OCEAN VISIONS
Catalyzing Solutions for Ocean Health

Harnessing the Power of the Ocean to Restore the Climate *and* the Ocean

OCEAN-BASED CARBON DIOXIDE CLEANUP

The Ocean & Climate: Inextricably Linked

The ocean provides countless services and benefits for the planet and humanity, with one of the most important being climate regulation. Covering 70 percent of Earth's surface, the ocean influences weather and climate by absorbing solar radiation, distributing that heat and moisture throughout the ocean and around the globe, and driving global weather systems.

The ocean has also buffered humanity and terrestrial organisms from the worst effects to date of climate disruption by directly absorbing about 30 percent of all anthropogenic carbon dioxide (CO_2) emissions and trapping more than 90 percent of the excess heat in the biosphere caused by CO_2 pollution. That excess heat absorbed by the ocean is staggering—equivalent to five Hiroshima-sized bombs of heat energy going into the ocean every second, of every minute, every day. The land and air temperatures of our planet would be much hotter without the heat absorption that the ocean has provided.

However both of these climate-buffering functions have come at a high cost: Together, the excess heat and absorbed CO_2 are bleaching corals, melting sea ice, and acidifying the sea at alarming rates—unraveling marine ecosystems and crippling the ability of the ocean to support the billions of people and other creatures dependent upon it.

Efforts to protect the ocean and its vitally important ecosystems and functions cannot be credibly considered in isolation from the challenge of stabilizing the destructive impacts of climate disruption.

"The projected responses of the ocean and cryosphere to... greenhouse gas emissions and ongoing global warming include climate feedbacks, changes over decades to millennia that cannot be avoided, thresholds of abrupt change, and irreversibility."

—Special Report on the Ocean and Cryosphere in a Changing Climate, Intergovernmental Panel on Climate Change

Overlooked Part of the Equation: Cleaning Up Greenhouse Gas Pollution

Currently, most global efforts to address climate disruption are focused on reducing current and future emissions of greenhouse gas pollutants. While vital, this path alone is no longer sufficient. Current levels of CO_2 in our air and ocean will drive dangerous change now, and will continue to do so for decades.

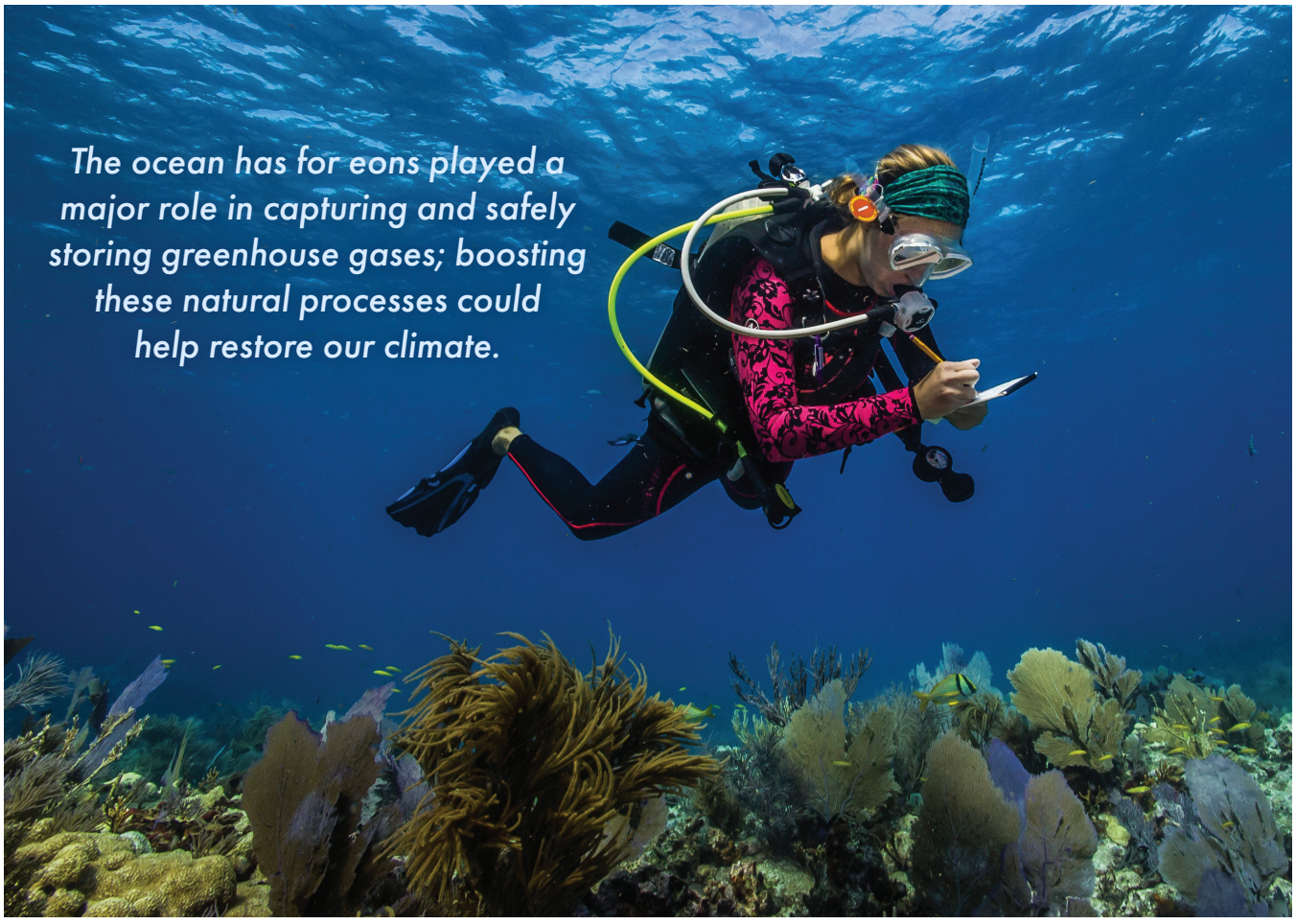
Scientific consensus of the "climate math" leads without fail to the need for large-scale carbon dioxide removal (CDR), on the order of between 100 and 1000 gigatons by the end of the century, just to hold temperatures to a 1.5°C increase—the goal set out in the Paris Agreement. And we are increasingly seeing that this goal itself, while hugely ambitious, does not provide *any* guarantees of climate safety and stability. Restoration of the climate is only possible by reversing the buildup of carbon in the biosphere—aka carbon dioxide removal.

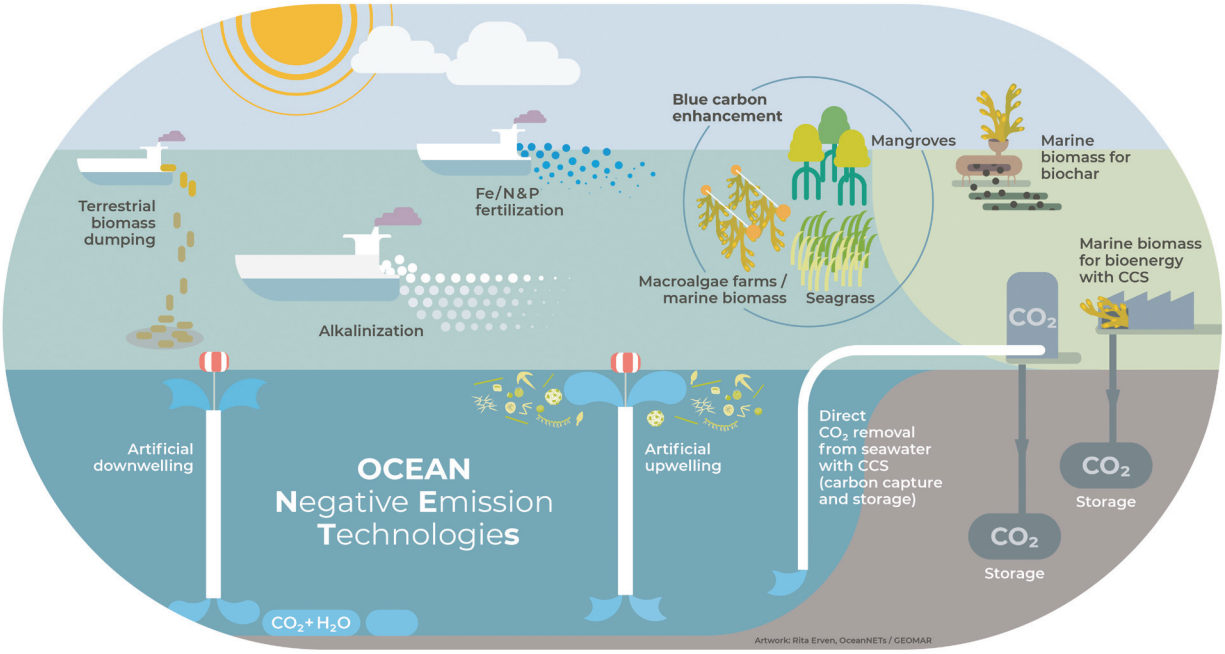
However, knowing that we need massive amounts of CDR and having the tools that can provide it are two very different things; the actual methods to achieve scalable, effective, safe, and socially acceptable pathways are nascent.

The good news is that there are many viable ways to clean up atmospheric and oceanic CO_2. Among the most promising are those that build on natural processes already occurring in the ocean.

The Ocean as a Part of the Climate Solution

The ocean already holds more carbon than any other part of the biosphere and, via its biological and geological processes, has the potential to contribute even more to removing and safely storing carbon. Although the ocean has enormous potential for CDR, most CDR development has been focused on land-based solutions, such as afforestation or direct air capture. While there are a number of emerging technologies and innovations, a great deal more research, development, and evaluation of approaches is needed.





Types of Ocean-Based Carbon Dioxide Removal

Ocean CDR can be divided into two broad categories—biological and non-biological (chemical/physical), with some overlap between the two. A summary of biological and chemical approaches is below.

Biological Approaches that Harness the Power of Plants and Photosynthesis	Chemical Approaches that Increase the Ocean's Capacity to Absorb Carbon Dioxide	Hybrid Methods
Seaweed Cultivation for Carbon Sequestration • Cultivating seaweeds (macroalgae) and sequestering the carbon embedded in it. Cultivation opportunities include existing coastal farms and expansion into offshore waters. Sequestration options include burial in the deep sea/land and/or harvesting for bioenergy, as well as production of long-lived bio-products.	**Ocean Alkalinity Enhancement** • Surface addition of alkaline minerals (either mined or manufactured) to seawater to increase alkalinity and, therefore, carbon storage in seawater.	**Direct Ocean Capture** • Use of chemistry, electrochemistry, gas exchange, or other methods to capture and/or store atmospheric CO_2 from seawater.
Microalgae Cultivation and Sequestration • Cultivating microalgae and sequestering the carbon embedded in it. Microalgae can be fertilized from surface application of nutrients (e.g., nitrogen, phosphorus, and/or iron), as well as artificial upwelling of nutrient-rich deep ocean water. Sequestration pathways include artificial downwelling and/or harvesting for shore-based bioenergy, as well as production of stable bio-products.	**Coastal Enhanced Weathering** • Application of silicate minerals in high-energy beach environments where natural chemical weathering can be accelerated. This process converts CO_2 in the atmosphere into stable, long-lived bicarbonate in the ocean.	**Accelerated Weathering of Limestone** • Limestone can be dissolved in a reactor with a concentrated source of CO_2, trapping the CO_2 as stable, long-lived bicarbonate in the ocean. As long as the CO_2 represents net removal, this is a carbon removal pathway.
Blue Carbon Management • Restoration and protection of blue carbon ecosystems, including mangroves, salt marshes, and seagrass meadows, to ensure continued carbon sequestration and long-term below-ground storage of organic carbon.		**Deep Storage** • Use of the ocean's deep stable layers, seafloor, and sediment to store CO_2 captured via a shore-based carbon removal process. Methods include biomass sinking and liquid CO_2 injection and via ships, platforms, or pipes.

Accelerating the Testing and Development of Ocean-Based CDR

Given the accelerating pace and scale of climate disruptions, and the danger of surpassing critical ecological tipping points, it is imperative to scale up the research and testing of various ocean-based CDR approaches. Doing so will take greatly increased investment and effort across numerous fronts at the same time.

To chart the way forward, Ocean Visions, working with experts from around the globe, has developed a series of technology road maps that lay out the key priorities to advance our collective knowledge of ocean-based CDR technology pathways. This knowledge is critical to ultimately determining what, if any, role each may ultimately play in addressing the climate crisis.

There are five big areas of action within which most of the first-order priorities in the road maps can be grouped, each needing greatly increased attention and funding:

- Addressing and filling key knowledge gaps in technology development and impacts assessment
- Initiating field testing of the most promising ocean-based CDR approaches with careful monitoring and evaluation frameworks
- Developing new capacity (including technologies and infrastructure) to support research, development, and demonstration (RD&D)
- Building a supportive enabling environment for RD&D, including participatory and transparent governance regimes
- Building public awareness and understanding of ocean-based CDR

To increase our chances of being able to slow and ultimately reverse the impacts of climate change, carbon dioxide removal is essential. Ocean-based approaches need careful research and testing.

Key Considerations

In addition to the areas for action above, there are some critical issues that must be considered.

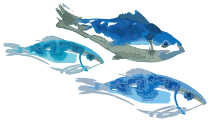
1. **Issues of equity and environmental justice in research and development of ocean-based CDR**

   All climate action will have impacts, positive and negative. It is critical that ocean-based research pays careful attention to those who might be negatively affected and takes all possible steps to ameliorate those impacts. Field trials need to be developed with as many communities of interest participating as possible. Extra attention must be paid to ensuring that historically marginalized communities—those most affected to date by climate change impacts—have a seat at the table as this field develops. Mechanisms must be put in place to equitably share benefits from the development of this field, as well as to equitably distribute risk. Field trials must advance with transparency and broad stakeholder and interest group involvement, and with third-party scientific review.

2. **Enabling governance for research and development**

   Advancing development and testing of ocean-based CDR approaches will require governance structures that both enable the permitting of legitimate testing and development and ensure that the public interests are protected. There are no current regulatory regimes that are fit-for-purpose for ocean-based CDR; new or modified regimes are needed to oversee this field. Coordination among sub-national, national, and international regulatory bodies will be needed to ensure continuity across boundaries.

The full suite of road maps is now fully available to contributors and interested parties. Ocean Visions is actively soliciting community engagement and input to keep the road map knowledge base up-to-date and cutting-edge.



TO LEARN MORE about ocean-based carbon dioxide removal, visit oceanvisions.org/CDR