Carbon to Sea Initiative

Poster Session Directory

Carbon to Sea's 2026 Annual Convening will feature a poster session reception on the evening of Wednesday, April 29th, showcasing the diverse research, developments and initiatives being conducted by dedicated scientists, organizers and professionals across the Ocean Alkalinity Enhancement (OAE) field. Below you will find a brief overview of each poster and its authors, grouped by topic.

ALKALINITY GENERATION & DISPERSAL

Reducing curtailment by harnessing excess variable renewable energy for ocean alkalinity enhancement

Presenting Author: Rocco D'Ascanio – Yale University, Research Associate
Co-Authors: Noah Planavsky, Joachim Katchinoff

Abstract:
Carbon dioxide removal (CDR) from earth's atmosphere is a critical tool to mitigate climate change, but many CDR technologies—including those classified as ocean alkalinity enhancement (OAE)—will require vast quantities of low-carbon electricity when deployed at scale. Simultaneously, electricity generation by variable renewable energy sources frequently outpaces demand, resulting in curtailment of the energy supply. Here, we compile reported curtailments by nation for 2024, and use this data to estimate future variable renewable energy curtailments through 2050. Then, we perform techno-economic analyses to evaluate whether excess electricity can be an effective, scalable energy source for CDR via OAE. Our techno-economic model constrains the cost of using low-capacity-factor rock comminution facilities to perform the energy intensive grinding of olivine from 100 to 5 microns for OAE applications, using intermittent otherwise-curtailed renewable energy. A case study where olivine is extracted in Aheim, Norway and ground to 5 microns at the Port of Dundee, Scotland using excess offshore wind energy suggests that certain deployment locations may provide a low-cost (>150 USD tCDR-1) pathway to producing feedstock for OAE. Further, we demonstrate that using otherwise-curtailed renewable energy for OAE may provide significantly more CDR than the potential emissions reductions realized by storing this energy and later displacing fossil fuel intensive electricity. These results highlight an alternative use of curtailed variable renewable energy beyond grid-level energy storage, and they suggest that capital intensive CDR processes may not need to operate at high capacity factors if exceptionally low cost, low carbon energy is available.

Electrochemical Technologies for Geochemical Based Marine Carbon Dioxide Removal

Presenting Author: Sam Fahrngruber – McMaster University, Master's Student
Co-Authors: Charles de Lannoy, Mahtab Masouminia, Sorour Ayoubian, Ashkan Irannezhad, Shashwati Da Cunha, Hussain Almajed, Abby Lunstrum

Abstract:
Literature on electrochemical marine carbon dioxide removal (mCDR) technologies has expanded rapidly over the past decade as interest in scalable ocean-based climate mitigation strategies has grown. As part of a broader systematic review of mCDR approaches, we conducted a systematic

review of proposed electrochemical mCDR technologies to evaluate their operating principles, carbon storage pathways, and current state of development. Most electrochemical mCDR approaches use either electrolysis or electrodialysis. Electrolytic systems rely on redox reactions occurring at spatially separated electrodes to generate distinct chemical products. In many cases, these systems operate through water electrolysis reactions that produce hydrogen and oxygen at either electrode, while simultaneously altering local solution chemistry to promote carbon dioxide removal. Electrodialysis systems, apply an electric field across electrolytes to drive the transport of charged ions across-selective membranes and separate them into distinct channels. The electrolytes are often seawater, desalination brines, or wastewaters. This ion transport results in the generation of alkaline- and acid-enriched streams that can be used to manipulate carbonate chemistry and facilitate carbon dioxide capture. These electrochemical approaches can be configured to store carbon dioxide in several forms, including aqueous carbonate and bicarbonate ions in seawater (Ocean Alkalinity Enhancement – OAE), stripped carbon dioxide gas streams (Direct Ocean Removal – DOR), and solid metal-carbonate precipitates (Electrochemical Mineralization – E-Min.). Each pathway represents a distinct mechanism for long-term carbon storage and presents unique technological challenges and opportunities. Some key findings include that electrodialysis generally has higher TRL while electrolysis can produce more valuable byproducts. This review synthesizes the current state of research in electrochemical mCDR technologies, identifies key knowledge gaps, and outlines research priorities and recommendations to guide future development and deployment.

Field trial reveals potential and limits of enhanced marine calcite weathering

Presenting Author: Dr. Michael Fuhr – Yale Center for Natural Carbon Capture, Postdoctoral Fellow
Co-Authors: Navenn Kumar Parameswaran, Klaus Wallmann, Stefan Sommer, Nicole Adam-Beyer, Mirjam Perner, Andrew W Dale

Abstract:
The ultimate premise to mitigate climate change is the reduction of greenhouse gas emissions. Still, in order to reach a net-zero balance, Carbon dioxide removal (CDR) is needed to target emissions that are hard to abate. Ocean alkalinity enhancement (OAE) has gained increasing attention as a potential measure to meet CDR goals.

Recent studies have identified calcite as a candidate material for enhanced benthic weathering (EBW) in shallow shelf sediments as a method to enhance ocean alkalinity. This study presents results from the first in-situ benthic incubation experiments on the seabed of the southwestern Baltic Sea. To assess the fate of calcite material that was added to a benthic chamber, the accumulation of weathering products in the chamber was used to calculate rate constants for calcite dissolution. These were in line with and therefore validated results from previous ex-situ dissolution experiments. The ratio of total alkalinity release to total oxygen uptake (TOU) allows to assess the global CO_2 uptake potential of calcite-based EBW. The results reveal that this potential lies between 0.4 Gt under very conservative assumptions, and 3.3 Gt with optimistic considerations, and is limited to a theoretical maximum of 3.6 Gt. These findings substantiate previous opinions that calcite based EBW cannot serve as a silver bullet to mitigate residual emissions. Yet, it has the potential to offset 4 – 37 % of these emissions and can therefore play a significant role in a portfolio of a variety of different carbon dioxide removal methods.

Characterization of Settling and Dissolution Dynamics of Alkaline Minerals for Ocean Alkalinity Enhancement

Presenting Author: Dr. Sugata Paul – University of Chicago, Postdoctoral Research Fellow

Co-Authors: B.B. Cael, Manon Duret

Abstract:
Alongside sustainable decarbonization of global industries, achieving global climate mitigation targets will require large-scale atmospheric CO_2 removal. Ocean Alkalinity Enhancement (OAE) is a promising strategy with the potential for gigaton-scale CO_2 sequestration, particularly when using alkaline materials already produced at industrial scale. When minerals such as quicklime (CaO), slaked lime ($Ca(OH)_2$), or olivine (Mg_2SiO_4) are introduced into the surface ocean, they increase seawater alkalinity and shift the carbonate chemistry equilibrium toward enhanced atmospheric CO_2 uptake. The effectiveness of mineral-based OAE depends critically on both the dissolution kinetics and the settling velocities of the added materials. These particles must dissolve predominantly within the surface mixed layer, where air–sea CO_2 exchange occurs. Consequently, alkaline minerals must have sufficiently slow settling velocities combined with sufficiently fast dissolution rates to ensure near-complete dissolution before they sink below the mixed layer, thereby efficiently increasing surface ocean alkalinity.

Our poster will present the OAE potential of a range of candidate alkaline materials—either as powder or slurry— as determined through laboratory experiments conducted to quantify their settling velocities and dissolution rates. We use a real-time size-and-settling-velocity instrument (RTSSV) to measure the settling process of particles within a vertical water column, enabling direct tracking of particle motion and size evolution. As particles descend, continuous dissolution leads to size reduction, allowing us to derive size-dependent velocity profiles. These measurements are essential for identifying optimal material properties —both for production and for deployment— that maximize residence time and dissolution within the mixed layer, and thus OAE efficiency. We also present calibration data from the RTSSV, characterizing the settling velocities of spherical particles in idealised conditions to validate the instrument. Additionally, we show how different shape characteristics affect settling velocities across a variety of mineral candidates for OAE.

Ultimately, this work will inform the large-scale feasibility of mineral-based OAE as a viable climate change mitigation tool.

BIOLOGICAL & ENVIRONMENTAL IMPACTS

Evaluating the effects of OAE on keystone ocean microbes via transcriptomics on field samples

Presenting Author: Dr. John Tracey – University of Chicago, Postdoctoral Research Associate
Co-Authors: B.B. Cael, Alessandra Valdivia, Manon Duret, Ben Daniels, Harriet Robertson, Maureen Coleman, Jacob Waldbauer, Aaron Ferderer

Abstract:
Additional research into the ecosystem effects and safety of OAE is necessary before deciding to deploy at gigaton scale. This in-progress project aims to resolve how key marine microbes will respond to OAE pilot interventions by performing genetic sequencing measurements before, during, and after OAE interventions at two pilot-scale field sites. Photosynthetic cyanobacteria and abundant heterotrophs respectively form the base of the marine trophic pyramid and remineralize large amounts of organic matter. Due to their short generation times, small size, and direct interaction with their surrounding fluid environment through their key ecological roles, there are many reasons to think marine prokaryotes will be sentinels for the effects of alkalinity additions within short (hours to days) timeframes. We are performing metatranscriptomics to examine the prokaryotic gene expression response to alkalinity additions and metagenomics to measure changes in the community before, during, and after alkalinity release at Ebb Carbon's Project

Macoma site as well as the University of Tasmania's field deployment site in a coastal sea grass bed. Together, these techniques will provide a picture of which microbes are present, if the microbial community changes around alkalinity addition, and how key microbes respond to OAE pilot interventions in an applied, field-scale setting. Our measurements will be combined with carbonate chemistry measurements to predict CO_2 flux as well as metabolomics, cell counts, and respiration rates to gain a complete picture of how the microbial community responds to alkalinity. These results will help identify the winners and losers in the microbial community after alkalinity addition. The ability to detect and assess ecological impacts is important if OAE efforts are to proceed with sufficient social licensing. These monitoring efforts will provide a framework for expanding OAE application by generating high-res datasets that are broadly applicable.

COMMUNITY & PUBLIC ENGAGEMENT

Co-Producing Communication and Research Plans: Insights from Community Engagement at the SeaCURE Weymouth Pilot

Presenting Author: Prof. Paul Halloran – SeaCURE, University of Exeter, Professor
Co-Authors: Guy Hooper, Haley D'Souza, Nita Pillai, Helen Findlay, Tom Bell

Abstract:
Scaling of mCDR technologies will not happen without public trust, transparent communication, and the development of social licence for field trials. This poster presents findings from a multi-stage engagement process conducted around the SeaCURE pilot, a 10s tonne/year research facility demonstrating of CO_2 removal from seawater on the South Coast of the UK. We widely advertised, then ran three facilitated workshops with local professionals, in-person public participants, and online community members. Each group co-created and iteratively refined a public-facing description of SeaCURE research goals, methods, potential impacts, and future plans.

Across workshops, participants expressed greatest enthusiasm for the climate rationale and efficiency of seawater CO_2 removal, the opportunity for Weymouth to contribute to emerging climate solutions, and the research team's transparent, accessible engagement approach. Participants consistently sought further clarity about marine ecosystem impacts, energy use and carbon accounting, the fate of captured CO_2, and what scaled-up deployment might look like. Feelings about future research were broadly positive but conditional: respondents emphasised the need for clear purpose, honest discussion of uncertainties and potential harms, and ongoing opportunities to stay involved.

The next phase of this work aims to co-develop and user-tests a guidance document that presents a structure to the process of engagement for mCDR field trials which we hope can be useful for trials across the globe. We would love to engage those of you who have, or have been thinking about, trialing mCDR techniques.

Physical controls on alkalinity variability in Halifax Harbour: The roles of wind and tides

Presenting Author: Dr. Hadar Berman – Dalhousie University, Postdoctoral employee
Co-Authors: Arnaud Laurent, Sean Morgan, Dariia Atamanchuk, Ruby Yee, Ruth Musgrave, Katja Fennel

Abstract:
Ocean Alkalinity Enhancement (OAE) is a promising method for marine carbon dioxide removal. By artificially increasing ocean alkalinity, OAE triggers chemical reactions within the carbonate system that reduce oceanic pCO_2 levels, thereby inducing an uptake of atmospheric CO_2 by the ocean. However, as alkalinity concentrations at the point of release can reach high levels, alkalinity addition is limited for environmental safety to ensure pH < 9. Pronounced alkalinity variability was observed in the Halifax Harbour (Canada), an operational OAE site since 2023. This variability is characterized by alternating high and low values with substantial differences in magnitude. Understanding the processes that generate this variability is essential for controlling its intensity and advancing toward optimized dynamic dosing strategies to maximize dosing while remaining within safe regulatory limits.

Observations of carbonate system parameters collected during and outside dosing periods in the Halifax Harbour provide a unique dataset to determine which factors control the occurrence and magnitude of the alkalinity variability. We combine in situ measurements with numerical modeling using the Regional Ocean Modeling System (ROMS), customized for the Halifax Harbour and implemented with a nested grid configuration (50–900 m horizontal resolution). We use a series of numerical simulations under different wind scenarios to examine the coupled effects of winds and tides on alkalinity dispersion. Our results show that the concentrations of added alkalinity are primarily controlled by tidal variability on daily and monthly timescales. Wind effects act as a secondary control, modulating tidal patterns and causing notable deviations, particularly during neap tides. Winds directed toward the open ocean enhance dispersion, whereas winds blowing into the basin tend to retain alkalinity near the release site, leading to higher local concentrations.

Field testing of ISFET-based pH and Total Alkalinity sensor

Presenting Author: Dr. Ellen Briggs – UCSD, Scripps Institution of Oceanography Research Engineer

Abstract:
We have demonstrated the proof of concept and field deployment of a solid-state, reagentless sensor capable of rapid and near-simultaneous measurement (<60 s) of pH and Total Alkalinity (AT). This pH−AT sensor utilizes ion-sensitive field-effect transistor pH-sensing technology coupled with a coulometric diffusion titration technique to additionally measure AT. Measuring 2 carbon parameters enables full constraint of the carbonate system setting this sensor apart from currently available observing technologies. In the latest, simplified 'dip probe' sensor design, a sensor error of 2.85 µmol kg−1 AT was achieved over 131 measurements by averaging (N = 5). Here we will report on recent field testing of the pH-AT sensor at multiple sites including Ebb Carbon's Macoma location in WA and in Bodega Bay, CA. The sensor was deployed at both the intake and outfall during normal operation and elevated pH experiments at the Macoma site demonstrating great value in having high frequency measurement capability as pH and AT varied rapidly over large extremes (~7.8 – 11.5 pH and ~2000 – 2800 µmol kg−1). The sensor was also used in mesocosm studies and in situ measurement in seagrasses in Bodega Bay for better

understanding carbon storage capacity associated with seagrass ecosystems. Future work in planned to monitor the mesocosms with the pH-AT probe during olivine dispersal.

Leveraging a High-Resolution Regional Model, EOFs, and Observations for MRV of the Halifax Harbour OAE site

Presenting Author: Jacob MacDonald – Dalhousie University, Student
Co-Authors: Bin Wang, Arnaud Laurent, Henry Bittig, Sean Morgan, Dariia Atamanchuk, Ruby Yee, Ruth Musgrave, Katja Fennel

Abstract:
Ocean Alkalinity Enhancement (OAE) is ongoing in Halifax Harbour, a small, mid-latitude estuarine fjord in Atlantic Canada. The Harbour consists of the 70-m deep Bedford Basin and a 20-m deep, narrow channel connecting the Basin to the adjacent Scotian Shelf. Current modelling efforts with a 3-level nested Regional Ocean Modelling System (ROMS) produce hindcast and forecast simulations of the Harbour that have been instrumental for the early OAE trials and generating counterfactual cases to help quantify the amount of carbon removal achieved. While the deterministic model performs well overall, the harbour's complex dynamics can influence properties like the relationship between total alkalinity and salinity and cause the model to diverge from observations. Therefore, this project aims to reinitialize model simulations and forecasts by leveraging the rich set of existing observations to improve the model's accuracy and maintain its reliability for monitoring, reporting, and verification (MRV). Updated model fields are created by using available observations to optimally combine Empirical Orthogonal Functions (EOFs) of the model hindcast. The results of various EOF reinitializations demonstrate how different observation types and sampling schemes contribute to improving the model state and forecasts. These results are the first steps toward a formal observing system simulation experiment (OSSE) for Halifax Harbour in order to guide the optimal use of observing assets. This work aims to strengthen both modelling and observational aspects of MRV in the harbour.

Early results from an operational assessment of USV deployments in an MRV context

Presenting Author: Dr. Sam Monk – National Oceanography Centre, Applied Scientist for Sensors and Marine Technology
Co-Authors: Birkir Bárðarson, Audria Dennen, Anna Madlener, Christopher Pearce

Abstract:
Uncrewed Surface Vessels (USVs) have the potential to act as flexible and cost-effective sensor platforms for Monitoring, Reporting and Verification (MRV) at marine Carbon Dioxide Removal (mCDR) sites. Their ability to collect both persistent and mobile observations is particularly relevant across a range of Ocean Alkalinity Enhancement (OAE) implementation scenarios. Previous studies have demonstrated strong spatial heterogeneity in OAE and proxy plumes, highlighting the need for mobile measurements to capture system complexity. For example, during an OAE trial release, Wynn-Edwards et al. (2025) observed rapid dissolution of an NaOH plume within 7 m of the release site; spatial scales that are challenging to resolve using fixed moorings or models alone. Relative to crewed research vessels, USVs offer the potential for lower operational costs and improved suitability for sustained monitoring applications.

This poster presents initial results from USV missions conducted in Hvalfjörður, Iceland, during Röst Marine Research Center's local hydrodynamics study. The USV was a modified second-generation Open Ocean Robotics DataXplorer (Angus et al., 2022), deployed for the first

time with a sensor payload adapted for MRV studies, including underway pH and pCO_2 sensors, a winch-mounted CTD, and an ADCP.

USV missions were designed with increasing complexity to assess whether USVs could collect MRV relevant data in a dynamic shallow fjord environment. Initial tests were conducted in a sheltered bay north of Hvalfjörður, followed by deployments during a dye tracer study to evaluate its capacity to map plumes. Deployments were assessed on system performance, data quality, and operational considerations.

Results indicate that USV platforms can deliver repeatable, high-resolution measurements relevant to OAE for MRV. Lessons learned from deployment planning, launch and recovery, multi-platform operations, and data handling are highlighted, along with implications for scaling to longer duration operations. These initial trials inform future development of autonomous survey strategies, sensor payloads, and operational best practice for MRV. Collectively these findings demonstrate the potential USVs offer to support sustained, high resolution MRV observations that are challenging to achieve using conventional platforms.

Introducing OAEMIP: The Ocean Alkalinity Enhancement Model Intercomparison Project

Presenting Author: Dr. Lauren Moseley – OAEMIP Research Fellow, Carbon to Sea Initiative and Dr. Jens Daniel Müller – OAEMIP Research Fellow, Carbon to Sea Initiative
Co-Authors: David Keller, Mike Tyka

Low-cost, high-accuracy pCO_2 sensor for measurement of CO2 fluxes related to marine carbon dioxide removal (mCDR)

Presenting Author: Jessica Oberlander – Pro-Oceanus, Application Scientist
Co-Authors: Michael Veenstra, John Paul Sol Cruz, Dariia Atamanchuk, Sean Morgan, Aaron MacNeil, Christopher Johnson, Travis Thompson, Mark Barry

Abstract:
The ever-growing field of marine carbon dioxide (mCDR) research requires robust measurement tools for purposes of accurate monitoring, reporting, and verification (MRV) and carbon crediting. The current standard dissolved CO_2 sensor is large in size, costly, and utilizes a considerable amount of power. Thus, integration of these sensors on autonomous surface and submersible vehicles has been difficult for those involved in the mCDR field. However, with research focuses shifting away from global climate CO_2 measurements and towards understanding smaller, interannual changes in CO_2, new opportunities for sensor development are arising.

Here we present a new air-sea CO_2 sensor that can collect data in a range of applications, such as mCDR, with easy integration onto many small surface platforms. This new sensor operates on one-tenth the power and is less than a third of the cost of a traditional high-accuracy air-sea CO_2 sensor. Having been tested in an array of conditions and integrated within multiple platforms, including on an autonomous vehicle in Halifax Harbour during an ongoing mCDR field trial. This sensor has the potential to increase the understanding of air-sea CO_2 fluxes in many understudied environments, and to provide the needed accuracy for mCDR MRV and carbon crediting.

MULTI-TOPICAL

Near-field monitoring and 1D modeling of particle dynamics from an ocean alkalinity enhancement deployment

Presenting Author: Dr. Alexander Andriatis – MIT, Postdoctoral Associate

Abstract:
Constraining the uncertainty of parameters governing mCDR efficiency is key to developing trustworthy monitoring, reporting, and verification (MRV) frameworks. From field observations of an ocean alkalinity enhancement (OAE) deployment and a semi-analytical 1D model, we investigate the influence of alkaline particle sinking and dissolution on intervention efficiency. We deployed a novel instrument, the Real Time Size and Settling Velocity (RTSSV) sensor at Planetary's OAE deployment in Halifax, Canada. The RTSSV is the first instrument capable of making non-disruptive in-situ measurements of particle size and settling velocity, using two cameras to characterize suspended particles as small as 3 microns. We deployed the RTSSV on a gimbaled bottom lander along with a suite of instruments, including unmanned surface vehicles and high-resolution ADCPs, to characterize the near-field dynamics of an effluent stream dosed with MgO particles. Observations of particle size distribution, settling rate, turbulence, and stratification are used to inform a low-order 1D model that tracks the evolution of dissolved inorganic carbon (DIC) and total alkalinity (TA) through coupled effects of particle dissolution, sinking, vertical mixing, and air-sea gas exchange. Computational efficiency of the model allows us to rapidly examine how uncertainties in particle properties and mixing dynamics contribute to uncertainty of intervention efficiency estimates. Our work highlights the need for targeted observations and process studies to improve the accuracy of MRV for mCDR.

Topics: Alkalinity Generation & Dispersal, CDR Quantification, MRV Observations & Modeling

Ocean Alkalinity Enhancement field research in Australia

Presenting Author: Dr. Lennart Bach – University of Tasmania, Associate Professor

Topics: Alkalinity Generation & Dispersal, Biological & Environmental Impacts, CDR Quantification, MRV Observations & Modeling

Identifying Barriers in mCDR Development in Canada and Potential Strategies for Addressing Them: Insights from Collaborative Workshop

Presenting Author: Tim Bachiu – Net Zero Atlantic, Director of Research
Co-Authors: Nicolle Jaramillo

Abstract:
There are numerous barriers to the advancement of mCDR technologies in Canada, including uncertainties around environmental and ecological outcomes, economic viability, social acceptability, technological readiness, regulatory and policy frameworks, and required resources and inputs. These barriers and potential actions to address them were examined during a workshop held in Halifax, Nova Scotia on December 4, 2025. Participants included regulators, project developers, academic researchers, community organizers, funders, and non-governmental organizations, who contributed diverse perspectives to identify key research and collaboration needs. This poster summarizes the barriers and proposed actions identified through that workshop, as well as commonalities across themes and intersections between actions.

Topics: Community & Public Engagement, Funding & Fieldbuilding, Governance & Policy

A low-cost floating chamber for coastal air–sea CO_2 flux measurements to support mCDR MRV

Presenting Author: Dr. Emily Chua – Dalhousie University, Postdoctoral Research Fellow
Co-Authors: Ruth Musgrave, Thomas Peacock, Alexander Andriatis

Abstract:
Accurately quantifying air–sea CO_2 fluxes is critical for verifying the efficacy of emerging marine carbon dioxide removal (mCDR) methods. However, existing flux measurement techniques are costly, complex, and difficult to deploy at scale, while commonly used gas-exchange parameterizations perform inadequately in nearshore regions where many mCDR methods are being implemented. To address this challenge, we are developing a scalable, low-cost platform for direct coastal measurements of air–sea CO_2 fluxes. The system leverages commercially available CO_2 forced-diffusion flux chambers (Eosense Inc.), which employ a membrane-based approach with simplified components and lower power requirements than conventional designs. Although originally intended for soil flux measurements, these chambers provide a promising foundation for aquatic applications. To enable deployment in coastal environments, we are integrating the chambers into a low-drag floating drifter designed to minimize flow disturbance and measurement artifacts. Initial laboratory experiments at MIT assessed chamber performance against independent CO_2 sensors under controlled CO_2 perturbations, demonstrating successful measurement of air–water fluxes under idealized conditions. Ongoing work focuses on characterizing the effects of platform-generated turbulence on flux measurements through wave-tank experiments. Field deployments are planned for summer 2026 at Planetary's ocean alkalinity enhancement site in the Bedford Basin to assess system accuracy and robustness in a controlled nearshore setting. By enabling accessible, direct measurements of air–sea CO_2 fluxes, this platform has the potential to strengthen monitoring, reporting, and verification (MRV) capabilities and support rigorous evaluation of a wide range of mCDR projects.

Topics: CDR Quantification, MRV Observations & Modeling

From Ocean Acidification to Ocean Alkalinity Enhancement: Hakai Institute's Integrated Research Capacity

Presenting Author: Dr. Wiley Evans – Tula Foundation / Hakai Institute, Research Scientist
Co-Authors: Iria Gimenez

Abstract:
The Hakai Institute operates coastal observatories on Calvert Island and Quadra Island, British Columbia — regions ideal for exploring marine carbon dioxide removal (mCDR) owing to their cold, weakly-buffered seawater. The Calvert Coastal Observatory is in the Great Bear Sea; the Quadra Coastal Observatory sits at the nexus between the Strait of Georgia, Bute Inlet, and Johnstone Strait. Both regions are dynamic, where water masses with distinct carbonate chemistry signatures converge, requiring a strong observing approach to constrain. Hakai Institute has this strength, in both observing and experimentation, and has produced the longest coastal record of surface pCO_2 in western Canada — establishing baseline conditions and resolving short-term variability. Combining data from sensors, surveys, and ships-of-opportunity, this integrated network provides coverage across spatial and temporal scales and is well positioned for the observation-based monitoring, reporting and verification needed for mCDR studies. Our Wet Lab facility at the Quadra

Coastal Observatory is uniquely suited for experimental studies replicating the variable conditions of coastal ecosystems. Its 40 large-volume flow-through mesocosms offer dynamic control of temperature, light, and pCO_2, and have supported work across algae, echinoderms, mollusks, crustaceans, and fish at all life stages. A dedicated lower-volume system — developed from Hakai's experience conducting some of the first rigorous decoupling of carbonate parameters (high alkalinity) to investigate biological sensitivity to ocean acidification — dynamically manipulates chemistry via alkalinity/acid additions, with real-time full carbonate system characterization, making it well-suited for ocean alkalinity enhancement (OAE) experiments. Monitoring data directly inform experimental design, grounding experimental treatments in local conditions and realistic future projections. This combined expertise in ocean carbon observation and biological impacts has positioned Hakai in a leading role developing British Columbia's OAH Action Plan, and translates into a unique capacity to offer rigorous, regionally grounded insights and expertise in OAE.

Topics: Biological & Environmental Impacts, MRV Observations & Modeling

Efficacy and environmental safety of enhanced silicate and carbonate weathering in benthic marine environments for ocean alkalinization

Presenting Author: Dr. Gunter Flipkens – University of Antwerp, Belgium, Postdoctoral researcher
Co-Authors: Astrid Hylén, Matthias Kreuzburg, Saïd De Wolf, Laurine Burdorf, Géraldine Fiers, Luna Geerts, Hannelore Theetaert, Sebastiaan van de Velde

Abstract:
Mineral-based ocean alkalinity enhancement (OAE) is a promising carbon dioxide removal strategy for long-term oceanic carbon storage. Enhanced benthic weathering of silicate and carbonate minerals accelerates natural climate-regulating weathering by distributing finely ground reactive materials in coastal environments, where hydrodynamics, microbial metabolism, and bioturbation may stimulate dissolution. We evaluated mineral-specific efficacy and environmental safety using experimental systems simulating contrasting benthic settings. Benchtop reactors mimicking bedload transport show that hydrodynamic forcing substantially enhances dissolution of both freshly mined and naturally weathered silicates, highlighting the importance of dynamic coastal environments for silicate-based OAE. Among tested materials, kimberlite and basalt exhibited lower trace metal-to-alkalinity release ratios than olivine, indicating a potentially lower ecological risk. In benthic mesocosms simulating 1 m^2 of natural seafloor, olivine dissolution in bioturbated sediments was markedly slower than under bedload conditions. Olivine addition also suppressed natural sedimentary alkalinity generation, reducing net alkalinity additionality. Nickel was largely retained in sediments but bioaccumulated in benthic fauna, increasing with decreasing olivine grain size. For carbonate minerals, dissolution occurs within microbially acidified surface sediments. Mesocosm experiments show that surface application of ground mussel shells significantly enhances sedimentary alkalinity efflux, without adverse effects on polychaete activity. Together, these results provide critical insights into dissolution kinetics, trace metal dynamics, ecological responses, and additionality of silicate- and carbonate-based OAE, informing the environmentally responsible deployment of benthic OAE in coastal systems.

Topics: Alkalinity Generation & Dispersal, Biological & Environmental Impacts

OAE in a bottle: Insight of the biological impact on seawater microbial communities - a mesocosm study

Presenting Author: Dr. Fanny Fronton – Dalhousie University

Co-Authors: Julie LaRoche, Hoang Nam Nguyen

Abstract:
Rising atmospheric CO2 has intensified interest in climate mitigation strategies, particularly Ocean Alkalinity Enhancement (OAE), which offers high CO_2 sequestration potential alongside ocean acidification mitigation. However, localized ecological impacts of elevated pH on microbial communities remain poorly studied. As pivotal ecosystem components, perturbations to these communities could yield far-reaching consequences. Conducted under the OAE Pelagic Impact Intercomparison Project (OAEPIIP), this study assessed NaOH and $NaHCO_3$-based OAE effects on microbes via a 19-day mesocosm experiment using Halifax Harbour surface water (44.6169, -63.5449) collected in late September. The Bedford Basin situation is unique in the world, as Planetary Technologies facilities is leading OAE $Mg(OH)_2$-based dosing directly in the water. Two treatments targeted a 500 µmol·kg−1 alkalinity increase were done: an equilibrated treatment simulating post air-sea gas exchange (HCO_3−-dominated) and an unequilibrated treatment representing pre-equilibration conditions. Monitoring encompassed alkalinity, pH, temperature, nutrients, particulate organic carbon/nitrogen (POC/PON), biogenic silica, and chlorophyll a, biological responses were evaluated using flow cytometry, imaging microscopy (FlowCam), and metabarcoding. Results indicated no biological impact in the equilibrated treatment. Conversely, the unequilibrated treatment showed modest but notable effects on phytoplankton biomass (increased POC/PON, chlorophyll a, biogenic silica, cell counts and species abundance) and bacterial composition (evidenced by β-diversity and differential abundance). Across all metrics, diatoms demonstrated resilience to elevated alkalinity, dominating the second bloom significantly more in the unequilibrated treatment. This initial assessment of OAE impacts on seawater communities provides a critical foundation for future research and informs policy development for OAE-based climate mitigation techniques.

Topics: Alkalinity Generation & Dispersal, Biological & Environmental Impacts

Salish Sea Integrated mCDR Research Initiative: Advancing Science-Based Marine Carbon Dioxide Removal in the Pacific Northwest

Presenting Author: Dr. Alexander Gagnon – School of Oceanography, University of Washington Associate Professor, Chemical Oceanography

Topics: Alkalinity Generation & Dispersal, Biological & Environmental Impacts, MRV Observations & Modeling

Regional Feasibility of OAE: Integrating Ecological, Economic and Policy Dimensions

Presenting Author: Dr. Patricia Grasse – iDiv Centre for Biodiversity Research, Senior Researcher
Co-Authors: Wilfried Rickels, Lotta Siebert

Abstract:
As we look toward an increasing number of in-water field trials for ocean alkalinity enhancement (OAE), there is growing need for approaches that connect scientific analysis with community perspectives and regional decision-making. Over four days, four in-person workshops were held in Port Angeles, WA, Victoria, BC and Vancouver, BC to explore how community members think about exploring OAE and direct ocean removal in their local coastal environment. Designed as a social-science research study led by American University in collaboration with physical ocean modelers from [C]Worthy, the workshops combined regional ocean biogeochemical modeling and physical and socio-political scenarios in a deliberative (discussion-based) format. A key innovation

was the development of plausible future deployment scenarios for the Salish Sea, ranging from research-scale pilots to larger regional deployments. These hypothetical scenarios were simulated using the C-Star ocean modeling framework, and results were shared directly with participants to support consideration of local trialing and deployment of carbon dioxide removal. From a [C]Worthy perspective, an important part of participating in the workshops was to learn more about how to better communicate highly technical information, to help folks understand what models can and cannot reveal, and to experience first-hand how model-based information interacts with community values, hopes, concerns, and questions. This talk offers early findings regarding Salish Sea community participants' priorities for mCDR development in the region, along with an overview of our engagement approach ranging from workshop design to scenario development to modeling results. More broadly, we consider how integrating physical modeling with participatory processes may help shape emerging norms for responsible governance of mCDR as the field evolves.

Topics: Alkalinity Generation & Dispersal, Biological & Environmental Impacts, CDR Demand & Markets

Geochemical perspectives on alkalinity enhancement - practical methods and their consequences

Presenting Author: Prof. Dr. Jens Hartmann – University of Hamburg, Professor
Co-Authors: Niels Suitner, Charly Moras

Abstract:
The poster summarizes results from a series of experiments with the purpose to determine the stability of added alkalinity to water along the salinity gradient in coastal zones, for different temperatures ranges, with a focus on the role of particles. The gained data can provide information for application of OAE and suggest in addition data gaps still existing. For example, in coastal areas the role of sediments their concentrations and quality need to be better understood. Stability of added alkalinity decreases with decreasing salinity, increasing temperature and abundance of particles.

Topics: Alkalinity Generation & Dispersal, CDR Quantification, MRV Observations & Modeling

Blue Carbon OAE as a Socially Ready and Measurable CDR Pathway

Presenting Author: Dr. Gabriella Kitch – Yale Center for Natural Carbon Capture, Marine Carbon Dioxide Removal Lead
Co-Authors: Nicolas Theunissen, Isabella Chiaravalloti, Mingyu Zhang, Kevin Kroeger, Mojtaba Fakhraee, Toby Bryce, Peter Raymond, Noah Planavsky

Abstract:
Mangrove forests deliver critical ecosystem services to coastal communities, including storm surge protection, fisheries support, and carbon sequestration in biomass and sedimentary organic carbon pools. Beyond organic carbon sequestration, restoration of these ecosystems also represents an underutilized and socially accepted pathway for carbon dioxide removal (CDR). Beyond organic carbon burial, mangrove ecosystems increase alkalinity through carbonate sediment dissolution and sulfate reduction coupled with pyrite burial, indicating their capacity to support durable (≥1000-year) CDR via ocean alkalinity enhancement (OAE). We refer to this process at Blue Carbon OAE. Incorporating these additional carbon fluxes into project accounting provides a pathway to enable CDR deployment beyond conventional carbon

markets, creating complementary financing mechanisms that can directly support long-term restoration. Mangrove-based Blue Carbon OAE is well suited for policy uptake and integration into existing coastal restoration frameworks, as it builds on established practices with well-documented co-benefits for climate adaptation, biodiversity, and coastal resilience. This alignment allows CDR to be pursued in parallel with mitigation and adaptation goals, while offering a low-risk and cost-effective source of alkalinity that can advance geochemical research and improve monitoring, reporting, and verification (MRV) for mCDR. Here, we present the practical strategies for monitoring alkalinity changes and their relationship to OAE MRV at large. We describe how Blue Carbon OAE can strengthen social and policy acceptance therefore accelerate community understanding and the uptake of OAE within broader climate strategies.

Topics: CDR Quantification, Funding & Fieldbuilding, MRV Observations & Modeling

Coastal alkalinity addition within safe environmental thresholds: numerical experiments in Halifax Harbour and surrounding areas (Canada)

Presenting Author: Dr. Arnaud Laurent – Department of Oceanography, Dalhousie University, Research Associate
Co-Authors: Katja Fennel, Frauke Kracke, Judy Savitskaya

Abstract:
Surface ocean alkalinity enhancement (OAE), through the release of alkaline materials (feedstock), is an emerging abiotic marine technology for marine carbon dioxide removal that could increase the storage of anthropogenic carbon in the ocean. Alkaline feedstock may, in theory, be released at any location in the surface ocean, but the use of pre-existing coastal infrastructures (e.g., sewage outfalls, cooling pipes) is cost efficient and lowers the emissions associated with the transport of feedstock. Release at these locations is regulated and needs to occur within safe environmental thresholds. It is therefore essential to understand how point source feedstock release alters the carbonate system to 1) maximize dosing while 2) ensuring the resulting perturbations remain within the safe zone of carbonate system parameters. Influencing factors may be the dosing level, the type of feedstock, pipe design and proximity of neighboring pipes, the background state of the carbonate system, and local circulation. Given the spatial distribution of some of these factors, their importance may vary regionally. Here, we use a coupled physical-biogeochemical model that is specifically designed for coastal OAE research to investigate where and how dosing can breach environmental thresholds in the Halifax Harbour and surrounding coastal areas. Simulations with various dosing rates and release sites are carried out and their results analyzed with respect to environmental thresholds (pH>9, precipitation risk). Benthic exposure to feedstock (particulate phase) is also considered.

Topics: Alkalinity Generation & Dispersal, Biological & Environmental Impacts, MRV Observations & Modeling

OAE Data Commons & Tools: Live Demo

Presenting Author: Jacki Long – Submarine Scientific, Co-Founder

Topics: Funding & Fieldbuilding, CDR Quantification, MRV Observations & Modeling

The Critical Alkalinity Period: how the CAP dictates OAE's efficienciy, understanding and identifying OAE's application pitfalls

Presenting Author: Dr. Charly A. Moras – University of Hamburg, Postdoctoral Research Associate
Co-Authors: Matias Saez, Peggy Bartsch, Jens Hartmann

Abstract:
Ocean alkalinity enhancement (OAE) is presented as a method of choice with high carbon dioxide removal (CDR) potential. But unwanted secondary mineral formation may occur when high alkaline environments are maintained for sustained periods of time, e.g., in the diffusive boundary layers of dissolving particles or at the alkalinity release site, decreasing its CDR potential. This is what we labelled the "Critical Alkalinity Period" – CAP.

While dilution and filtration may decrease the CAP duration, another overlooked ally is CO_2 ingassing, which is mostly missing in current OAE laboratory experiments, despite being a key player in real-world application. To bridge such a gap, we conducted long-term experiments, opened to the air, investigating the dissolution kinetics of two minerals of interest for OAE, i.e., $Ca(OH)_2$ and $Mg(OH)_2$, and controls with sodium hydroxide. Bottles were also either kept static or exposed to circular advection.

This low yet more realistic advection led to lower alkalinity generation. Calcium carbonate (CaCO3) and magnesium hydroxide precipitation was also observed, decreasing the CDR potential, though not as severely as previously reported. Also, a new precipitation pattern was identified where instead of entering a runaway fashion, the process quickly stopped within days, maintaining positive CDR potential. This was later linked to CO_2 ingassing, which quickly shortened the CAP, as one could expect in natural settings.

Hence, this research supports that OAE implementation is less likely to trigger $CaCO_3$ formation compared to observations made in laboratory setups. Our experiments were representative of calm open ocean conditions with wind speeds of ~3 m s-1. Despite the low wind speed, the persistence of positive CDR potential suggests that implementing OAE in rougher seas may lead to optimum CDR. The stronger water disturbances would lead to higher dissolution rates, while the stronger CO_2 ingassing would limit $CaCO_3$ precipitation.

Topics: Alkalinity Generation & Dispersal, CDR Quantification

How temperature and salinity shape ocean alkalinity enhancement performance: experimental insights and modeling implications

Presenting Author: Matias Saez – University of Hamburg, PhD Student
Co-Authors: Janine Börker, Peggy Bartsch, Jens Hartmann , Charly A. Moras

Abstract:
Ocean alkalinity enhancement (OAE) is a promising carbon dioxide removal approach, yet major uncertainties remain on how temperature (T) and salinity (S) influence mineral dissolution and carbonate formation. Most laboratory studies focus on specific conditions, limiting comparability, while ocean models often assume that added materials dissolve instantly and completely. This overlooks the T–S dependence of dissolution kinetics and can lead to overestimations of carbon-uptake potential.

We address these gaps through the first systematic assessment of the dissolution behavior of three OAE feedstocks, $NaHCO_3$, Ca(OH)2 and $Mg(OH)_2$, across 16 T–S combinations. Experiments

were conducted under semi-open conditions that allowed frequent CO_2 ingassing, providing insights of the effects of T and S on both mineral dissolution and precipitation kinetics. Based on these results, we developed empirical parameterizations of alkalinity addition (fTA) as functions of T, S and time for each material.

NaHCO3 dissolved rapidly under all conditions, showing minor T–S sensitivity. In contrast, hydroxides were strongly influenced by environmental changes. While runaway precipitation occurred at high T and S, in most cases the alkalinity generation was reduced but remained stable over time, likely explained by the buffering effect of CO_2 ingassing. $Ca(OH)_2$ performed better in colder environments but declined sharply with increasing T due to partial precipitation, making high-latitude regions most suitable for implementation. $Mg(OH)_2$ was also most effective in colder waters but dissolved more slowly and steadily across environments, performing better than $Ca(OH)_2$ in temperate and tropical regions.

The resulting fTA functions offer conservative bounds on the alkalinity that can be sustainably delivered under given T–S conditions. Integrating these functions into ocean models can support more realistic assessments, improve site selection and monitoring, and enhance the safe scaling of OAE.

Topics: Alkalinity Generation & Dispersal, MRV Observations & Modeling

C-Star: scientific, reproducible model evaluation of marine carbon dioxide removal (mCDR) siting, effects, and efficacy

Presenting Author: Dr. Benjamin Saenz – [C]Worthy, Head of Applications
Co-Authors: Ulla Heede, Abigale Wyatt, Scott Bachman, Dafydd Stephenson, Sam Maticka, Christopher McBride, Scott Eilerman, Nora Loose

Abstract:
Marine carbon dioxide removal (mCDR) shows promise as a scalable method for storing excess anthropogenic carbon in the ocean. However, ocean circulation and the large amount of carbon already stored by the oceans present challenges for evaluating the impacts and efficacy of mCDR activities. Minutes to days after an mCDR intervention, its environmental signal can become indistinguishable from background noise. Thus, further evaluation must be conducted using modeling tools that can track the intervention and resolve biogeochemical carbon transformations and air-sea gas exchange. The open-source C-Star software stack, engineered by [C]Worthy, streamlines the setup and use of nested, state-of-the-art regional oceanographic models to enable siting assessment and carbon accounting for mCDR. C-Star can be used to build and execute scientifically credible and reproducible workplans tailored to different computational environments and includes tools for rapid analysis of environmental and mCDR metrics such as efficiency over time. Current applications of C-Star include generation of community outreach materials, direct evaluation of Ebb Carbon's alkalinity enhancement trial in Port Angeles, WA, USA, and examining the potential environmental response to mCDR activities in Hvalfjörður, Iceland. Metrics from these experiments, including maximum environmental pH, alkalinity and DIC retainment and mixing, and atmospheric CO_2 uptake and CDR efficiency, can be evaluated using uncertainty ensembles, optimized to reduce total compute resources. Additional applications for C-Star include rapid development of regional models to support conservation, coastal planning, aquaculture, and 'blue economy' endeavors.

Topics: Biological & Environmental Impacts, CDR Quantification, MRV Observations & Modeling

An appeal (and suggestions) for integrating the commercial fishing industry into the OAE field

Presenting Author: Sarah Schumann – Fishery Friendly Climate Action, Campaign Director

Abstract:
The mCDR/OAE community recognizes the importance of engaging coastal stakeholder communities early and often in project design, research agenda-setting, and siting and permitting processes. But there have been few opportunities for affected stakeholders to communicate directly to the mCDR/OAE community at-large about how these stakeholders would like to be involved in these activities, and what kinds of support they will need in order to participate productively. The presenter of this poster is a commercial fisherman who has spent two years interfacing with the mCDR/OAE research and field-building community, raising awareness and collecting input from the US commercial fishing community (through interviews, focus groups, and co-writing exercises), and closely observing the LOCNESS field trial. In this poster, she will draw on these experiences to shed light on how the commercial fishing industry interprets responsible and irresponsible mCDR/OAE and how its members would like to be involved in the OAE field as it matures. Recognizing that there is no one-size-fits all approach and that every member of this community should have the right to speak for themselves, the presenter will not prescribe a framework. Instead, she will extract lessons from her ongoing work with members of her industry to provide suggestions for engagement and co-design aimed at (a) OAE research projects, (b) funders, (c) field builders, and (d) public and private governance actors (including regulatory agencies and standards-setting entities).

Topics: Community & Public Engagement, Funding & Fieldbuilding, Governance & Policy

Progress Towards Quantifying Alkalinity Dissolution Through Particle-Based Measurements

Presenting Author: Kirby Simon – Sequoia Scientific, Inc., Science & Technology Lead
Co-Authors: Ole Mikkelsen

Abstract:
Mineral-based ocean alkalinity enhancement (OAE) is one of the most promising marine carbon dioxide removal (mCDR) strategies, however many knowledge gaps still exist that need to be addressed before OAE can be considered for deployment on global scales. For example, the dissolution rate of alkaline material (feedstock) is a critical area of research. Dissolution rates are largely modeled using simplifying assumptions about particle properties, and there are few reports of measured (laboratory or field) dissolution rates; this creates uncertainty in model and experimental validation when scaling mineral-based OAE to the field. Additionally, these rates are significantly impacted by feedstock-specific properties, including composition, particle size distribution, particle shape, and concentration. These properties vary in space and time after dosing as the feedstock transports and dissolves. They will also vary between feedstock type, source, and upstream processing steps. Therefore, a thorough understanding of feedstock particle properties and how these properties change as the feedstock dissolves is necessary to produce more accurate dissolution models and to better contextualize laboratory and in-situ measurements of alkalinity dissolution.

Here we will present results from laboratory experiments using optical sensors developed by our team at Sequoia to measure key feedstock properties (particle size, size distribution, concentration) and how these properties evolve during alkalinity dissolution. We will use these measurements to estimate alkaline material dissolution rates of different feedstocks and compare

these rates to experimental and modeled rates found in literature. Finally, we will demonstrate how these laboratory measurements can complement and inform in-situ monitoring strategies for assessing the efficacy of an OAE intervention.

Topics: Biological & Environmental Impacts, MRV Observations & Modeling