OceanNETs – Key messages on ocean-based CO_2 removal (CDR)

David P. Keller on behalf of the OceanNETS consortium

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Ocean-based CO_2 removal (negative emission technologies)

- What are emerging ocean-based CO_2 removal (CDR) options?
- How is the field developing?
- What did we learn in OceanNETs?
  - Filling of key knowledge gaps
  - Case studies on ocean alkalinity enhancement
    - Prospects for ocean-based CDR to help meet climate targets

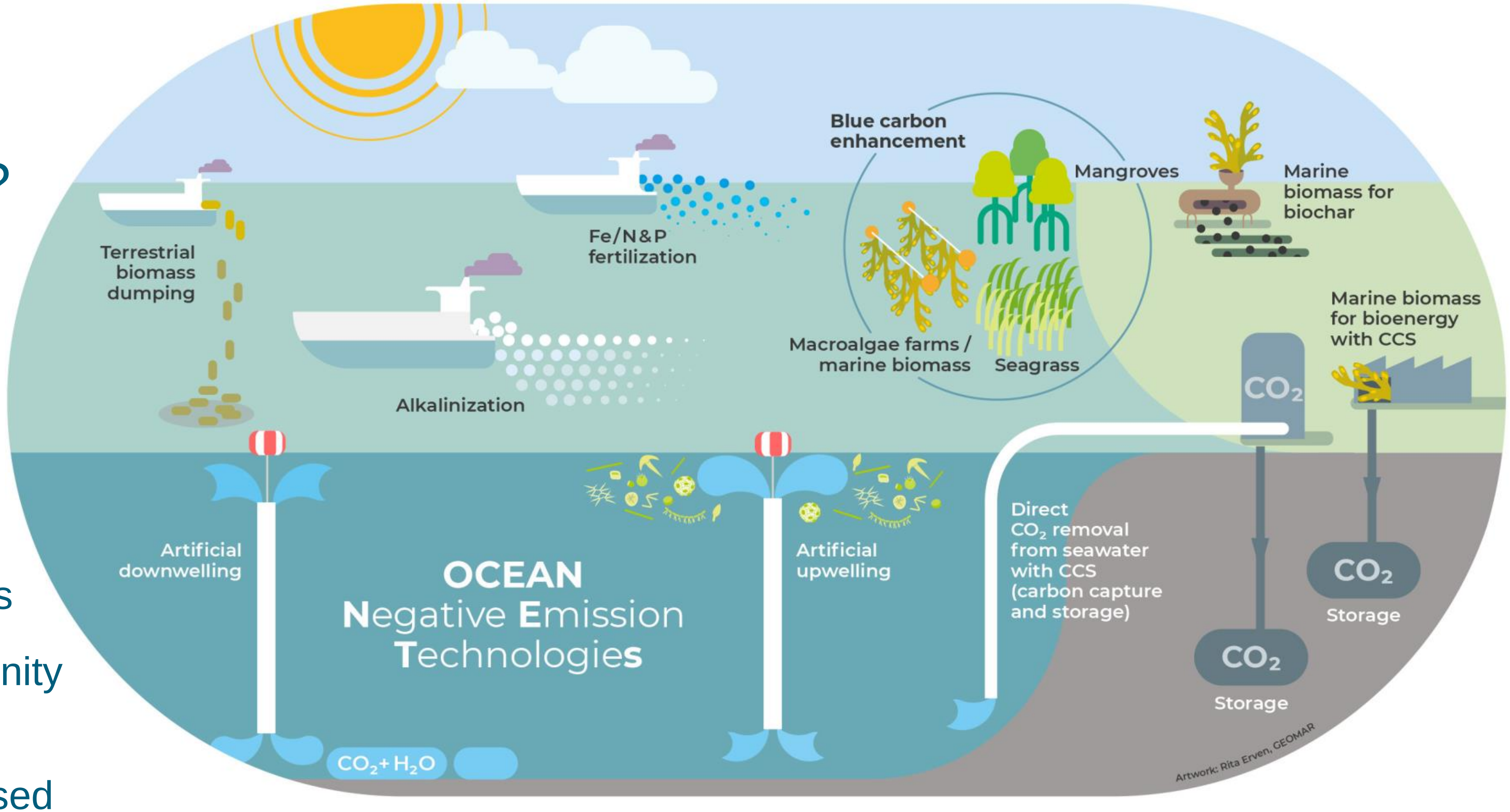


Figure 1: Overview of some mCDR methods, Rita Erven, GEOMAR/OceanNETs

Ocean-based CDR is a quickly growing field

2018

Modeling and theoretical academic research by a few

Little public funding

2024

Research, synthesis, and advocacy by many

Substantial Public and private funding

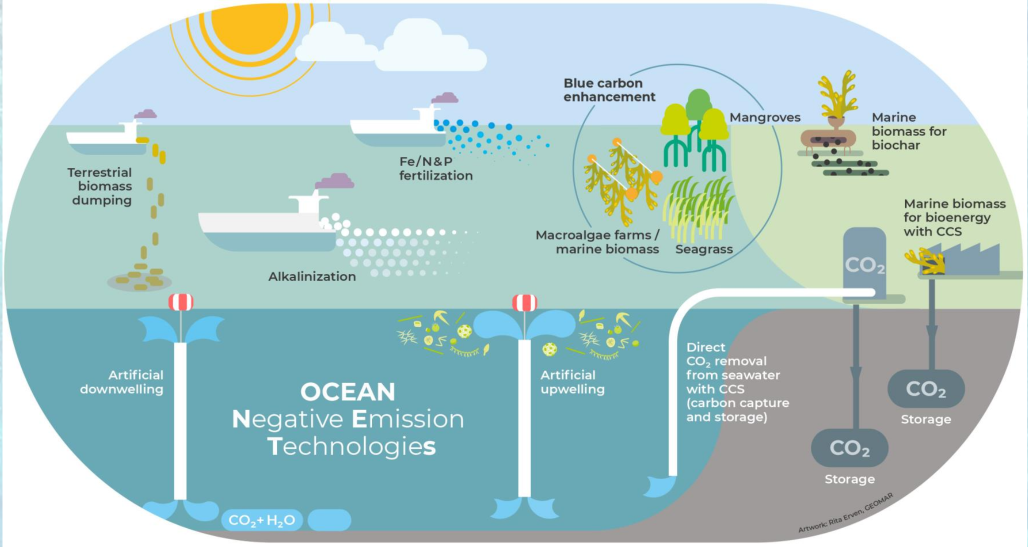
Start-ups

Field Trials

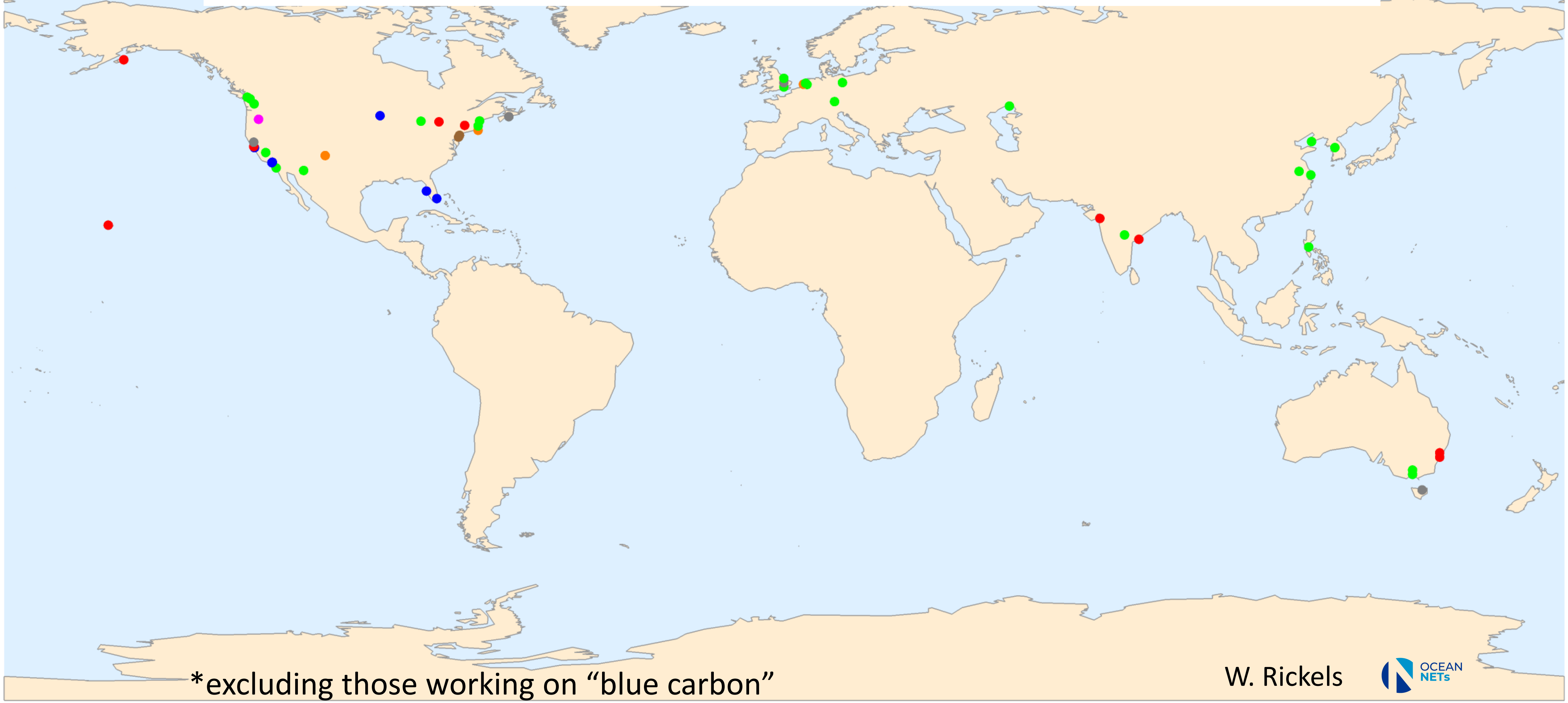
Corporate engagement (voluntary carbon market)

Recent research funding

- EU projects - SEAO2-CDR (€ 6.9M), RESCUE (€ 8M)
- National projects
  - Germany (CDRmare projects: € **26**M for phase I, € **18**M phase II)
  - USA
    - NOAA $**24.3**M
    - ARPA-E $**45**M
  - China – ONCE program ($**347**M)
- Private funding
  - Carbon to Sea Initiative: $**50**M +
  - Shopify / Stripe / Frontier: $**7**M (Sept. 2023)
  - Other: $10s of million in venture capital

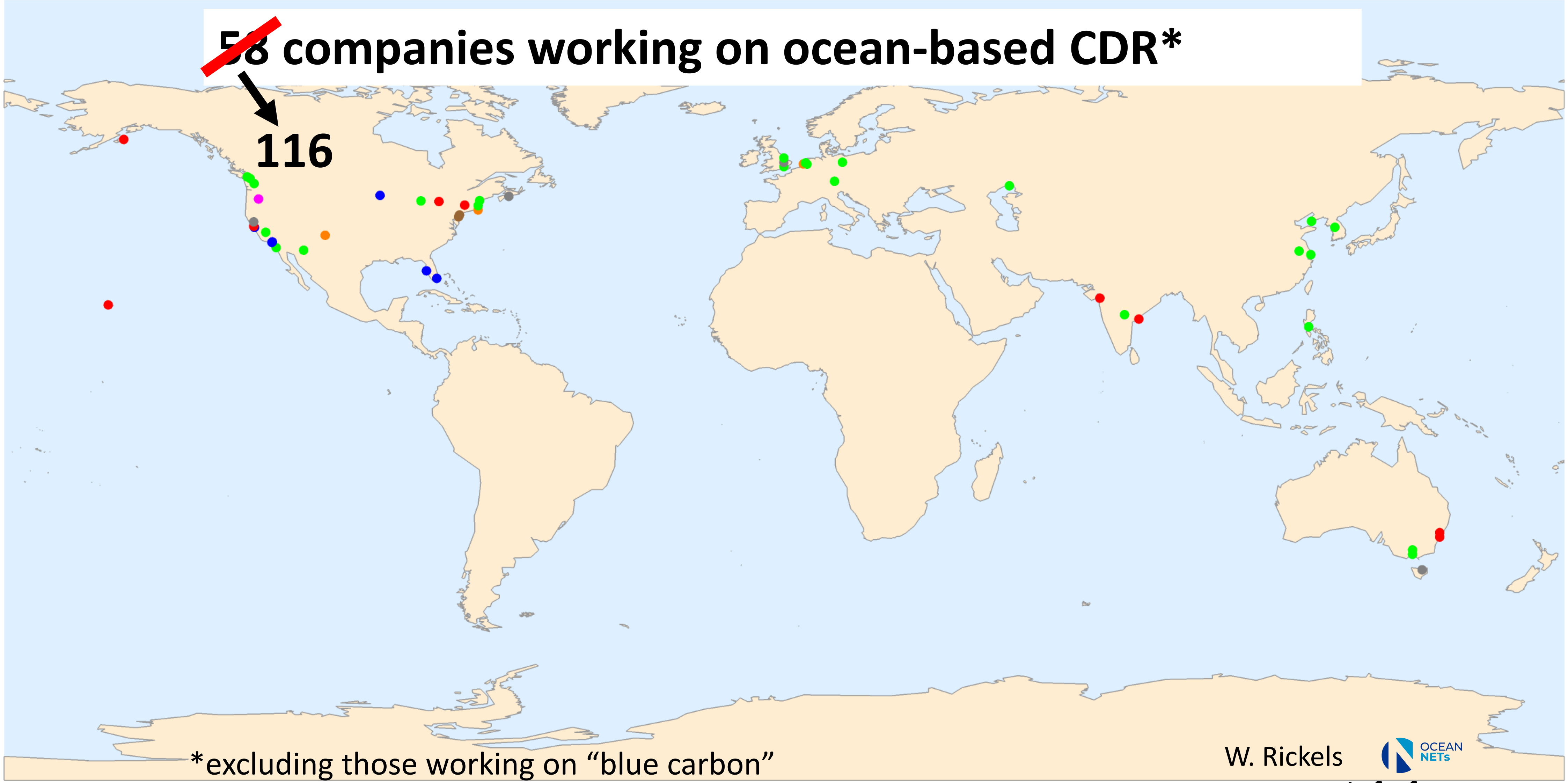


58 companies working on ocean-based CDR* in 2021



- Artifical Upwelling
- Ocean Fertilization
- Electrochecmical Weathering
- Alkalinity Enhancement
- Marine Biomass Farming
- Marine Biomass Sinking
- Coral Reef Restoration

~~58~~ companies working on ocean-based CDR*



+ info from GESAMP WG 41

- Artifical Upwelling
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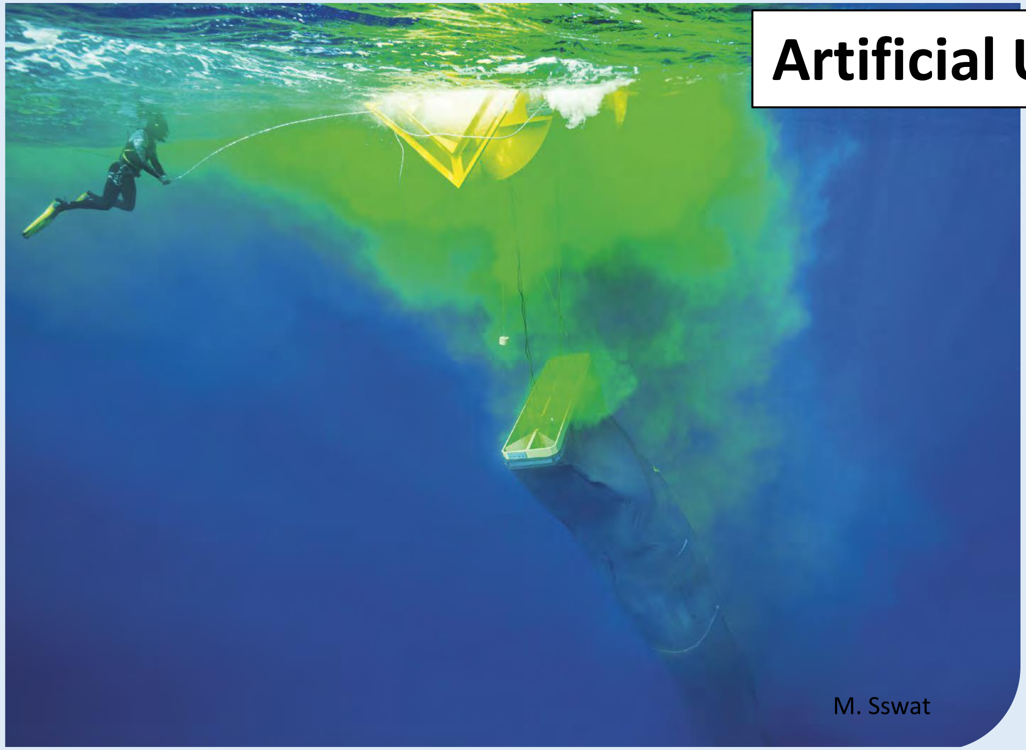
~~58~~ 116 companies working on ocean-based CDR*

Field trials have begun!

Artificial Upwelling



Ein spanisches Forschungsschiff setzt im November 2022 die Wellenpumpe der CDRmare-Forschungsmission für Testzwecke aus.

Foto: Diego Gutierrez

~~58~~ companies working on ocean-based CDR*

116

Field trials have begun!

Direct Removal of CO_2 from seawater

~~58~~ 116 companies working on ocean-based CDR*

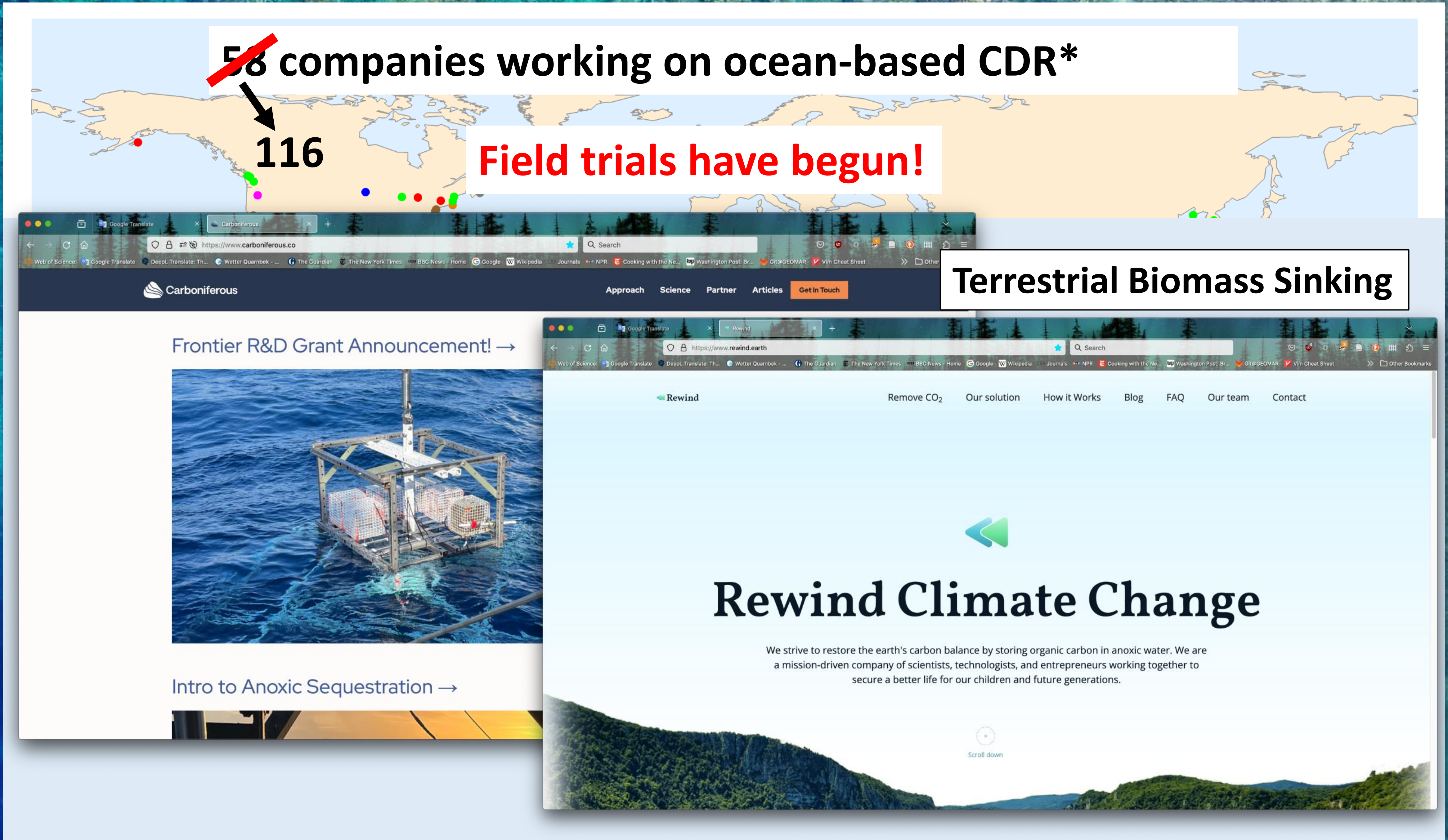
Field trials have begun!

Ocean Alkalinity Enhancement

Olivine added to a beach

Bedford Basin, Canada dye release prior to OAE

Ebb Carbon – electrochemical OAE
100 tons CDR per yr^{-1} in Sequim Bay, USA


58 companies working on ocean-based CDR*
116
Field trials have begun!
Terrestrial Biomass Sinking
https://www.carboniferous.co
Carboniferous
Approach
Science
Partner
Articles
Get In Touch
Frontier R&D Grant Announcement! →
Intro to Anoxic Sequestration →
https://www.rewind.earth
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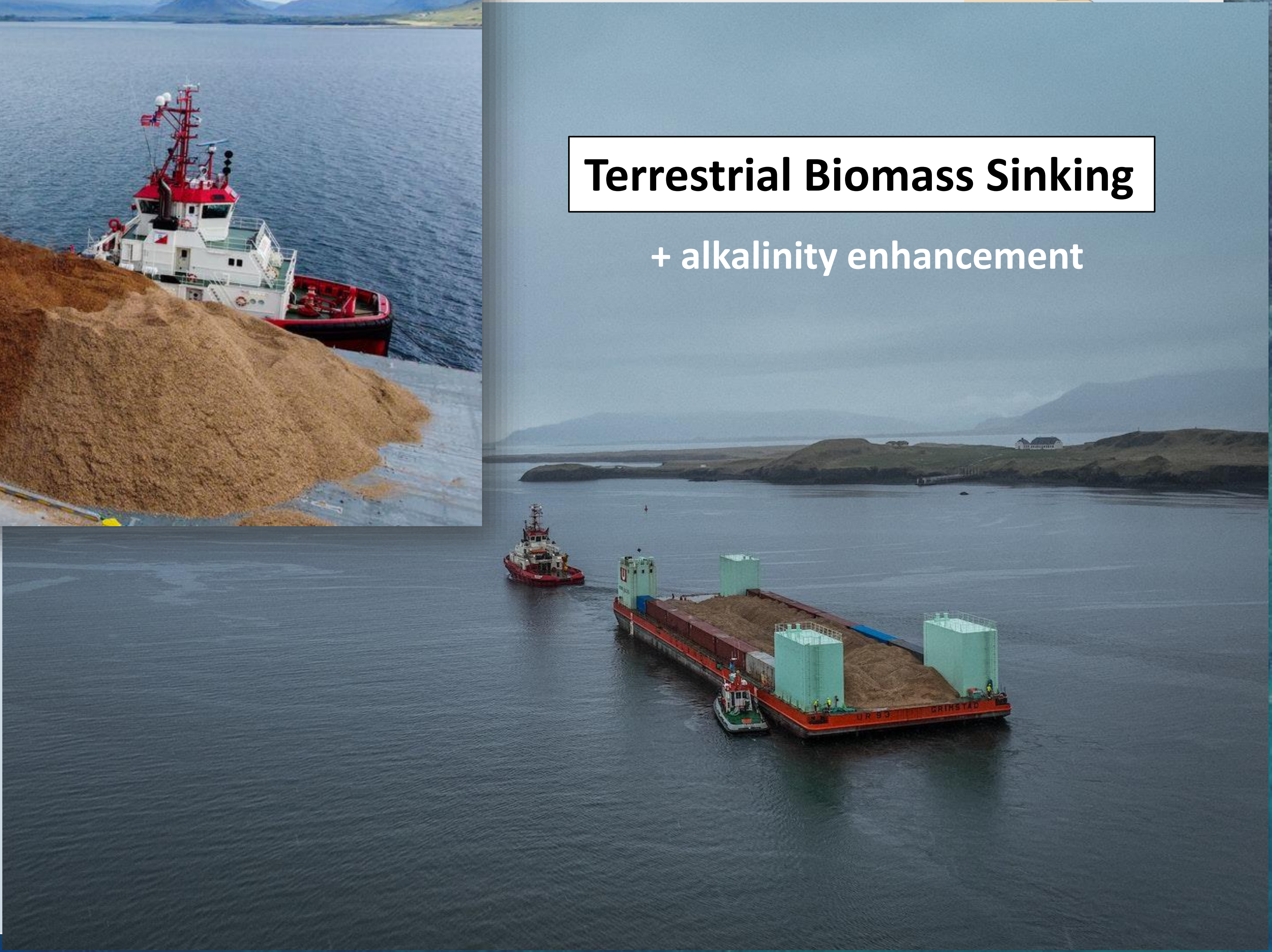
Remove CO2
Our solution
How it Works
Blog
FAQ
Our team
Contact
Rewind Climate Change
We strive to restore the earth's carbon balance by storing organic carbon in anoxic water. We are a mission-driven company of scientists, technologists, and entrepreneurs working together to secure a better life for our children and future generations.
Scroll down

based CDR*



Terrestrial Biomass Sinking

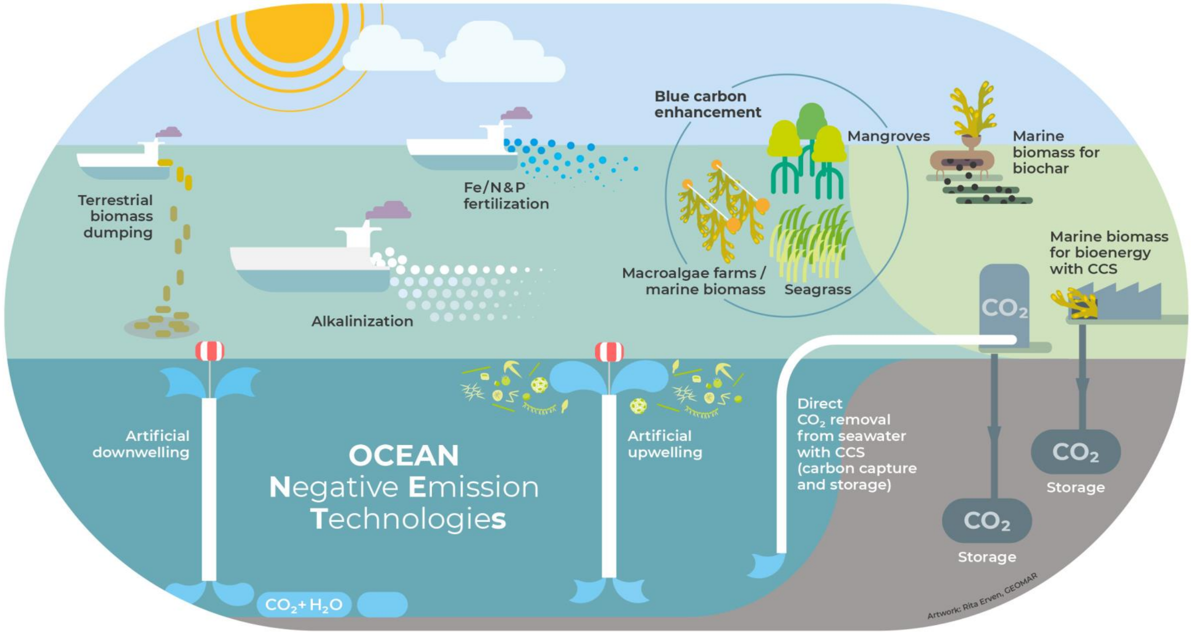
+ alkalinity enhancement

Running Tide

What have we done in OceanNETs?

OceanNETs – key topics

- Economics – (see later presentation by W. Rickels)
- Governance & law – (see later presentation by B. Neumann)
- Public perception – (a few slides in a later presentation)
- Responsible research and innovation on ocean-based CDR
- Earth system modelling
- Ocean Alkalinity Enhancement
  - Biogeochemical impacts
  - Mineral dissolution dynamics
  - Case studies



Can ocean-based CDR help us meet climate change mitigation targets?

Ocean alkalinity enhancement case study results

Ocean Alkalinity Enhancement Case Studies

Cases
Ocean alkalinization using lime in Europe
Ocean alkalinization using water desalination brines in Spain

Lead Participants:

Heriot Watt Univeristy

Dr Phil Renforth

Dr Spyros Foteinis

Dr. James Campbell

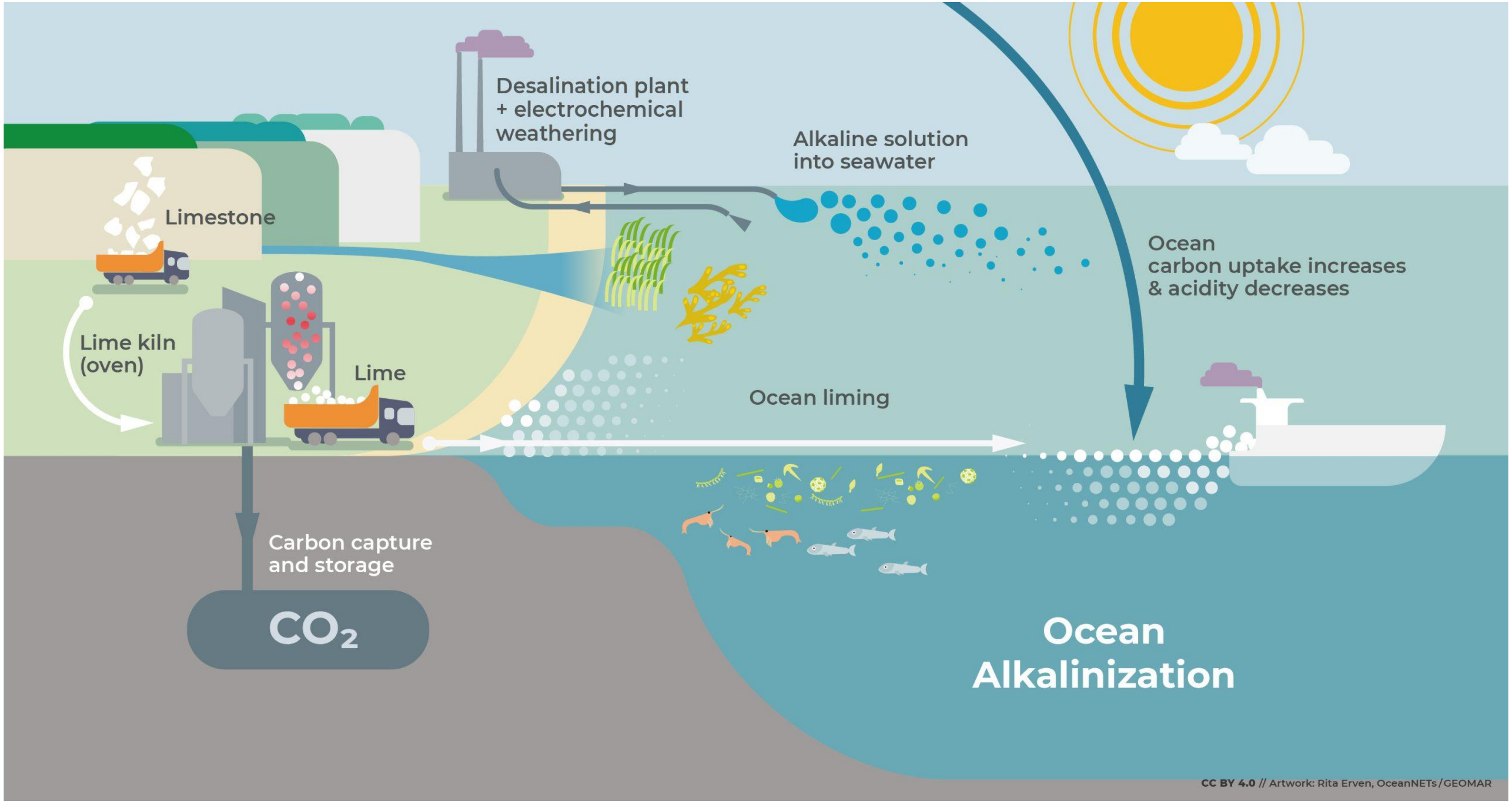
University of Oxford

Dr Jose Maria Valenzuela

Dr Javier Lezaun

- with input from other OceanNETs partners

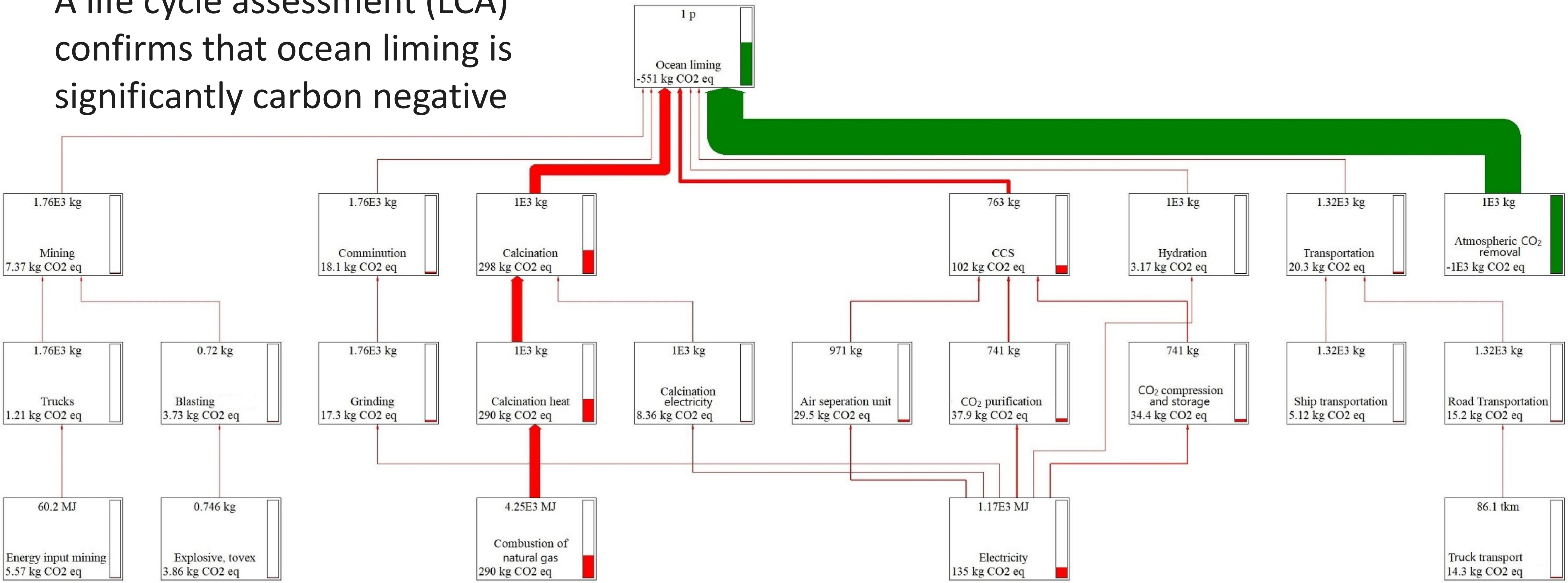
Ocean Alkalinity Enhancement Case Studies



Source: https://www.oceannets.eu/ocean-alkalinization/

Technical findings: Ocean Liming

A life cycle assessment (LCA) confirms that ocean liming is significantly carbon negative

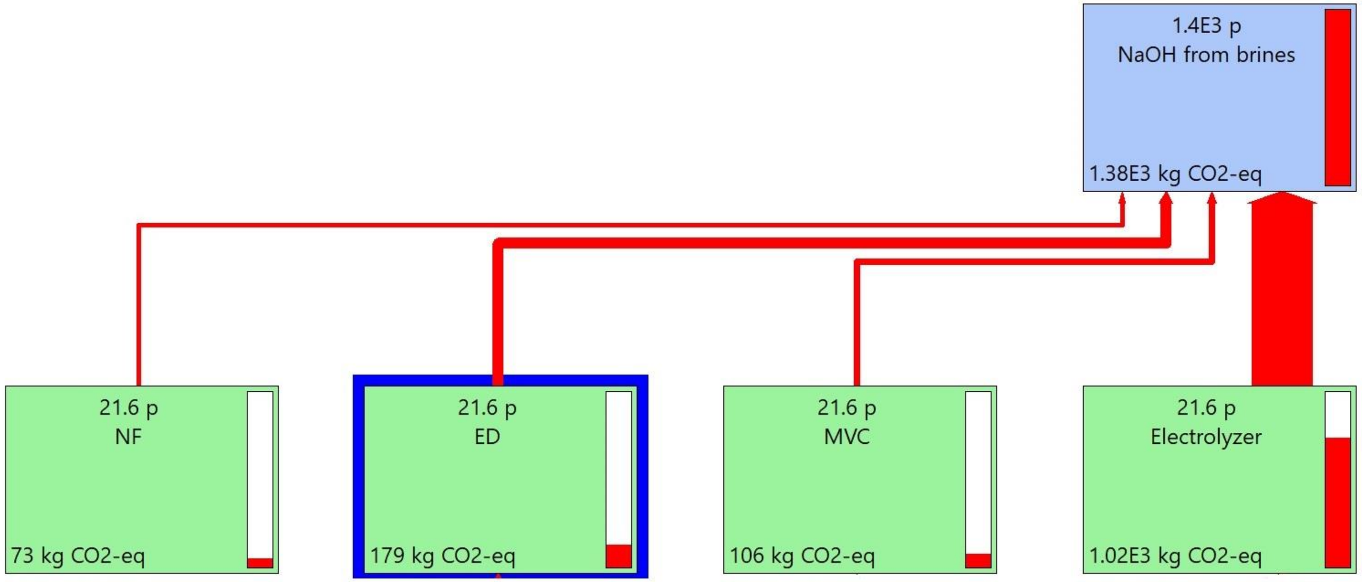


Source: Foteinis et al., 2022

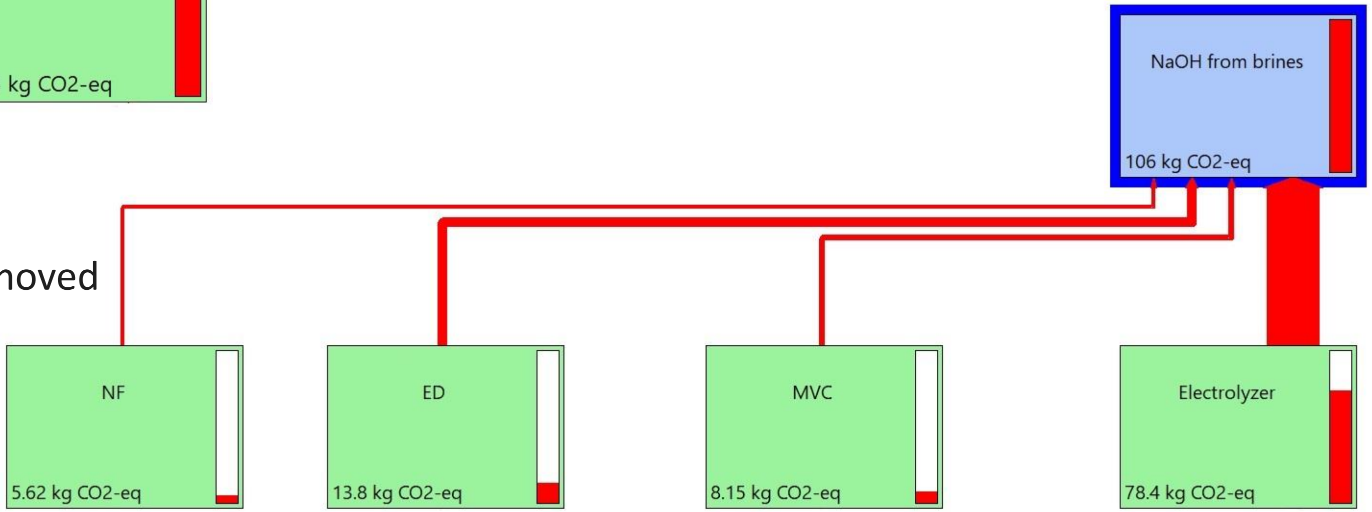
- Calcination energy is the main environmental hotspot
- In decarbonised economies the maximum amount of removals can be achieved along with avoided emissions

Technical findings: Brine splitting (electrochemical OAE)

A life cycle assessment (LCA) confirms that brine splitting is only carbon negative when 100% renewable energy is used

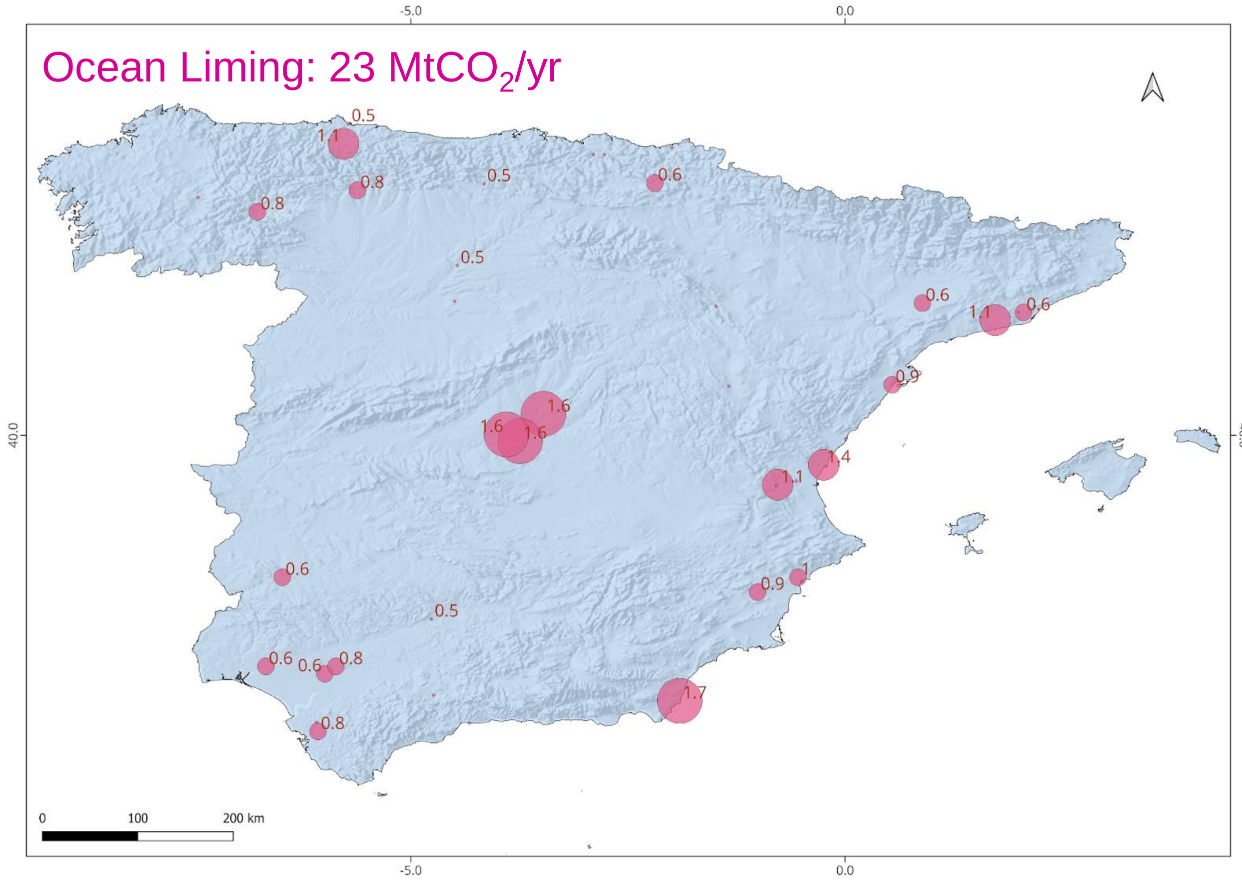


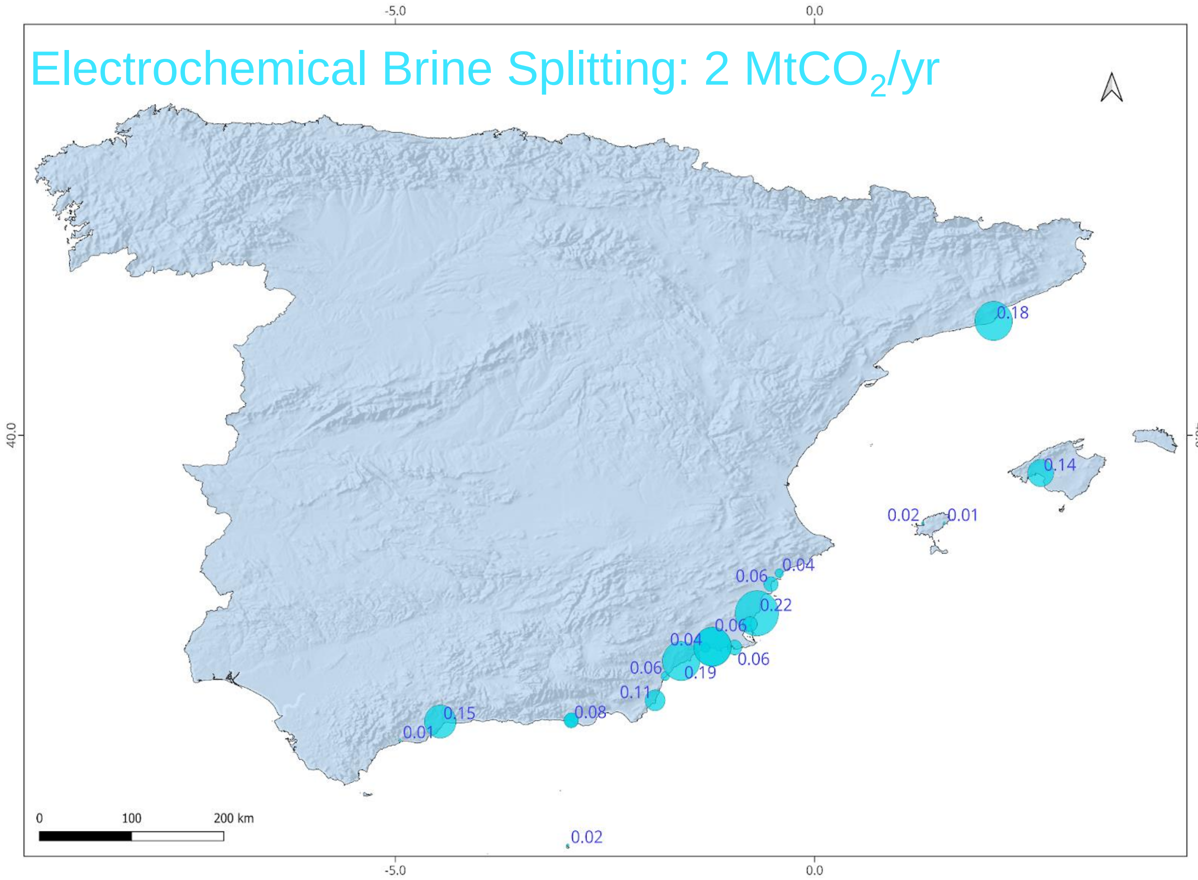
Spain's grid electricity: 1.38 tCO_2 emitted per tCO_2 removed
Not net negative



Onshore wind (turbine > 3MW): 106 $kgCO_2$ emitted per tCO_2 removed
Highly net negative

Annual realistic ocean alkalinity enhancement potential of Spain





Coastal enhanced weathering can contribute a further 2 $MtCO_2$/yr (Foteinis et al., 2024, in preparation)

Ocean liming (1/2)

Envisioning the scale of deployment	**Uncertainties** regarding OAE deployment are contingent on the **intended scale of deployment**; i.e., will it be used to offset companies' own emissions (smaller) or national climate objectives (larger).
Considering sectors decarbonization	**High confidence on the availability of low/zero emissions lime by 2030**, and high progression of fuel substitution in the maritime industry by 2040. **But open question about the share of low-emissions lime in the total lime market**.

Ocean liming (2/2)

Uncertainties regarding dispersion logistics and economics	**Difficult to imagine in detail what the deployment infrastructure might look like**. This depends on the scale and the actors involved. e.g. Will commercial fleets incorporate it in their activities? Will there be state funded purpose-built fleets?
Availability of limestone	**Difficult to contemplate a large expansion of mining licenses**, at least in Europe. This constitute a clear constraint on large-scale deployment, which current models and LCAs do not take sufficiently into account.

Electrochemical Brine Splitting (1/2)

Integration with existing infrastructure	In addition to its integration with existing plants (or new integrated designs), the grouped discusses the **conditions for integration with existing electricity grid system** and prospective low-emissions energy.
Discharge infrastructure and location conditions	**Current regulation pH of discharges** and concrete installation differences (depth) might require additions to existing instrumentation.
By-product (and input) markets	**Mining of brines for other minerals**, changing market conditions for by-products, but also infrastructure requirements (transportation) and the requirements for materials to neutralize acid.

Electrochemical Brine Splitting (2/2)

Changes in the economics of splitting technologies

Increased competition for splitting technologies/renewable energy might create scarcity (ie. electrodialysis users) and at the same time the demand (ie. lithium industry) might produce significant cost reductions.

Regional acceptance

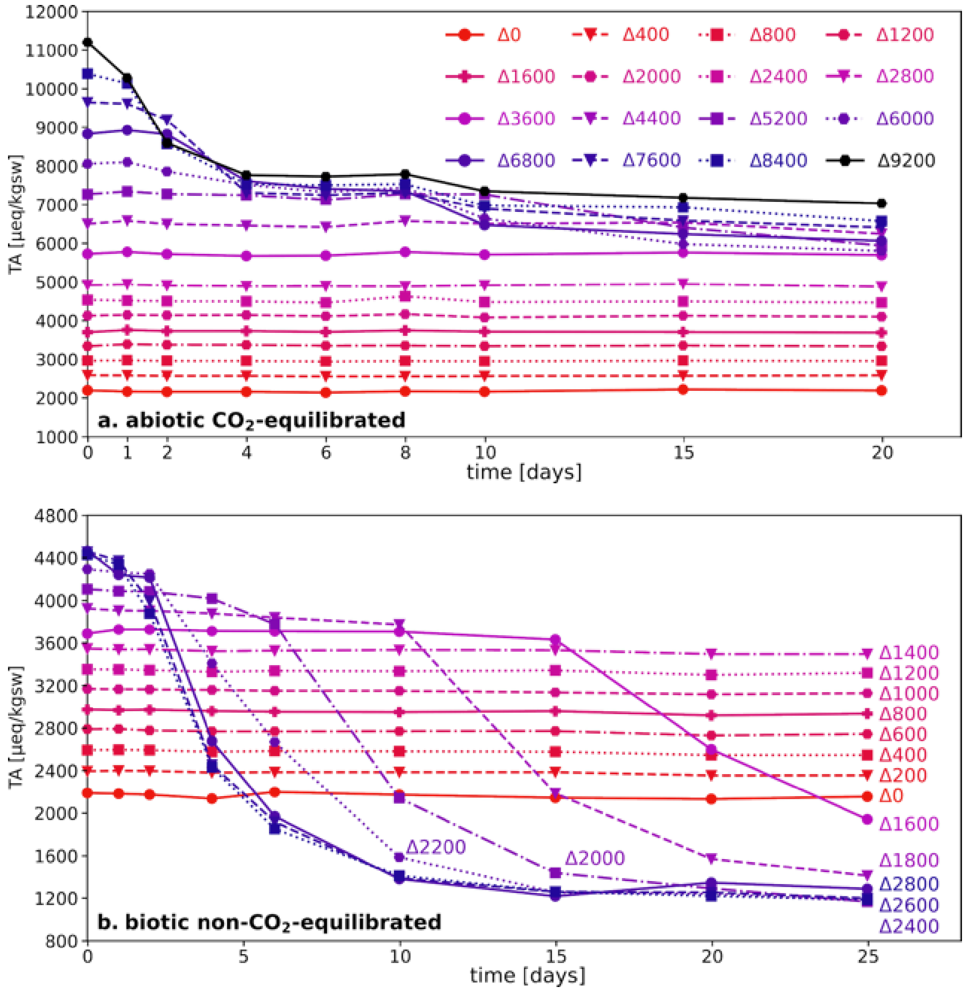
Climate change and water scarcity will shape peoples' perception of desalination/brine mining

What can we say about actually increasing alkalinity in the ocean?

Ocean Alkalinity Enhancement Stability

- If alkalinity is increased too much, then precipitation of CaCO3 can occur reducing alkalinity and releasing CO_2
- Can be avoided by not exceeding certain thresholds or by diluting the water
- Large CDR potential still exists, but there is a limit on how much alkalinity can be increased in any one place and how it is added

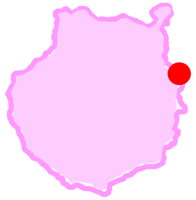
Stability of alkalinity in bottle incubation experiments



Suitner et al., 2023

Ocean Alkalinity Enhancement Biogeochemical Impacts

Mesocsoms experiments

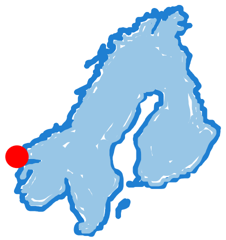


Experiment I (Gran Canaria, ES):

CO_2-equilibrated OAE

9 OAE intensities tested

(through addition of $NaHCO_3$ & Na_2CO_3)



Experiment II (Bergen, NO):

Un-equilibrated OAE

Mineral-inspired (Ca and Si)

5 OAE intensities tested per mineral

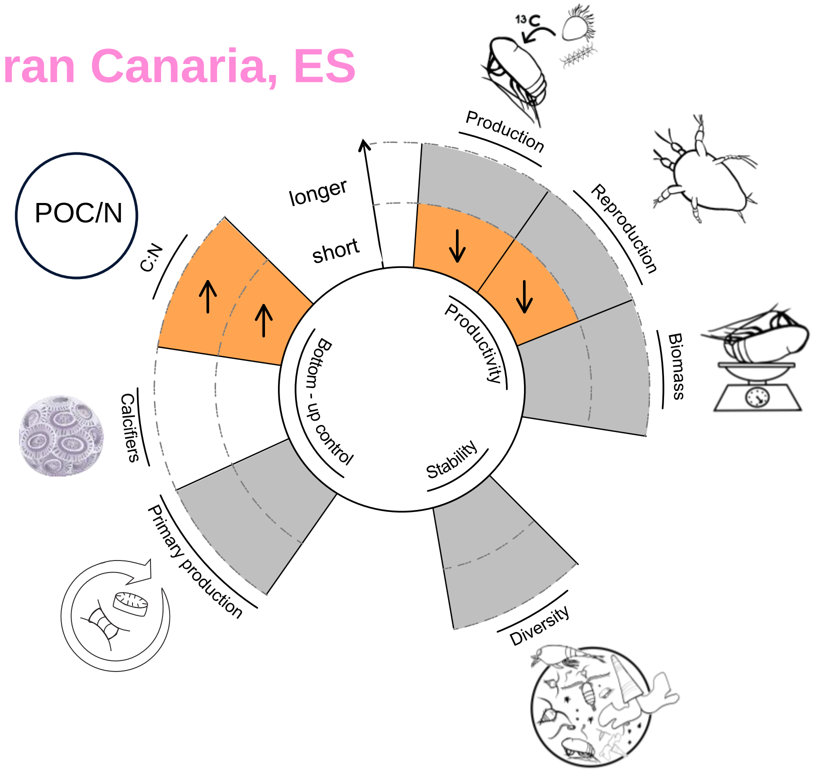
(through addition of NaOH with $CaCl_2$, or $MgCl_2$ and Na_2SiO_3)

Ocean Alkalinity Enhancement Biogeochemical Impacts

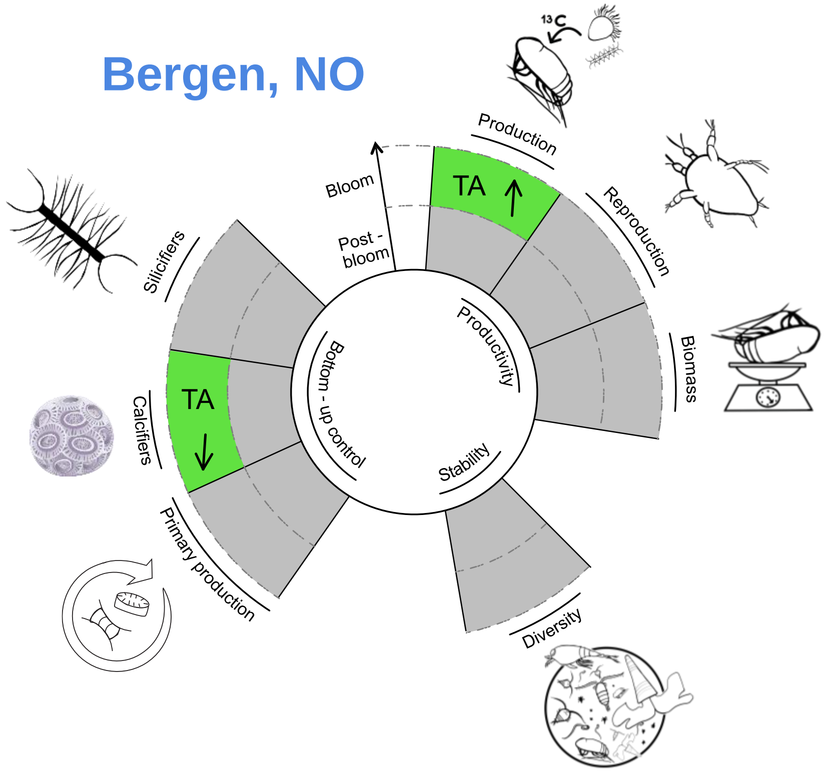
OCEAN NETs

Food web responses to alkalinity enhancement

Gran Canaria, ES



Bergen, NO

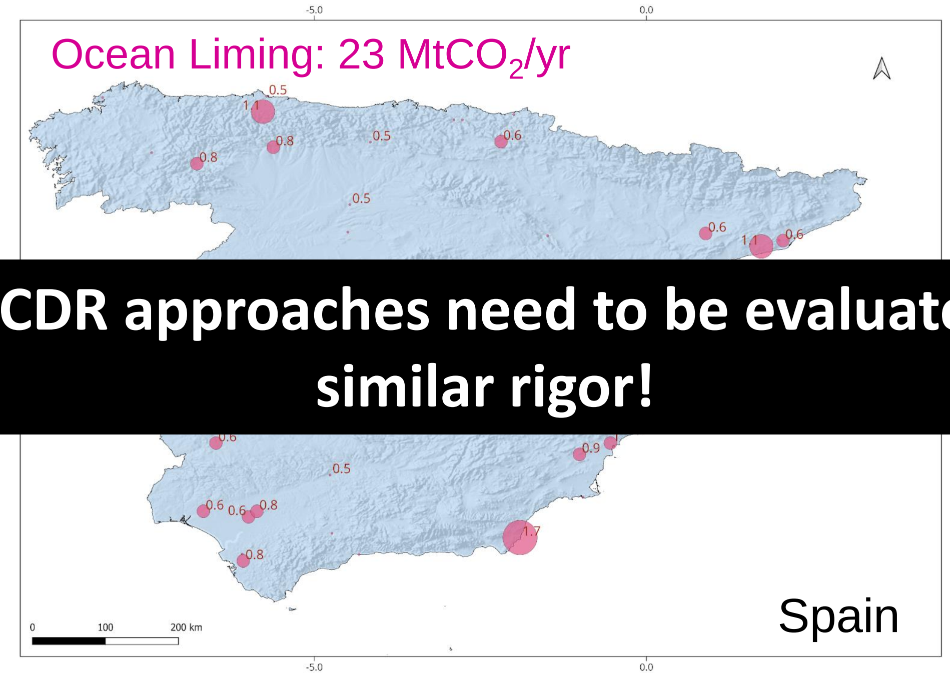


Responses were assessed based on phase-average values using linear regressions.
Grey = no effect, orange = negative effect, green = positive effect, blank = no data. Arrows indicate direction of change with OAE.

- Equilibrated ocean alkalinity enhancement had **minor impacts** on a subtropical food web, **without lasting consequences** for food web functioning and biogeochemical cycling.
- Un-equilibrated, mineral-inspired OAE had **no impacts** on a post-bloom temperate food web.

Ocean Alkalinity Enhancement Case Studies - Conclusion

- Case studies suggest that ocean alkalinity enhancement can play a role in mitigation pathways
  - Not as the only solution, but maybe part of a CDR portfolio
- How to scale and actually deploy these approaches is unclear
  - Field trials & engineering needed!
  - Experiments provide insights on what not to do (don't increase alkalinity too much in any one place!)

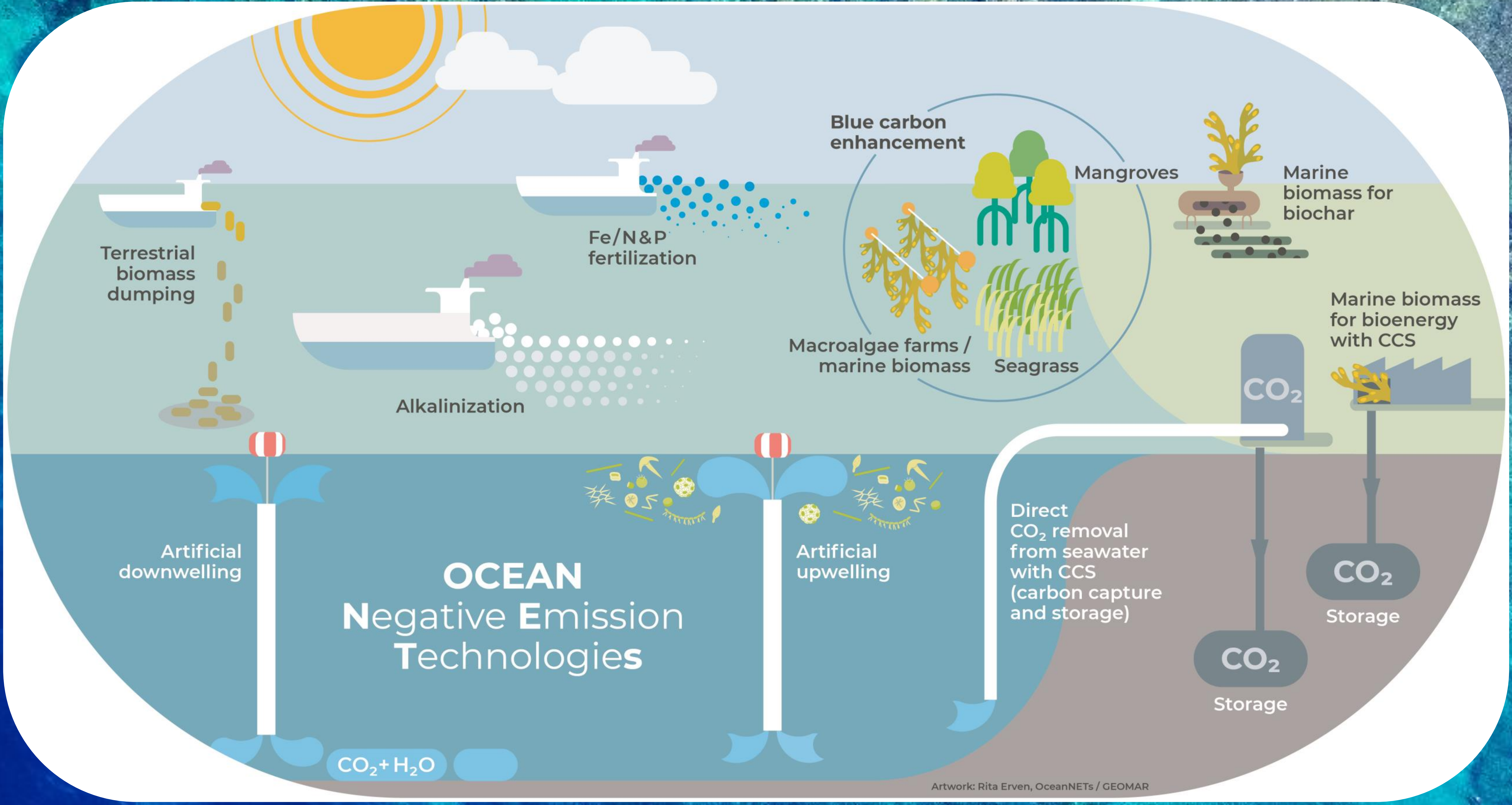


Other CDR approaches need to be evaluated with similar rigor!

- Governance, public perception, and policy must be enabling
- Monitoring, reporting, and verification (MRV) protocols need to be established

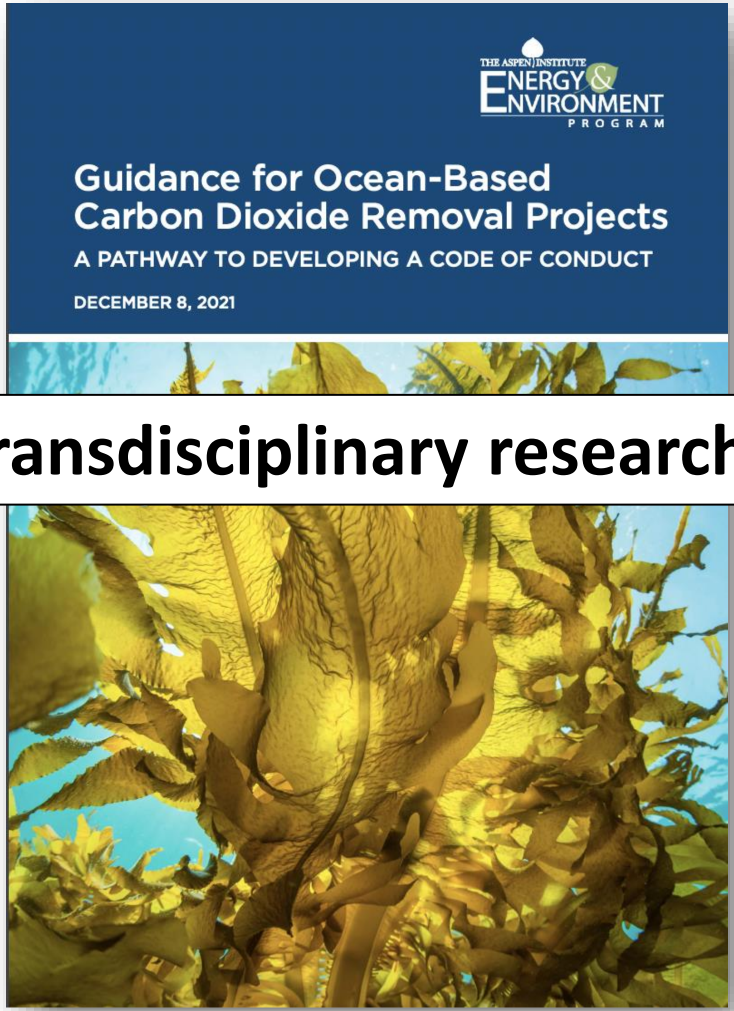
Major knowledge gaps and challenges

- How do we deploy & scale up ocean-based CDR?
  - Engineering challenges
  - Field trials needed…but don't get ahead of the science
- How to do monitoring, reporting, and verification (MRV)?
  - Ocean observing community not prepared for CDR
- Need to assess what CDR approaches are feasible and desirable for different locations

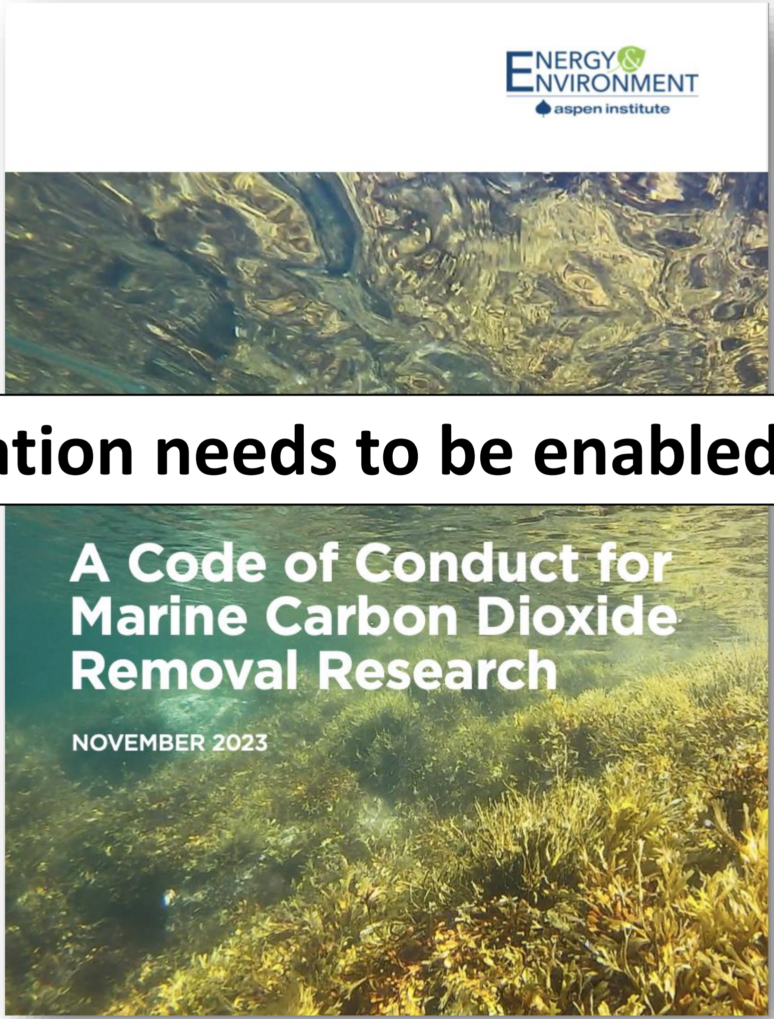


Blue carbon enhancement
Mangroves
Marine biomass for biochar
Terrestrial biomass dumping
Fe/N&P fertilization
Macroalgae farms / marine biomass
Seagrass
Marine biomass for bioenergy with CCS
Alkalinization
CO_2
Artificial downwelling
OCEAN
Negative Emission Technologies
Artificial upwelling
Direct CO_2 removal from seawater with CCS (carbon capture and storage)
CO_2
Storage
CO_2
Storage
$CO_2 + H_2O$
Artwork: Rita Erven, OceanNETs / GEOMAR

Dec.
2021



Nov.
2023



Transdisciplinary research & innovation needs to be enabled!