resilience of the Gulf of Maine ecosystem and the communities that depend on it. We collaborate with stakeholders to support healthy ocean ecosystems, a thriving marine economy, sustainable seafood, and climate-resilient coastal communities. Learn more at GMRI.org.

Bold Ocean Venture Fund

Led by independent, experienced investment professionals, Brady Bohrmann and Tim Agnew, Bold Ocean Ventures Fund I LP is a first-time venture capital fund that supports the growth of innovative, sustainable ocean-related businesses.