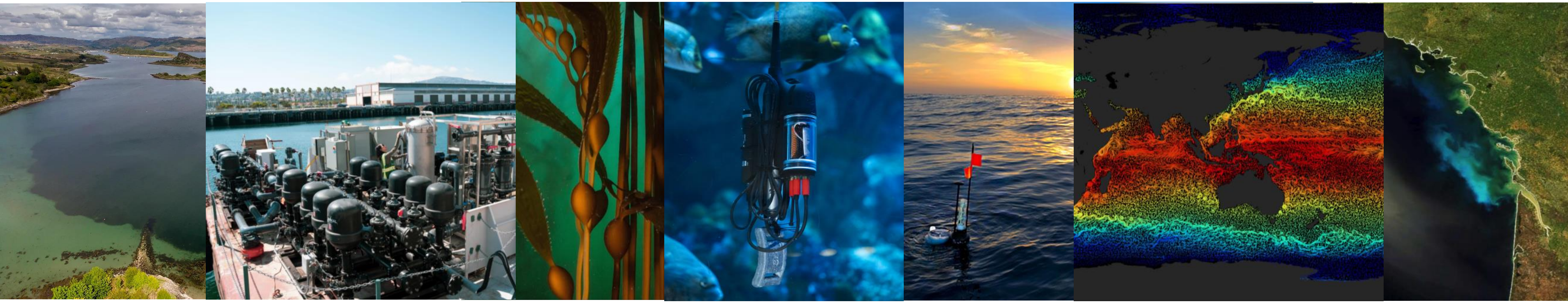
MARINE CARBON DIOXIDE REMOVAL: WHAT YOU NEED TO KNOW ABOUT THIS EMERGING SECTOR



October 2, 2024

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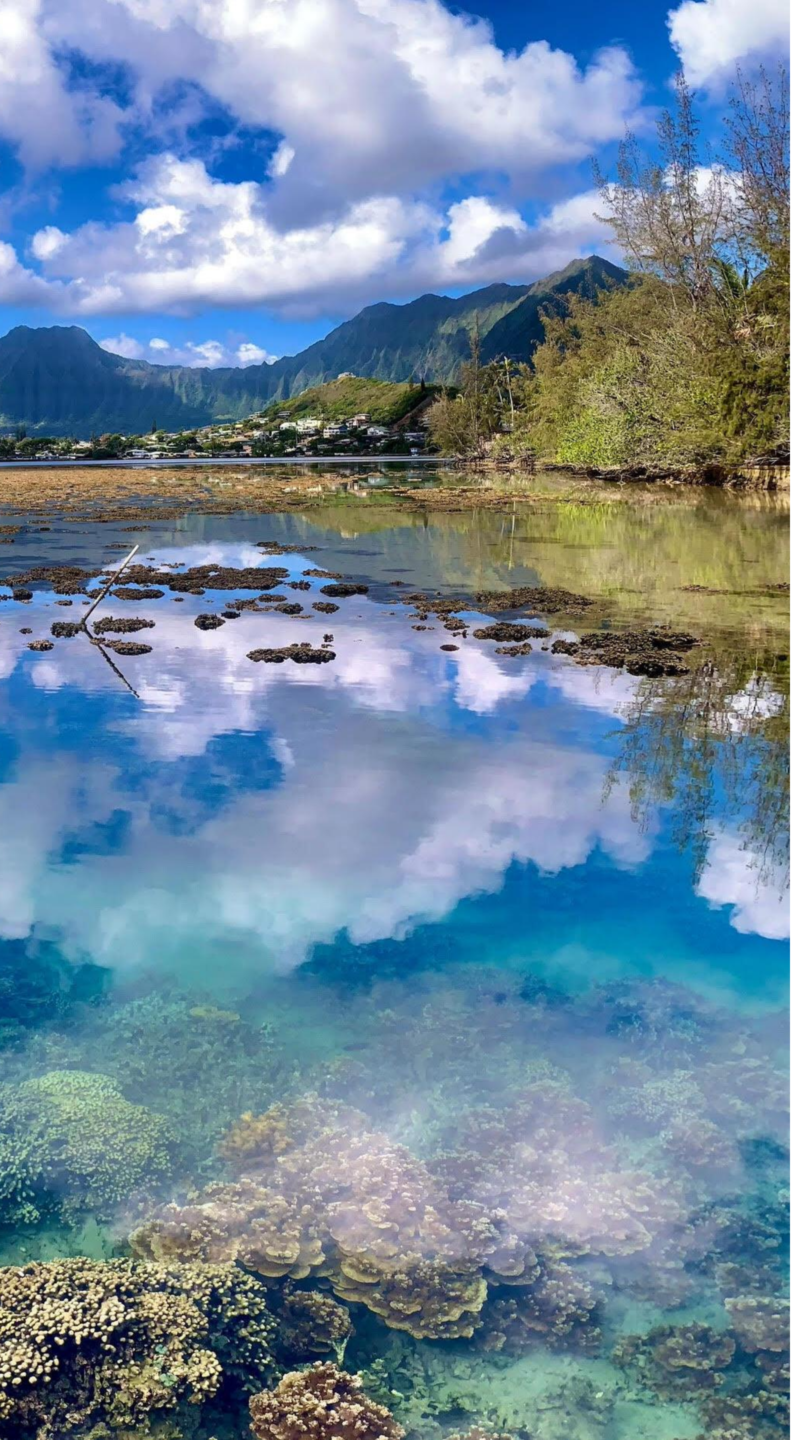

AGENDA

- Introductions to New England Aquarium's BalanceBlue Lab and SeaAhead
- What is mCDR?
  - mCDR Techniques
- What are carbon credits and the carbon market, and why does it matter?
- Key finding: Need for cheaper, more accurate MRV
- MRV Opportunities: Platforms, Sensors, Models
- Panel Section
- Q & A
- Summarize what has been covered
- Next steps

WHO WE ARE

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Early-stage startup platform supporting and promoting companies developing ocean-related innovation: “bluetech”

- First-mover that created and operates one of the first global bluetech innovation hubs
- Partnered with NEAq to conceive and operate the BlueSwell Accelerator program
- Convenes and manages the SeaAhead Blue Angels Investor Group
- Consults with the public & private sector on blue economy & bluetech innovation topics

www.sea-ahead.com

BalanceBlue Lab

INNOVATIVE MARKET-BASED SOLUTIONS THAT ENHANCE
A VITAL AND VIBRANT OCEAN FOR ALL

Engaging the World on Blue Innovation

Innovators

Advancing Emerging Ocean & Climate Tech

Industry

Informing & Influencing Blue Economy

Investors

Educating Ocean Investors

Creating New Blue Partnerships

Anderson Cabot Center for Ocean Life
at the New England Aquarium

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FUNDING ACKNOWLEDGEMENT

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Marine Carbon Dioxide Removal: Investing in Science and Innovation to Build a Responsible Industry

UpSwell Whitepaper

Published September 2024

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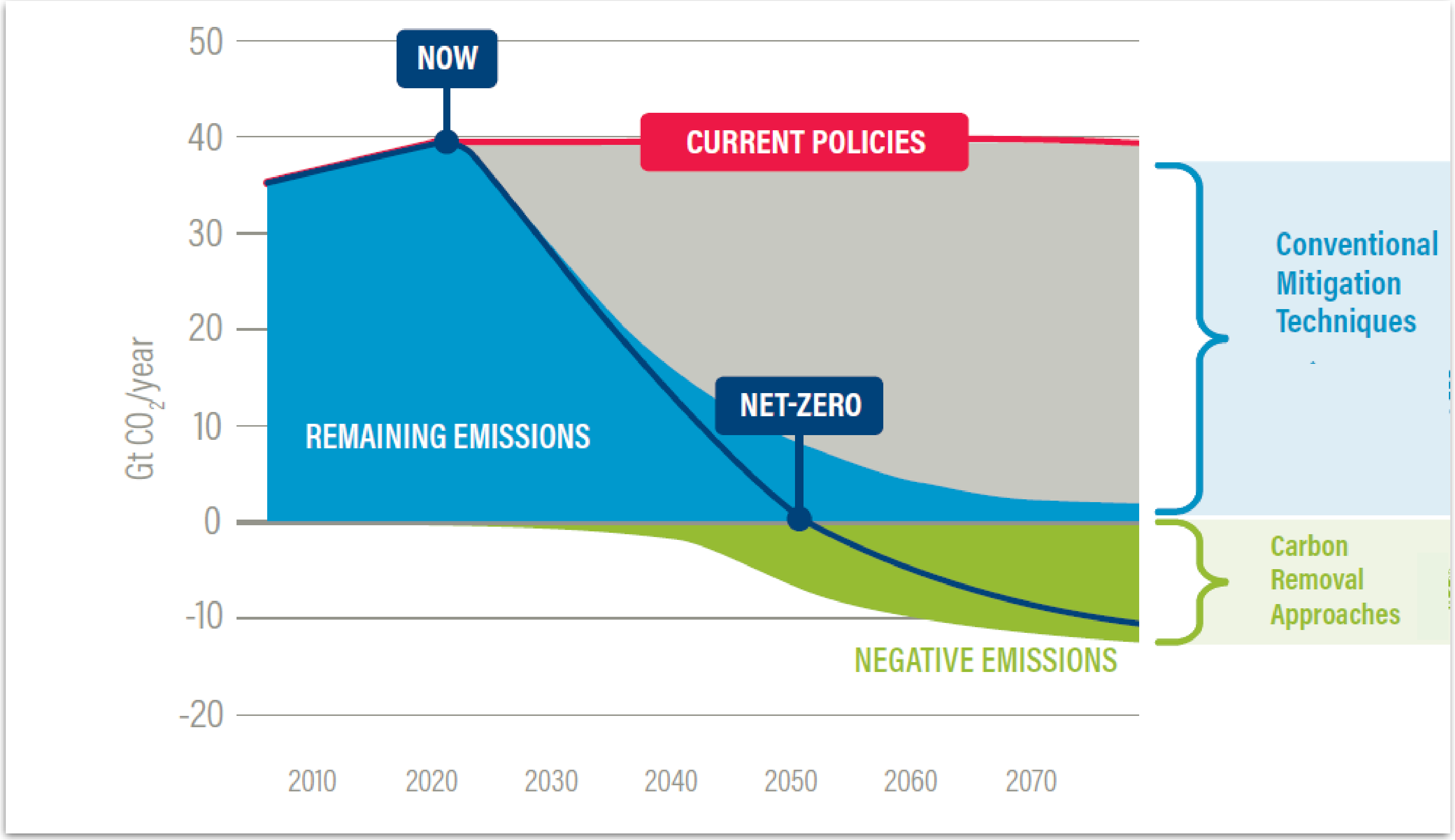
THE OCEAN IS THE SOLUTION

- Covers 70% of the Earth's surface and holds ~50x more carbon than the atmosphere.
- Has sequestered 30% of CO_2 emissions since the industrial era.
- However, decarbonizing and restoring carbon-rich ecosystems will only take us so far.

Staying Below 1.5 °C of Global Temperature Rise



SOURCE: Lebling et al. (2022) at WRI.org based on IPCC (2018) and CAT (2022)

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WHAT IS MCDR?

- mCDR could be a key sector in the emerging carbon economy, but is **limited by available Measurement, Reporting, and Verification (MRV) technologies**
- mCDR techniques we will discuss today
  - Coastal and Ocean Ecosystem Recovery (aka Blue Carbon)
  - Ocean Alkalinity Enhancement (OAE)
  - Electrochemical CO_2 Removal
  - Seaweed Cultivation and Sinking
  - Ocean Fertilization

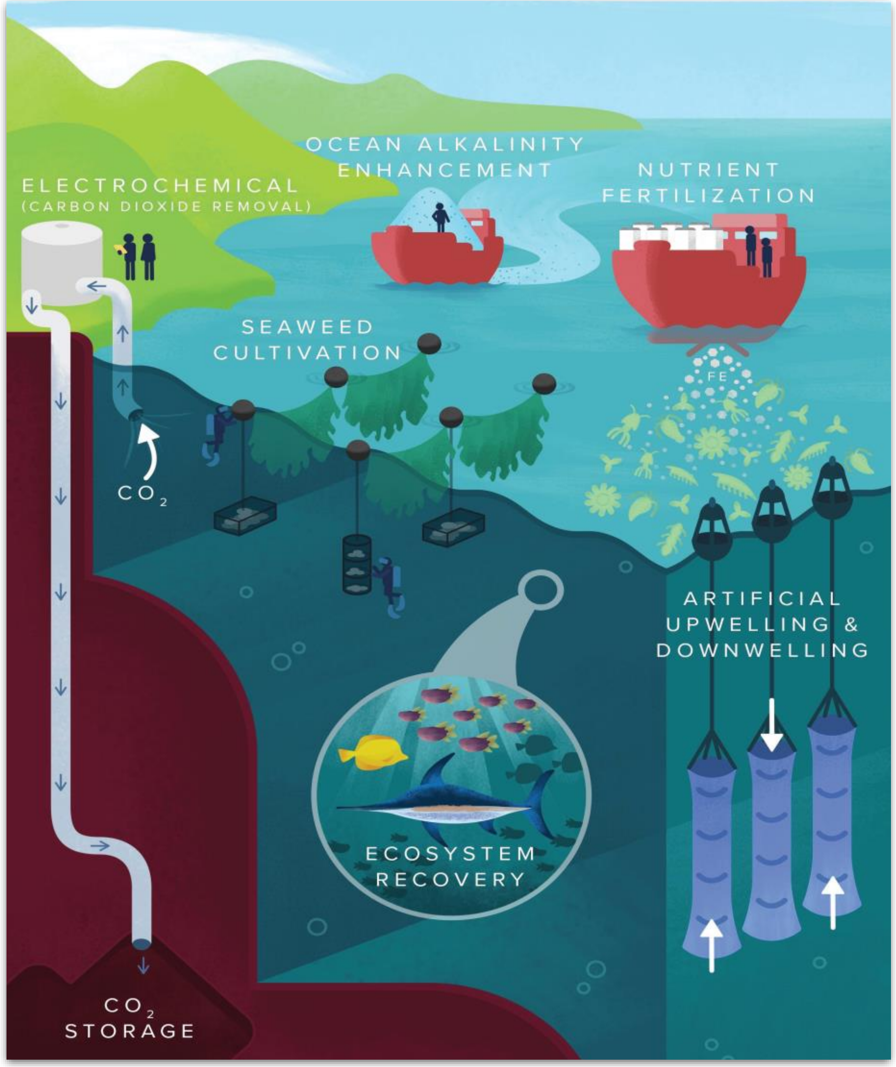

Illustration of different mCDR techniques

NATIONAL ACADEMIES Sciences Engineering Medicine

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COASTAL AND OCEAN ECOSYSTEM RECOVERY

Seagrass meadow in Loch Craignish, Scotland. SOURCE: Seawilding

Seawilding volunteers processing rhizomes for a seagrass restoration area. SOURCE: https://seawilding.org/seagrass-project

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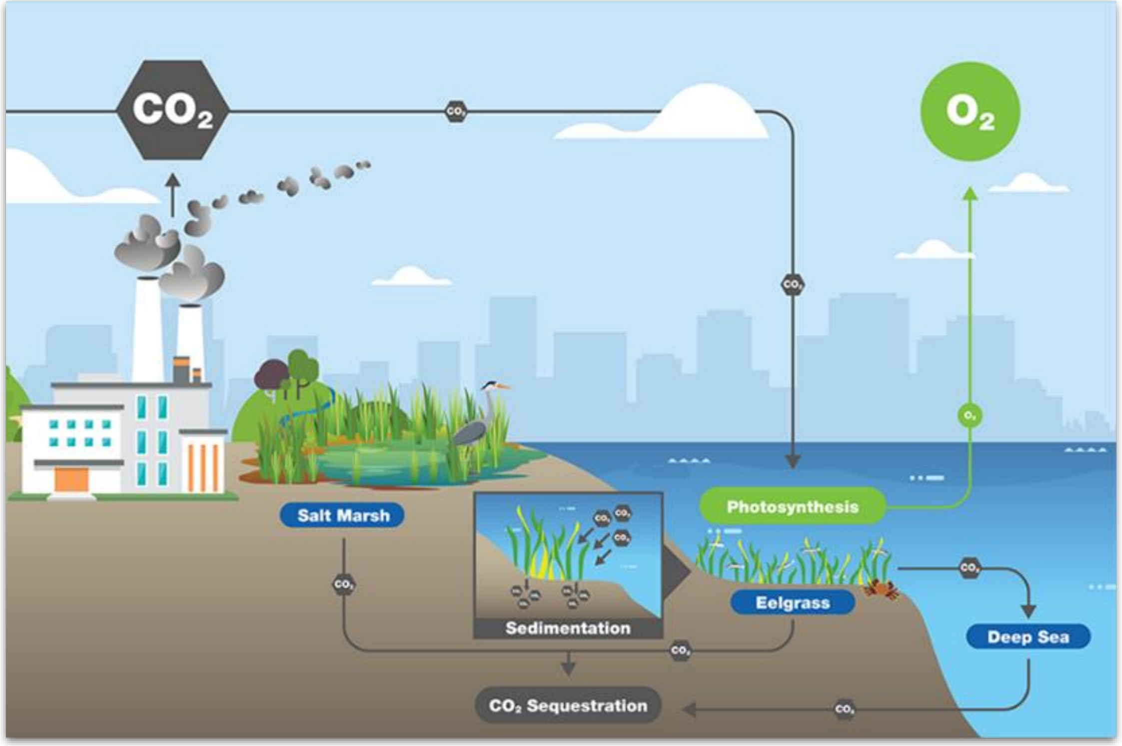
COASTAL AND OCEAN ECOSYSTEM RECOVERY

- Carbon sequestration through conservation, restoration, or enhancement of coastal ecosystems also known as “Blue Carbon”
- Nature positive solution with up to 10x the sequestration intensity of terrestrial solutions and many co-benefits
- Credits are currently available for sale on VCM at premium to forestry average
- Coastal restoration could sequester up to 14% of carbon needed to remain below 2C, however, ecological factors may lower the realistic ceiling



Overview of the carbon cycle related to blue carbon. SOURCE: New England Aquarium

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OCEAN ALKALINITY ENHANCEMENT (OAE)

Sampling boat in a dye plume as part of an OAE experiment in Nova Scotia. SOURCE: Planetary Technologies

Dr. Kai Schultz adds rock flour to a mesocosm part of the Ocean-Alk Align experiment in Kiel Fjord. SOURCE: Michael Sswat, GEOMAR

Dye plumes as part of an OAE experiment in an Australian coral reef flat study site. SOURCE: Cyronak et al. OAE Guide 2023 Ch 7

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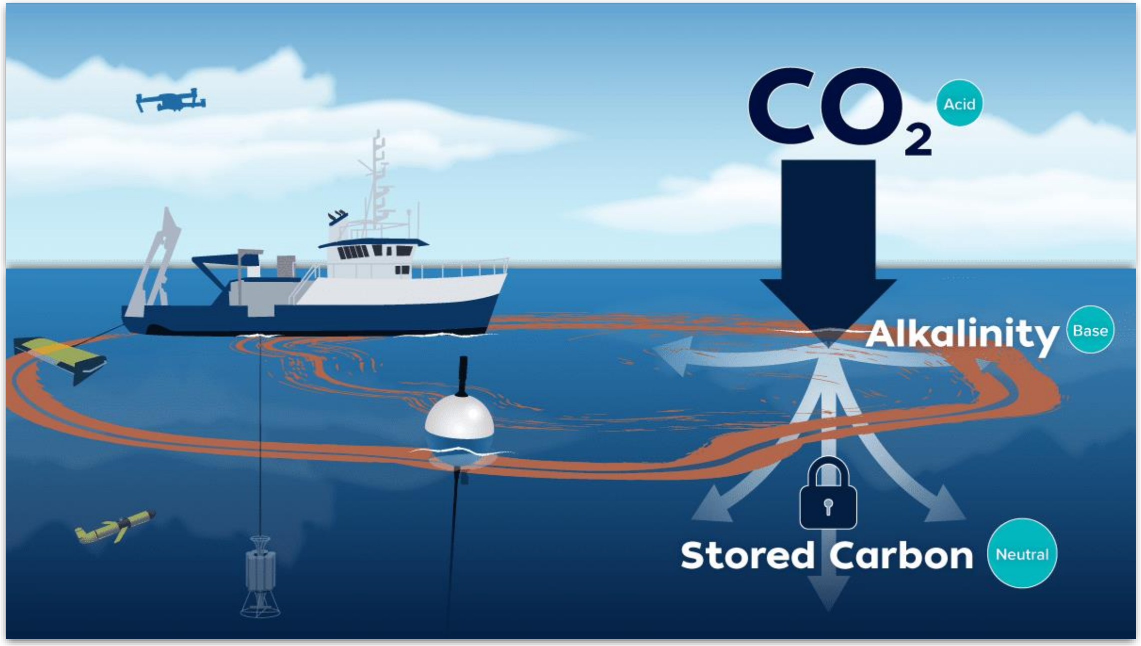
OCEAN ALKALINITY ENHANCEMENT (OAE)

- Altering pH of seawater to increase CO_2 absorption
- Augments the ocean's natural ability to sequester carbon and may address other issues resulting from ocean acidification
- Ecological impacts of introducing basic materials and the footprint needed to mine those materials need to be considered
- Multiple different methodologies in various stages of development and commercialization

SOURCE: Illustration by Eric S. Taylor, Woods Hole Oceanographic Institution



Depiction of the numerous monitoring components deployed for WHOI's LOC-NESS project, a controlled and monitored OAE field trial due to start summer 2025.

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ELECTROCHEMICAL CO_2 REMOVAL

Captura's direct ocean capture system.
SOURCE: https://capturacorp.com/technology/

Equatic's pilot plant in Los Angeles for electrochemical CO_2 removal.
SOURCE: Equatic/The Verge

Ebb Carbon's electrochemical OAE system.
SOURCE: https://www.eisamanlab.com/ebb-carbon

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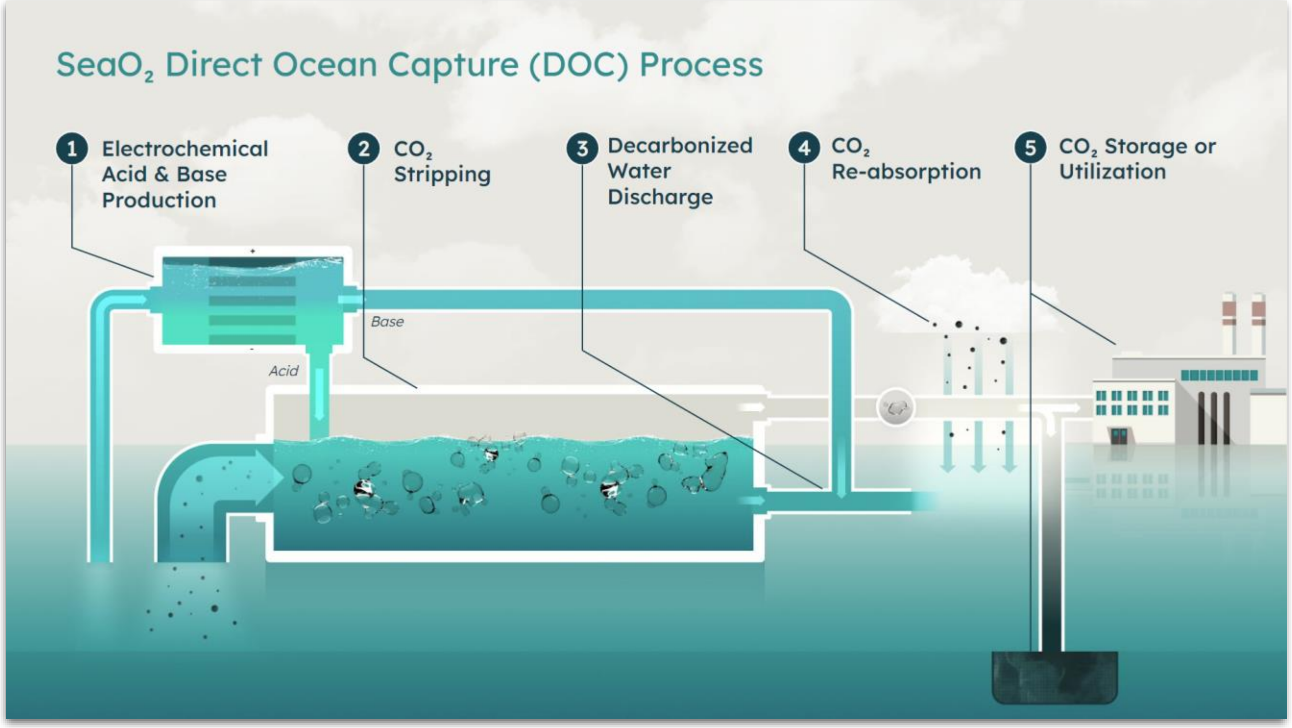
ELECTROCHEMICAL CO_2 REMOVAL

- Using electricity to liberate CO_2 from seawater and sequester it, or to change seawater chemistry to enable more CO_2 absorption
- Potential for scale and colocation with renewable energy projects, but cost and footprint of energy may be limiting
- Long-term impacts on local ecosystems should be studied
- Currently commands some of the highest spot prices for credits



The schematic depicts the general flow of seawater and technology processes for ocean electrochemical CO_2 removal. SOURCE: https://www.seao2.com/technology

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SEAWEED CULTIVATION AND SINKING

Sugar kelp preparation at Running Tide, Dr. Rishi Masalia. SOURCE: https://rishimasalia.com/running-tide/

Seafields' sargassum barrier in the Fram Strait long-term observatory. SOURCE: Seafields/ecomagazine

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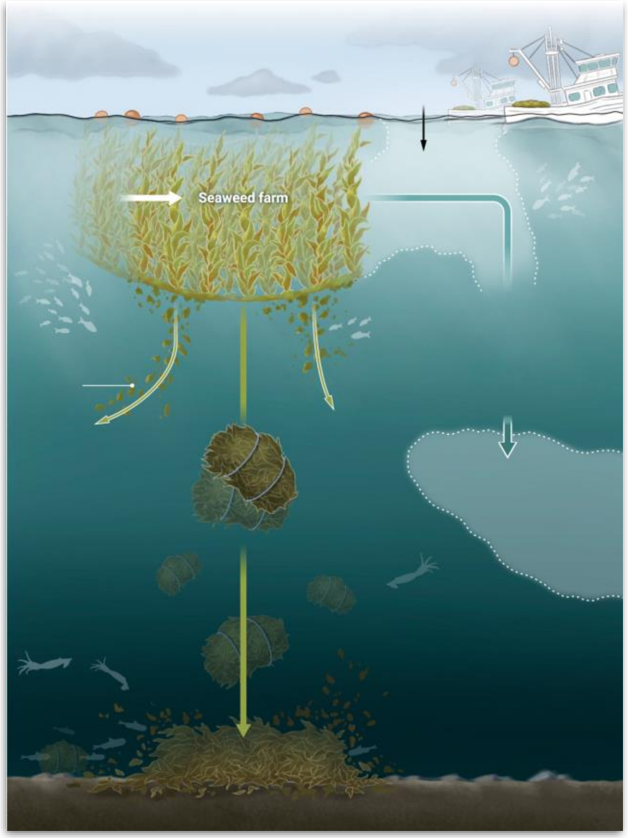
SEAWEED CULTIVATION AND SINKING

- Using macroalgae to remove CO2 from seawater and sequester carbon by downward transport or conversion into biochar and other materials
- Macroalgae can be grown with minimal inputs and positive co-benefits, re-balancing local ecosystems as it absorbs CO2 into biomass
- Large scale sequestration by sinking seaweed is controversial and may have negative unintended consequences
- Carbon sequestration is only one potential use case for a burgeoning macroalgae sector

SOURCE: A. Fisher, Science, Vol 385 (6712), 2024



Seaweed cultivation and biomass sinking with arrows indicating carbon pathways.

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OCEAN IRON FERTILIZATION (OIF)

Mineral-rich airborne dust off France's coast contains micronutrients to phytoplankton and supports a coastal phytoplankton bloom (light blue). SOURCE: NASA Earth Observatory

Carbon flux explorer developed by Dr. Jim Bishop, Lawrence Berkeley Nat'l Lab. SOURCE: Roy Kaltschmidt, LBNL

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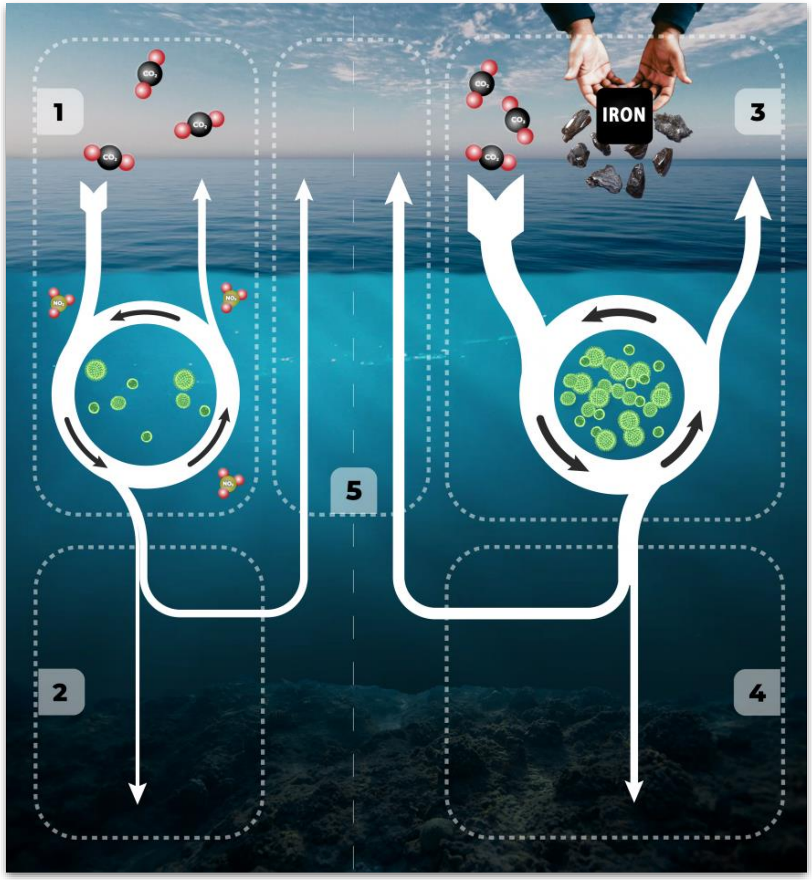
OCEAN IRON FERTILIZATION (OIF)

- Mimics the natural occurrence of wind-blown mineral-rich desert sands or volcanic ash fertilizing phytoplankton with micronutrients.
- Current focus is on Iron Fertilization experiments.
- Past Iron Fertilization experiments did not show a significant enhancement of long-term carbon storage.
- Environmental risks may include nutrient diversion from other oceanic regions and unpredictable phytoplankton species responses.
- International treaty bodies have initiated steps for developing rules around ocean fertilization research and testing.

SOURCE: T. Rohr, JSPG, Vol 15, Issue 1, 2019



An idealized schematic of carbon cycling in a natural (left) and iron fertilized (right) ocean. Arrows represent carbon transport.

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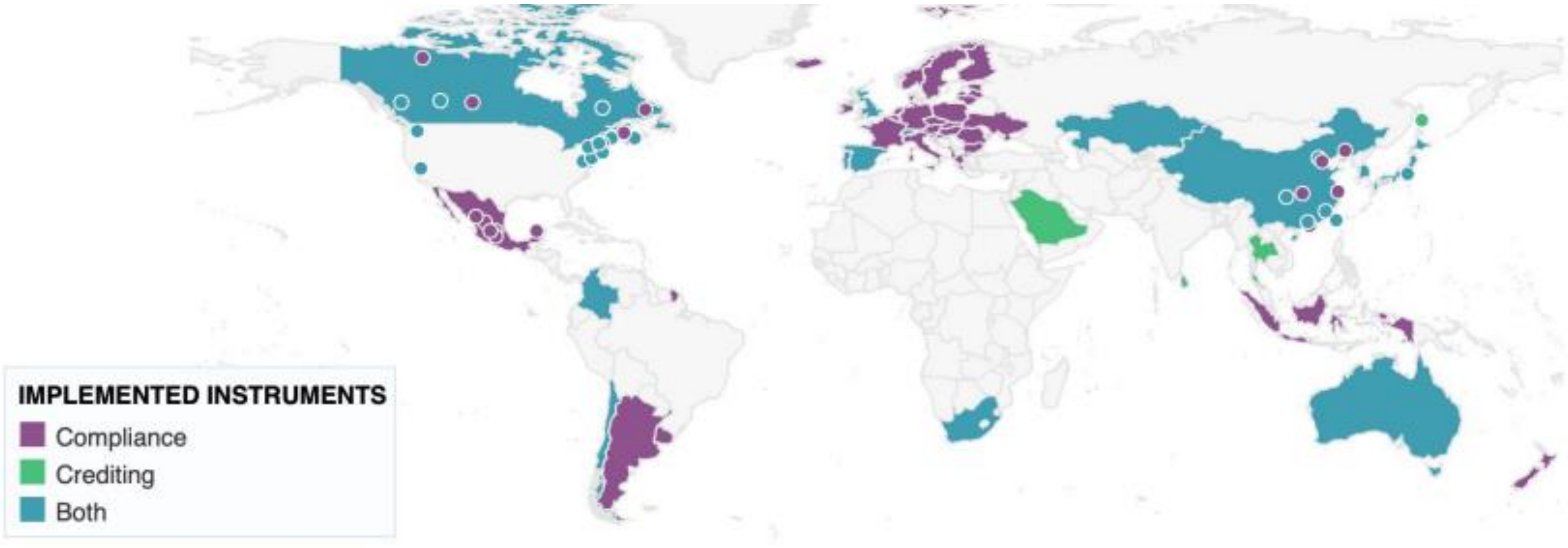
BUSINESS CASE FOR CARBON



Source: World Bank

CARBON CREDITS AND MARKETS

Carbon credits

- Represent the right to emit one ton of CO_2 or equivalent greenhouse gases (CO_2e).
- Generally used in compliance carbon markets (CCMs) like "cap and trade" systems.

Carbon offsets

- Represent one ton of CO_2e removed from the carbon cycle and stored ("removal offsets") or that was not emitted compared to a baseline scenario ("avoidance offsets").
- Primarily traded in Voluntary Carbon Markets (VCMs) or in direct sales.

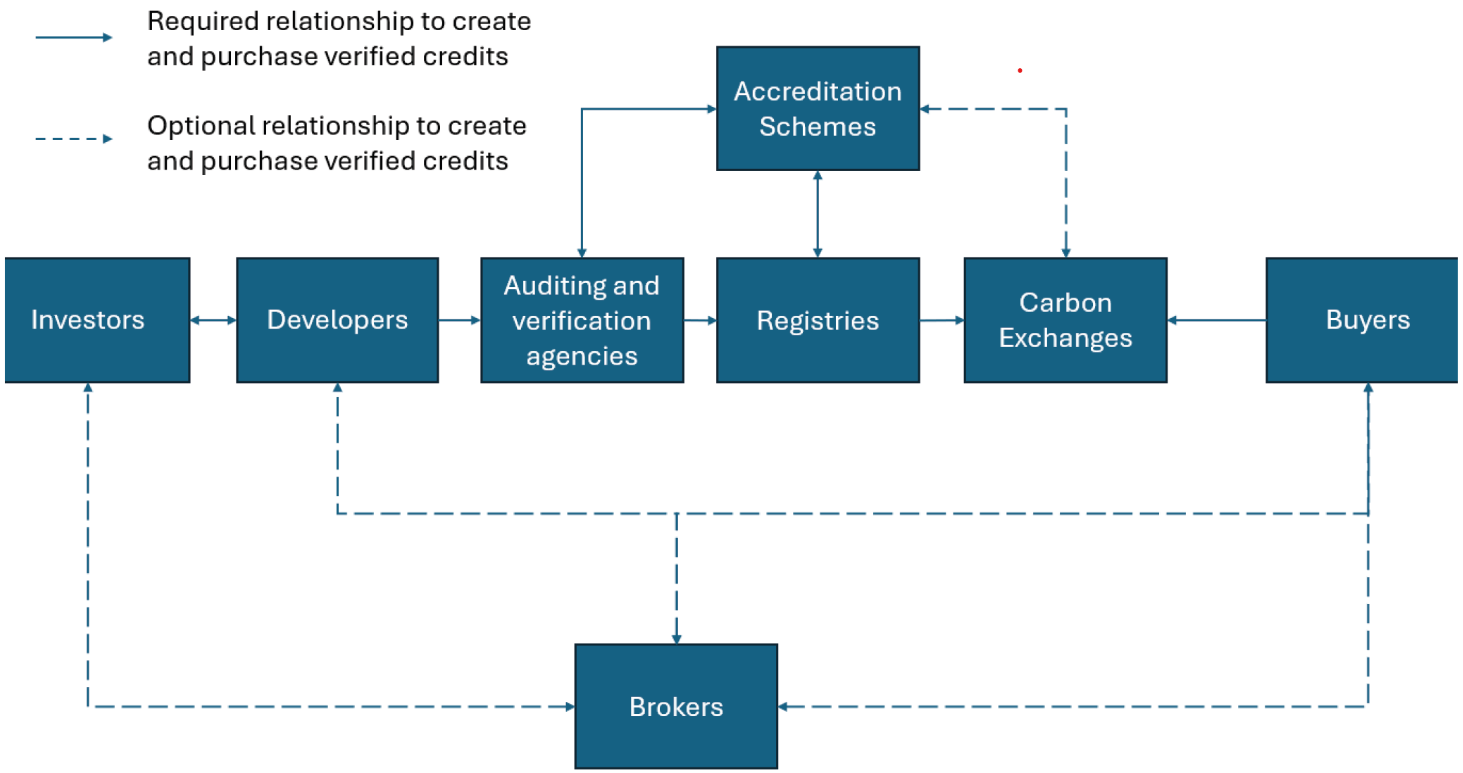
Compliance Carbon Markets (CCM)

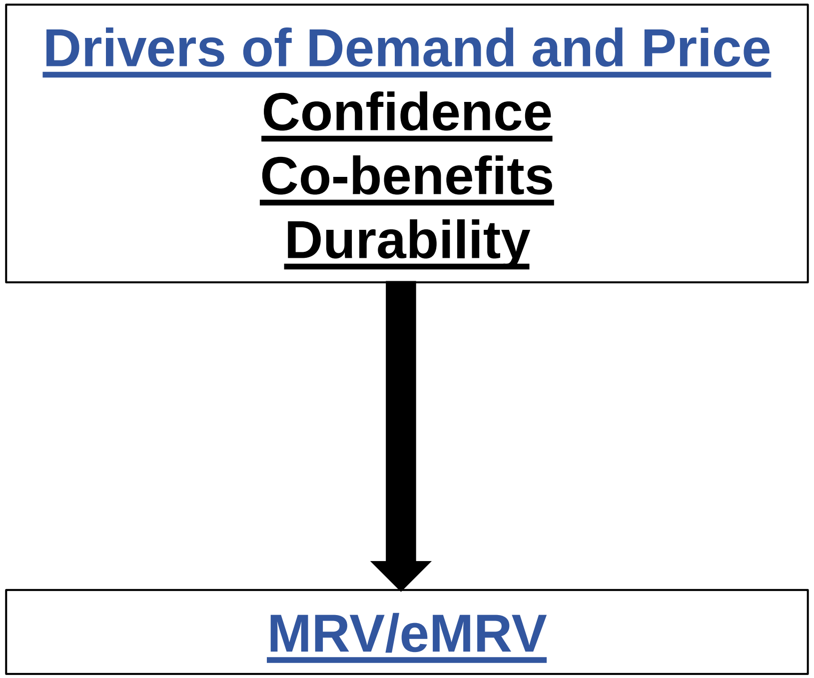
- Backed by a government mandate pricing GHG emissions and enforcing compliance.
- Examples include Emissions Trading Schemes (ETS) or carbon taxes.
- There are CCMs at the international, national, and subnational level, and some analyses put their overall value at over $900B.

Voluntary Carbon Markets (VCM)

- Private marketplaces with no government mandate to participate or penalty for non-compliance.
- Complex value chain, have been the subject of much recent investment, hype, and scrutiny.
- The overall value of the VCM was as high as $2B but has recently retracted to around $720M.

THE CARBON VALUE CHAIN





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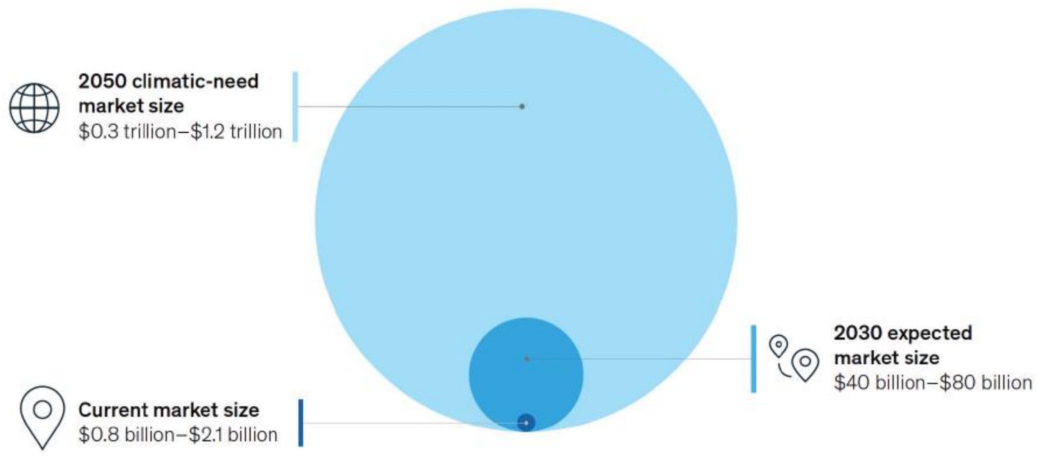
CARBON MARKETS: THE NEXT BIG THING?

Huge potential…

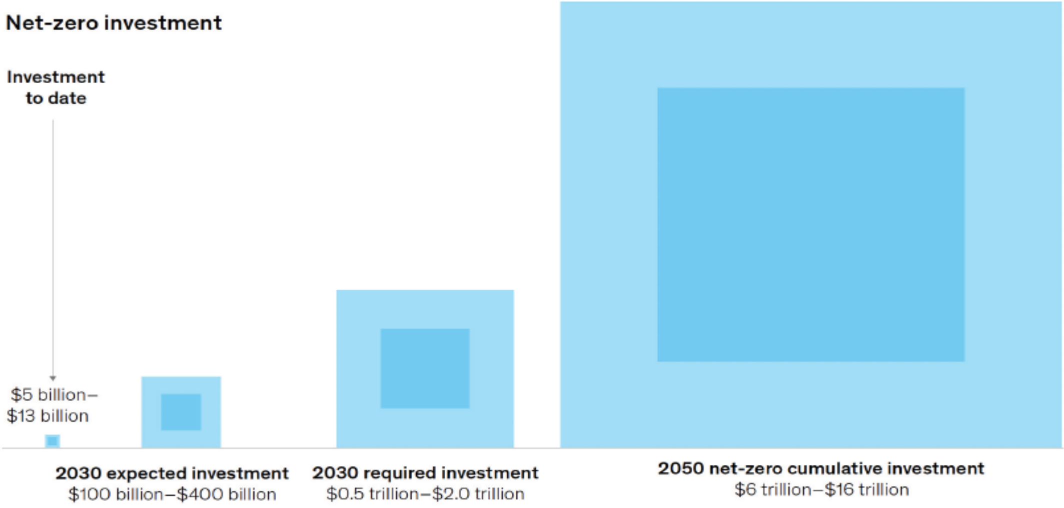
Delivering six to ten metric gigatons of carbon removals could create an industry worth $0.3 trillion to $1.2 trillion annually by 2050.



Credit: Mannion et al, 2023. McKinsey & Co.

… hampered by underinvestment

Delivering CO_2 removal capacities for net zero will likely require $6 trillion to $16 trillion of cumulative investment by 2050, far below expected levels.



Credit: Mannion et al, 2023. McKinsey & Co.

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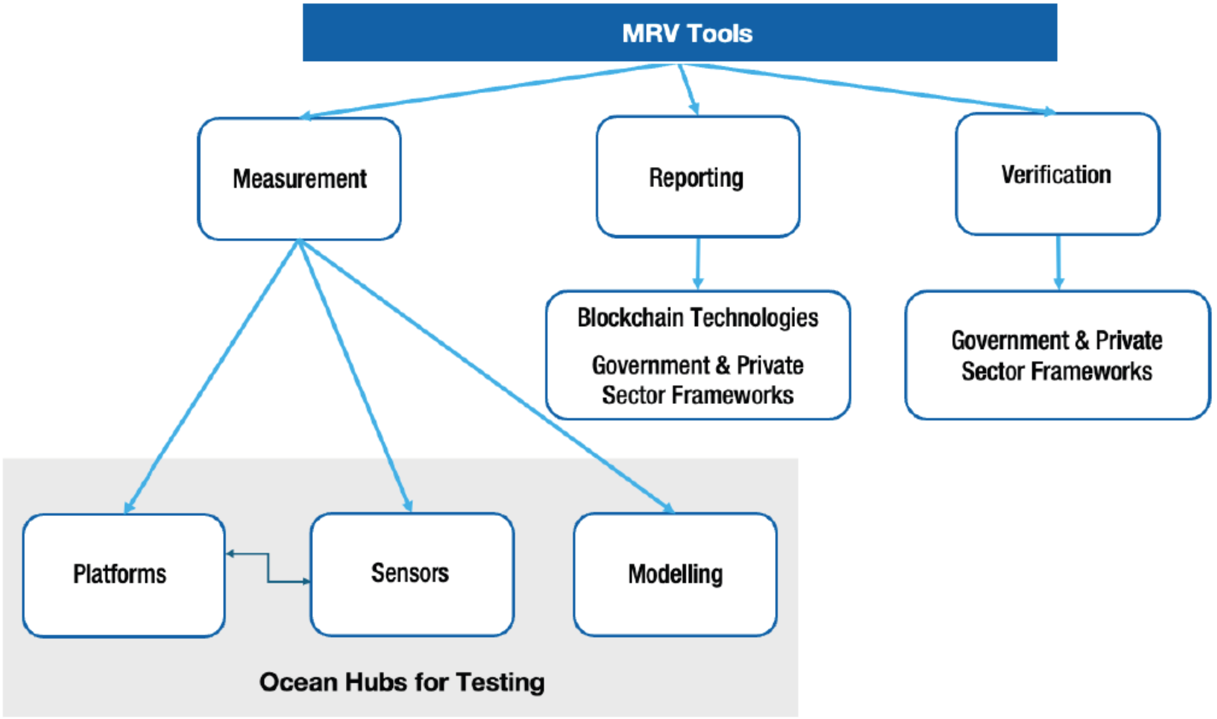
KEY FINDINGS: NEED FOR CHEAPER AND MORE ACCURATE MRV

- MRV consistently identified as **the key capability gap** impeding mCDR
- Areas of need for MRV can be met with technologies applicable to other ocean data sectors
- Innovation in three core technological areas present an opportunity for science and investment to unlock the full potential of mCDR



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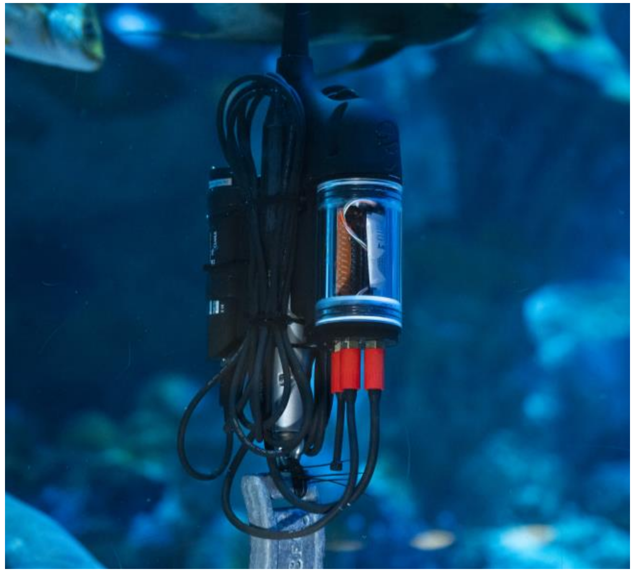
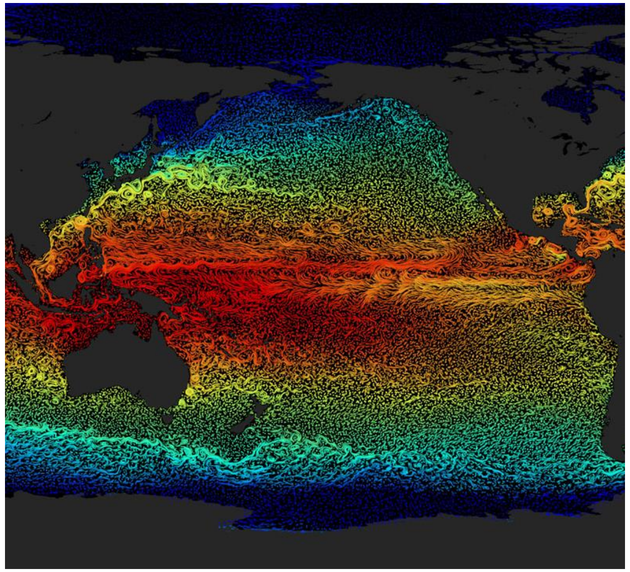
THREE AREAS OF NEED FOR INNOVATION

Platforms	Sensors	Models
		

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DATA COLLECTION PLATFORMS

Opportunities and Needs

- Data collection platforms are a bottleneck for high-confidence MRV at a viable price point
- The technologies needed for low-cost, high-duration, wide field data gathering have applications in sectors beyond mCDR.
- Key design attributes:
    - modular compatibility with existing and future sensor payloads
    - incorporation of metadata
    - data transparency
    - low power needs and/or onboard generation
    - autonomous operation.

OPENOCEAN ROBOTICS

Apeiron Labs

JAIA ROBOTICS MICRO IS MORE

The above is a non-exhaustive list of companies relevant to the space and should not be construed as an endorsement by SeaAhead or the NEAq.

SENSORS

Opportunities and Needs

- Legacy sensors do not allow for accurate measurement of key metrics needed to establish sequestration at an attainable price point
    - Partial pressure of CO_2
    - Dissolved Inorganic Carbon
    - Total alkalinity
    - pH
- Sensors are needed for environmental MRV (eMRV) to detect any negative impact on local ecosystems
- Key design attributes:
    - Compatibility with deployment platforms
    - High accuracy
    - Self-calibration
    - Data transparency

AQUATIC LABS

VYCARB

planblue

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MODELS

Opportunities and Needs

- Recent breakthroughs in computing power have unlocked new capabilities for ocean modeling
- Combined with high quality data sets collected by new sensors and platforms, models can enable MRV and strategic planning for mCDR projects that would be prohibitively expensive
- Modeling alone is not the answer, and successful models will need several characteristics
  - Ground-truthing with onsite measurements
  - Utilization of a standardized data architecture
  - High degree of transparency for verification, attribution, and confidence building

[C]Worthy

atdepth MRV

OCN.AI

The above is a non-exhaustive list of organizations relevant to the space and should not be construed as an endorsement by SeaAhead or the NEAq.

OUR PANEL

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Q&A

SUMMARY AND KEY CONSIDERATIONS

- Stakeholders in science and industry all identified a need for cheaper and more accurate MRV
  - Enabling technologies for MRV are an area where innovative companies can unlock these capabilities and may appeal to early-stage investors
- Each enabling technology type has specific attributes and abilities that emerged as core capabilities needed in future products

Platforms

- Sensor compatibility
- Incorporation of metadata
- Optimized power use
- Autonomous operation
- Data transparency

Sensors

- Compatibility and standardization
- High accuracy
- Self-calibration
- Data transparency

Models

- Validated against onsite measurements
- Standardized data architecture
- Data transparency

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NEXT STEPS

https://neaq.org/news-and-stories/upswell-whitepapers/

https://www.sea-ahead.com/whitepapers

1. Read the whitepaper
2. If you're a bluetech startup or know of a bluetech startup reach out about the SeaAhead Blue Angels and BlueSwell programs
3. Join the SeaAhead Blue Angels for accredited investors: https://www.sea-ahead.com/blue-angels
4. Reach out to us for more information and questions.

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