Lab, mesocosm, and field trials for electrochemical ocean alkalinity enhancement

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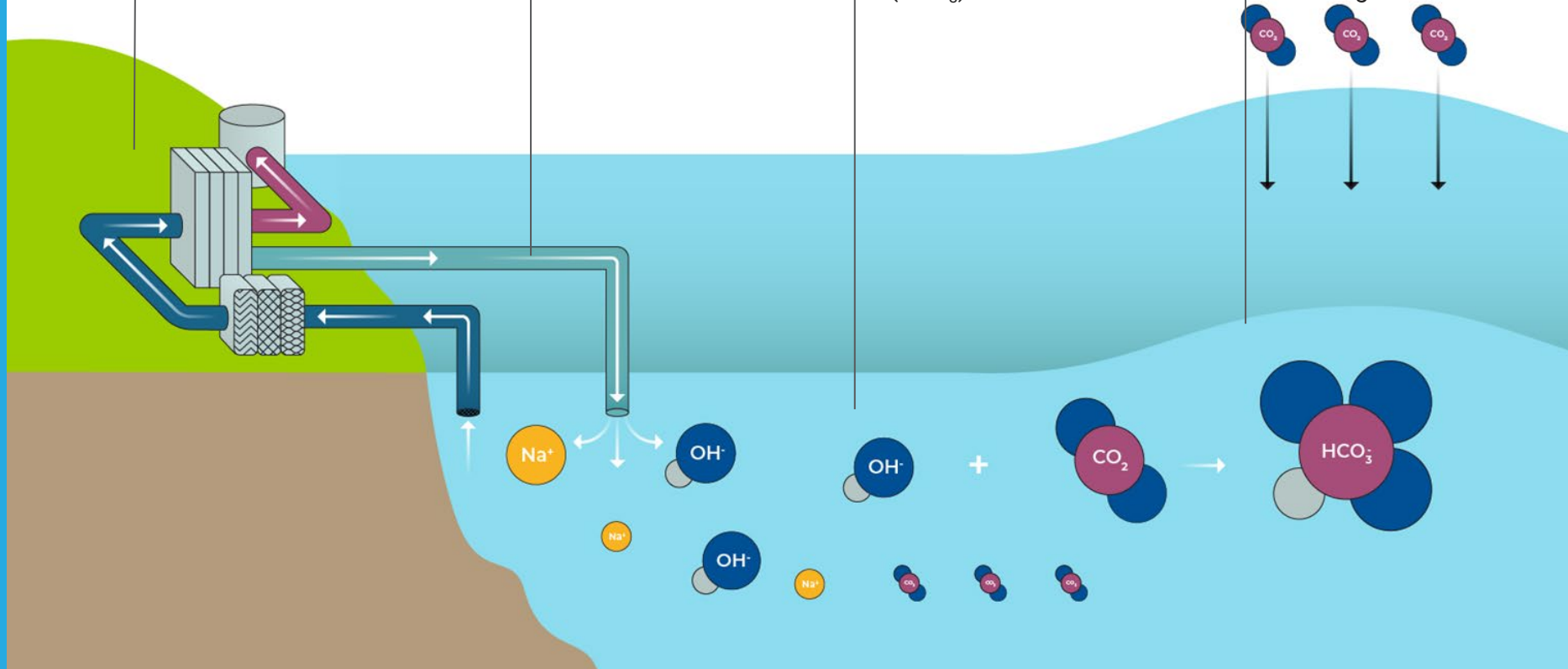
Electrochemical Ocean Alkalinity Enhancement

1. Ebb's process separates (saltwater brine into acidic (HCl) and alkaline (NaOH) streams
2. Alkaline stream (NaOH) is measured and monitored as it returns to the ocean
3. CO_2 concentration of seawater lowers as alkalinity (OH^-) reacts with dissolved CO_2 to form bicarbonate (HCO_3)
4. Additional CO_2 is removed from the atmosphere through air-sea gas exchange



Our Journey

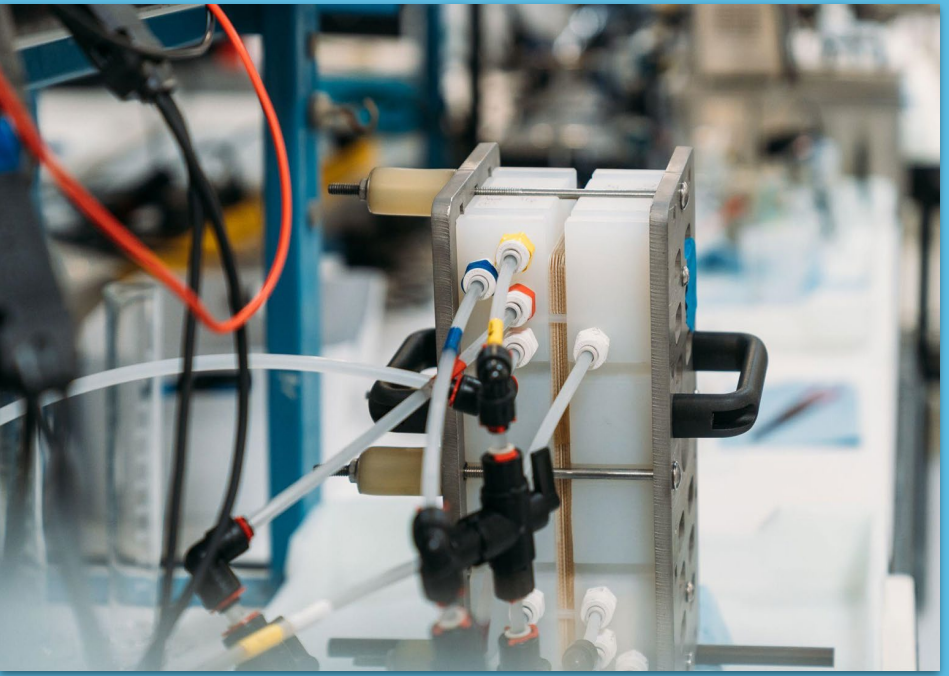
Technology development

Public-private partnership demonstration

Research pilots

Integrating with existing coastal infrastructure

Technology development



Demonstration at PNNL-Sequim

Including Electrochemical Acid Sequestration to Ease Ocean Acidification (EASE-OA)

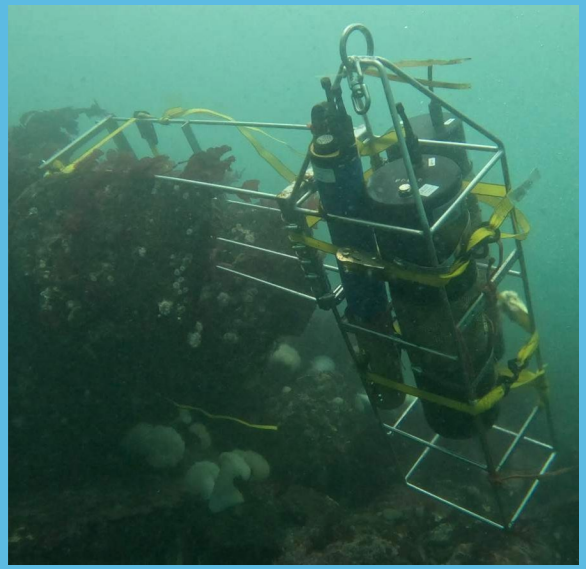
U.S. DEPARTMENT OF ENERGY

NOAA

Pacific Northwest NATIONAL LABORATORY

PMEL

UNIVERSITY of WASHINGTON



Demonstration at PNNL-Sequim

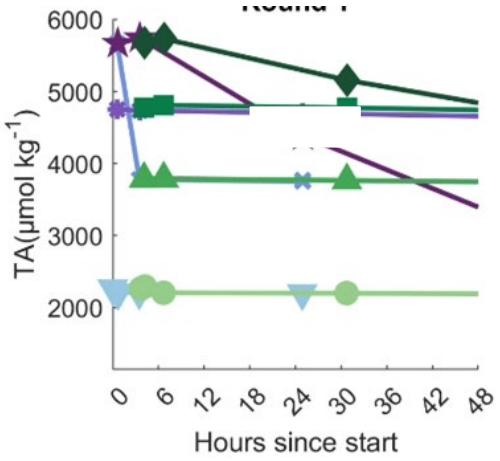
Field trials
- Savoie et al. 2025, *in press*: FOAK release of electrochemically generated alkalinity to Sequim Bay

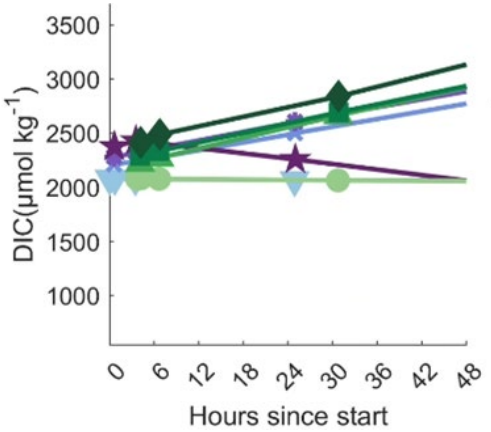
Efficiency
- Savoie et al., *in preparation*: Description of mesocosm experiments throughout EASE-OA program
- In progress experiments on secondary precipitation

Species response
- Jones et al. 2024: Eelgrass epifauna response to elevated alkalinity

Modeling
- Khangaonkar et al. 2024: Salish Sea Model simulations of hypothetical OAE in Sequim Bay
- Use of PLUMES 2.0 in modeling near-field

Novel acid uses
- Hibbeln et al., 2024: Acid use in marine algae cultivation
- Mineral extraction from brines






Vancouver
Washington
Oregon
California
100 km
Port Angeles
Sequim
5 km
PNNL-Sequim
Port Angeles Project Macoma

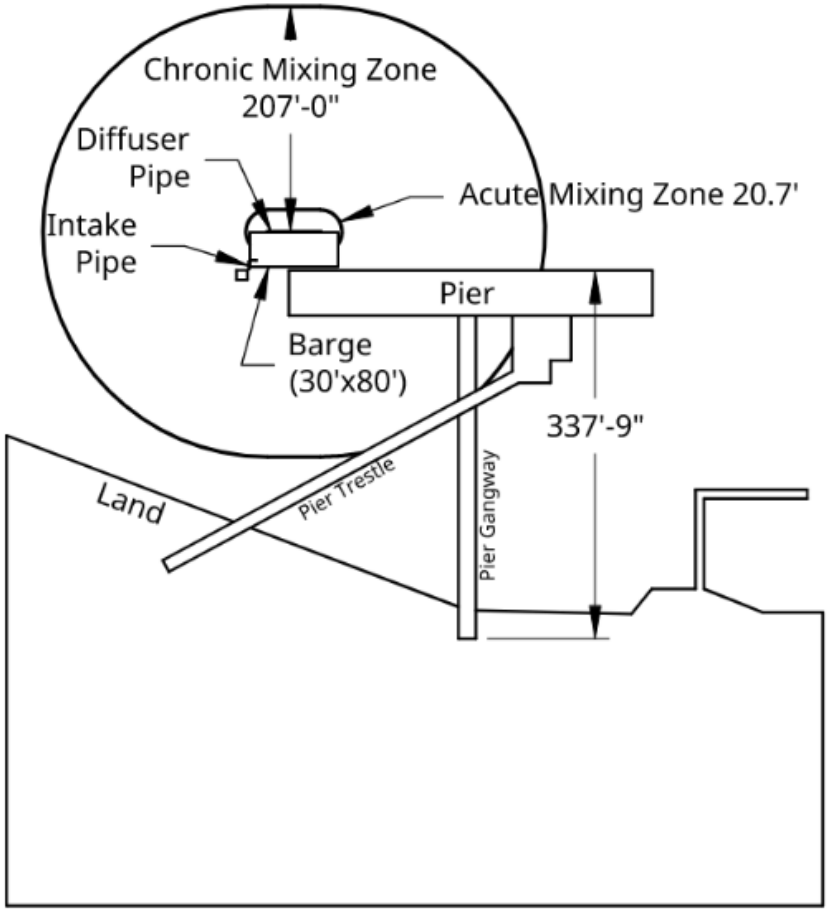

project
macoma


project
macoma
Seawater intake +
outfall
Desalination
integration
Electrochemical
processing
HCl processing

Project Macoma

First of a kind NPDES permit for mCDR under the Clean Water Act

- Alkaline-enhanced seawater may be released up to pH 9.8 under routine operations within a mixing zone
- Water quality must meet excellent standards by the edge of the chronic mixing zone
- 10 local, state, federal permits required to operate



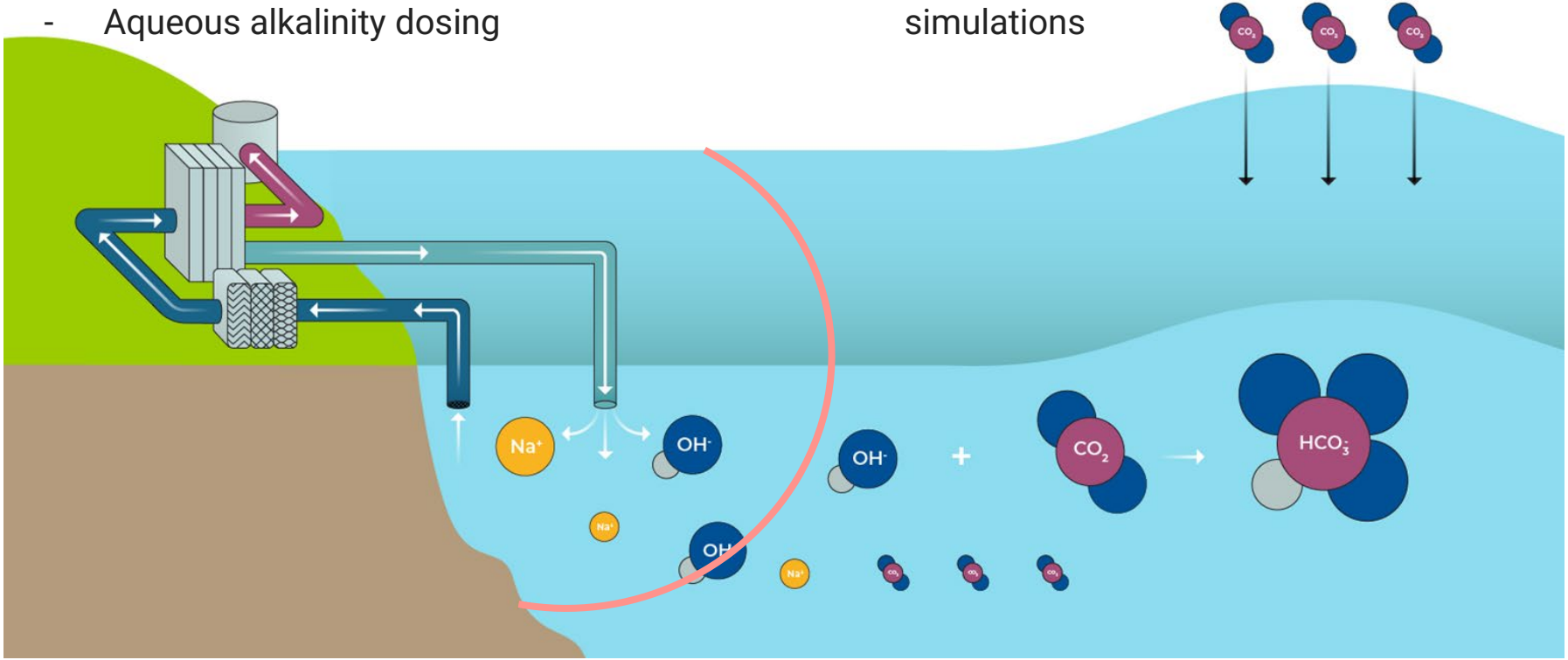
PLAN VIEW
SCALE 1:2000

Near-field:

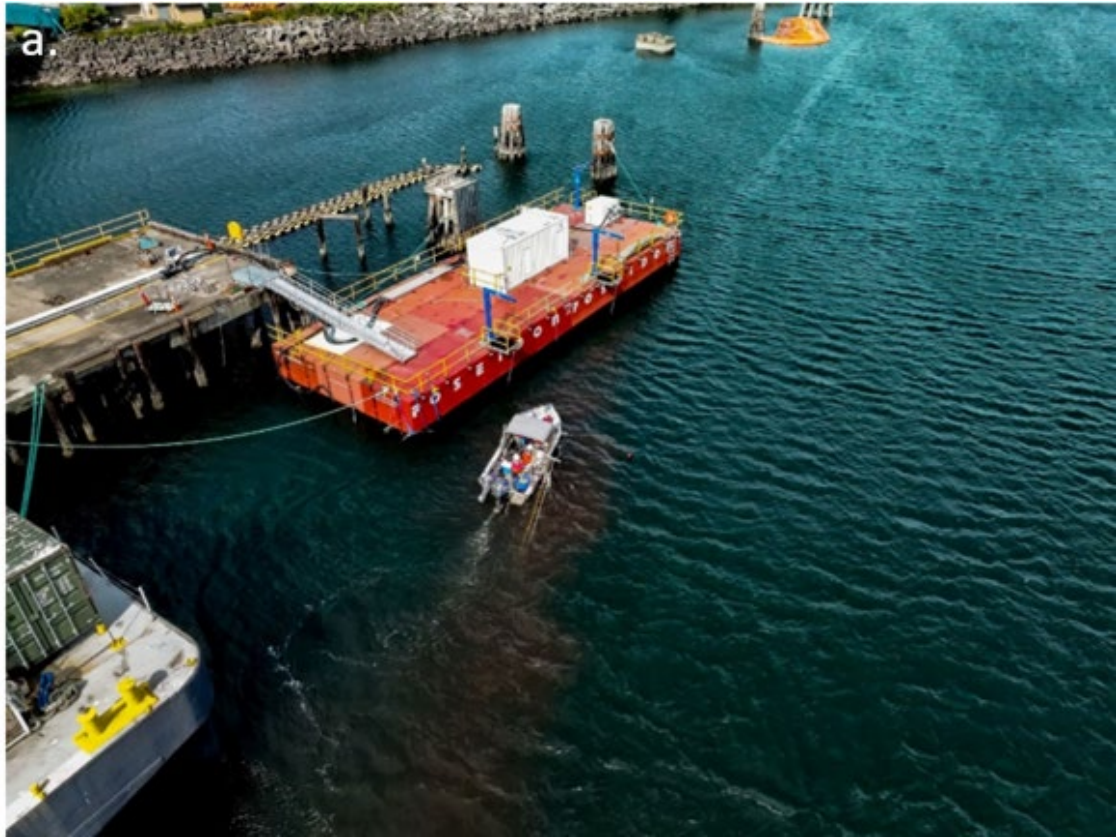
- Systems monitoring
- Near-field dilution modeling
- Environmental baseline measurements
- Ecosystem safety
- Aqueous alkalinity dosing

Further afield:

- Regional oceanographic modeling to track movement of the alkalinity plume and subsequent air-sea gas equilibration relative to counterfactual simulations



Dye tracer study



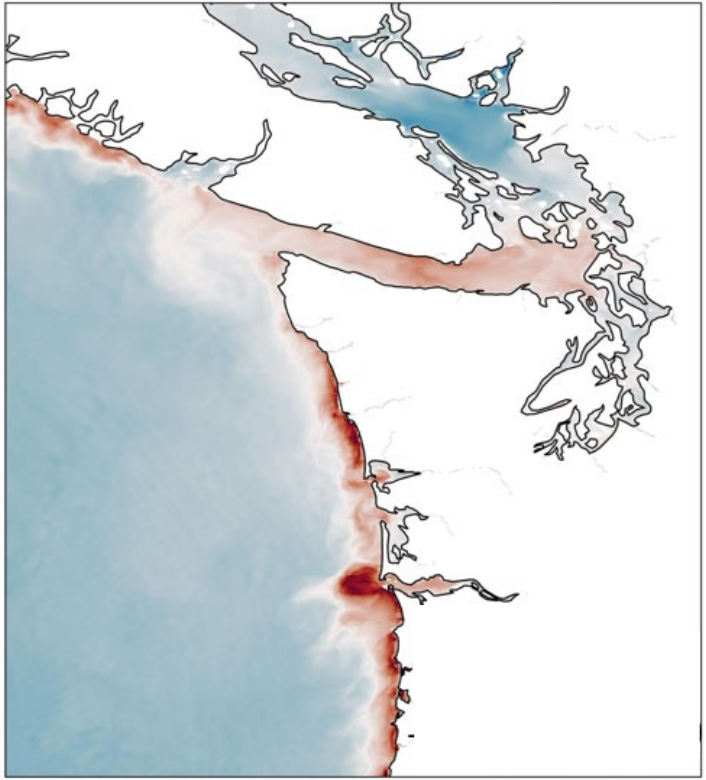
- Dye released through diffuser and observed in-situ:
  - Long-term ADCP records
  - Outfall samples
  - Surface underway measurements
  - Water column CTD + fluorometry
- Model accurately predicts dilution with distance from the diffuser

Regional ocean modeling to calculate gross CDR

(1) **Baseline simulation:**
- Simulation of historical conditions without Project Macoma

(1) **OAE simulation:**
- Adds alkalinity to represent the OAE deployment
- Compared against the baseline to evaluate carbon storage over time

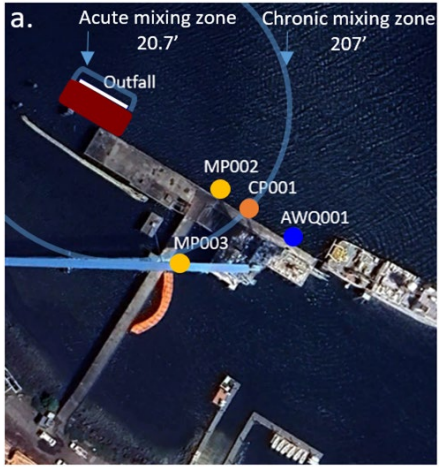
(3) **Uncertainty assessment:** OAE simulations across seasons and years generate a holistic range of uncertainty

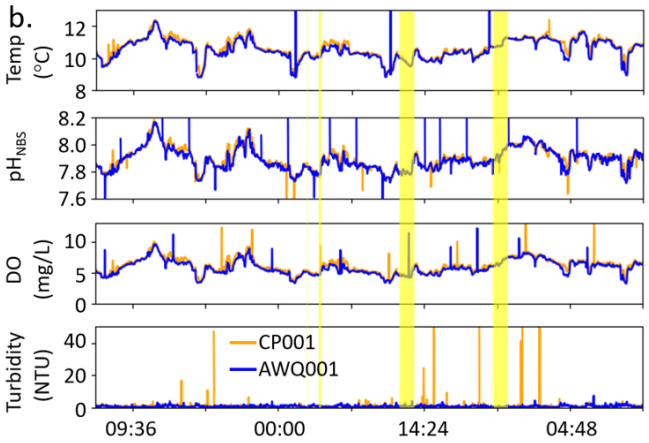


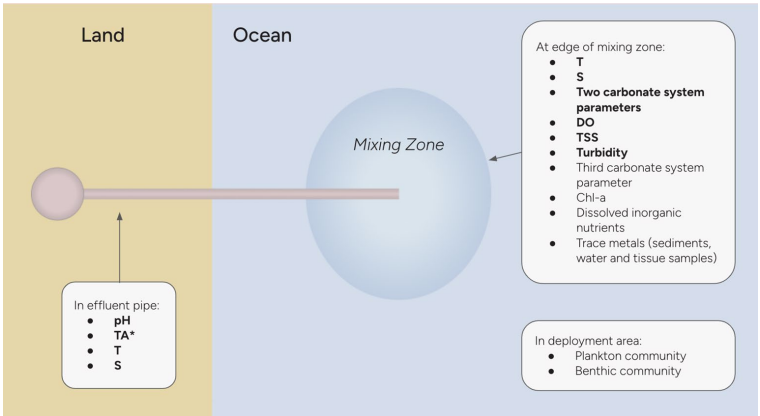
University of Washington LiveOcean ROMS

In-situ measurements

Water quality sensing and sampling to ensure environmental protection and regulatory compliance



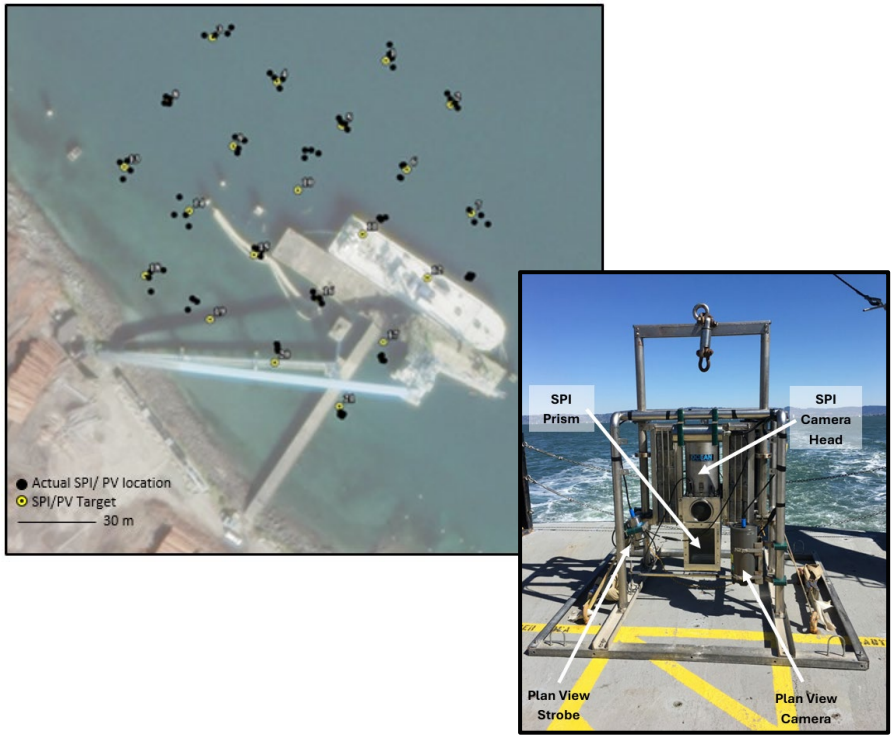




Additional scientific sensing following Isometric protocol for OAE from Coastal Outfalls

Developing an Ecological Safety Methodology

Aquatic vegetation survey



Sediment Profile Imaging

Developing an Ecological Safety Methodology

Ex-situ salmon study

In-situ shellfish study

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Extras

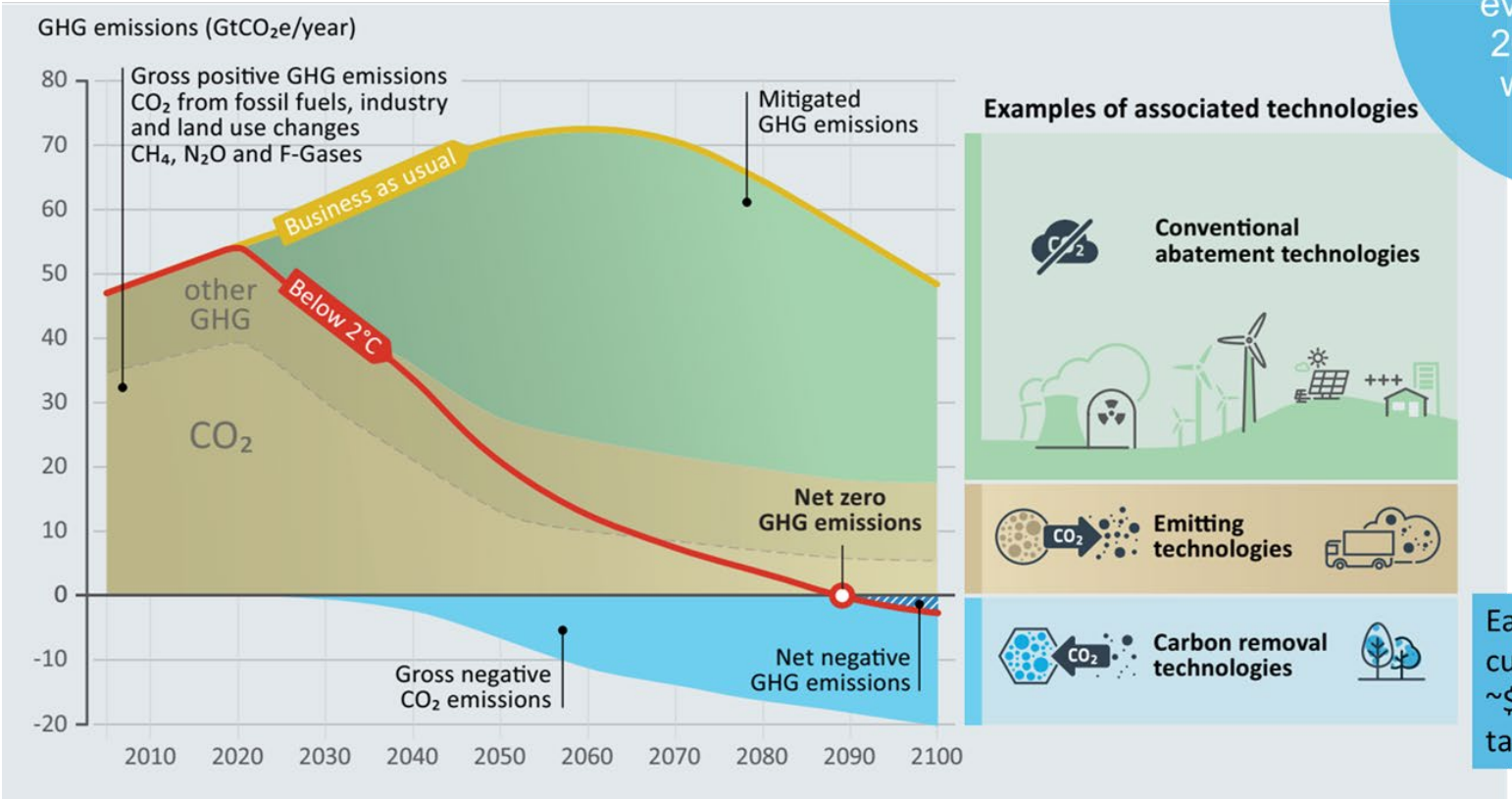
We are Ebb Carbon

Ebb Carbon is a climate and ocean health company.

Our mission is to remove billions of tons of legacy CO_2 pollution while addressing coastal acidification.

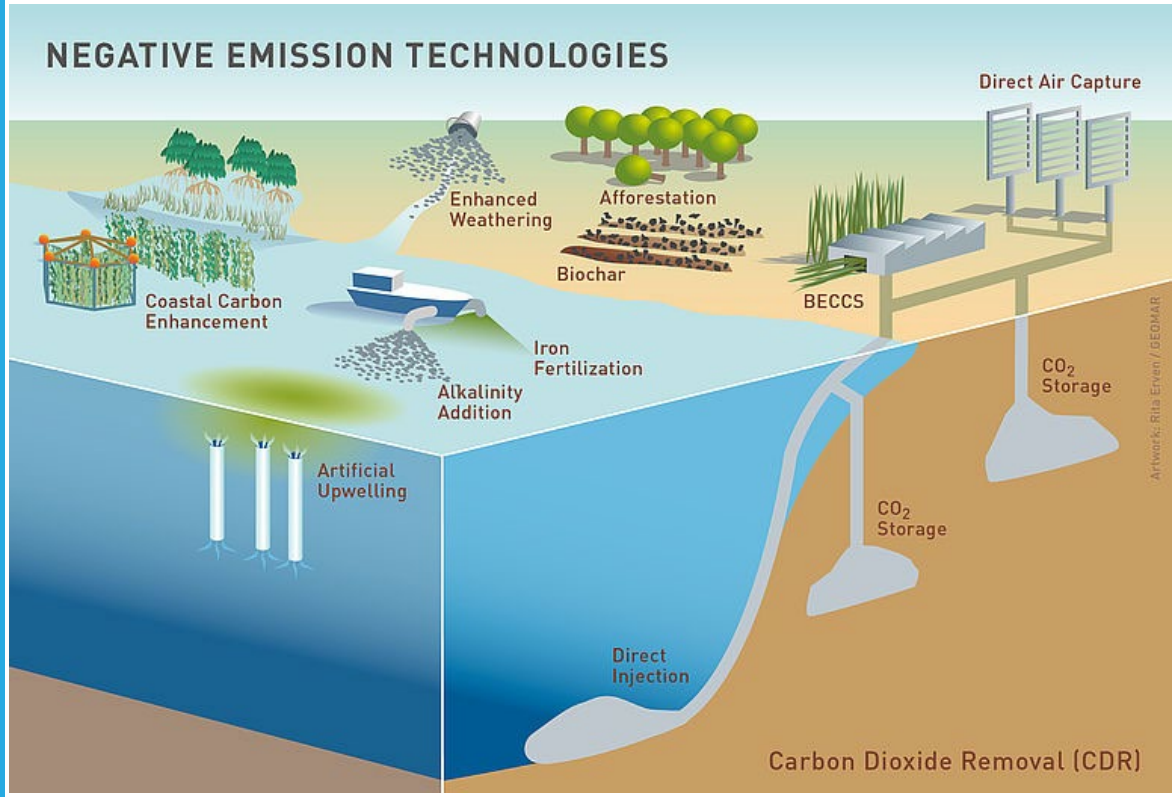
Emissions and Carbon Dioxide Removal

We must remove 5-15 Gt of atmospheric CO_2 every year by 2050 to limit warming to 1.5°C.



Each ton of CO_2 currently costs ~$500-2000, with a target of <$200/ton

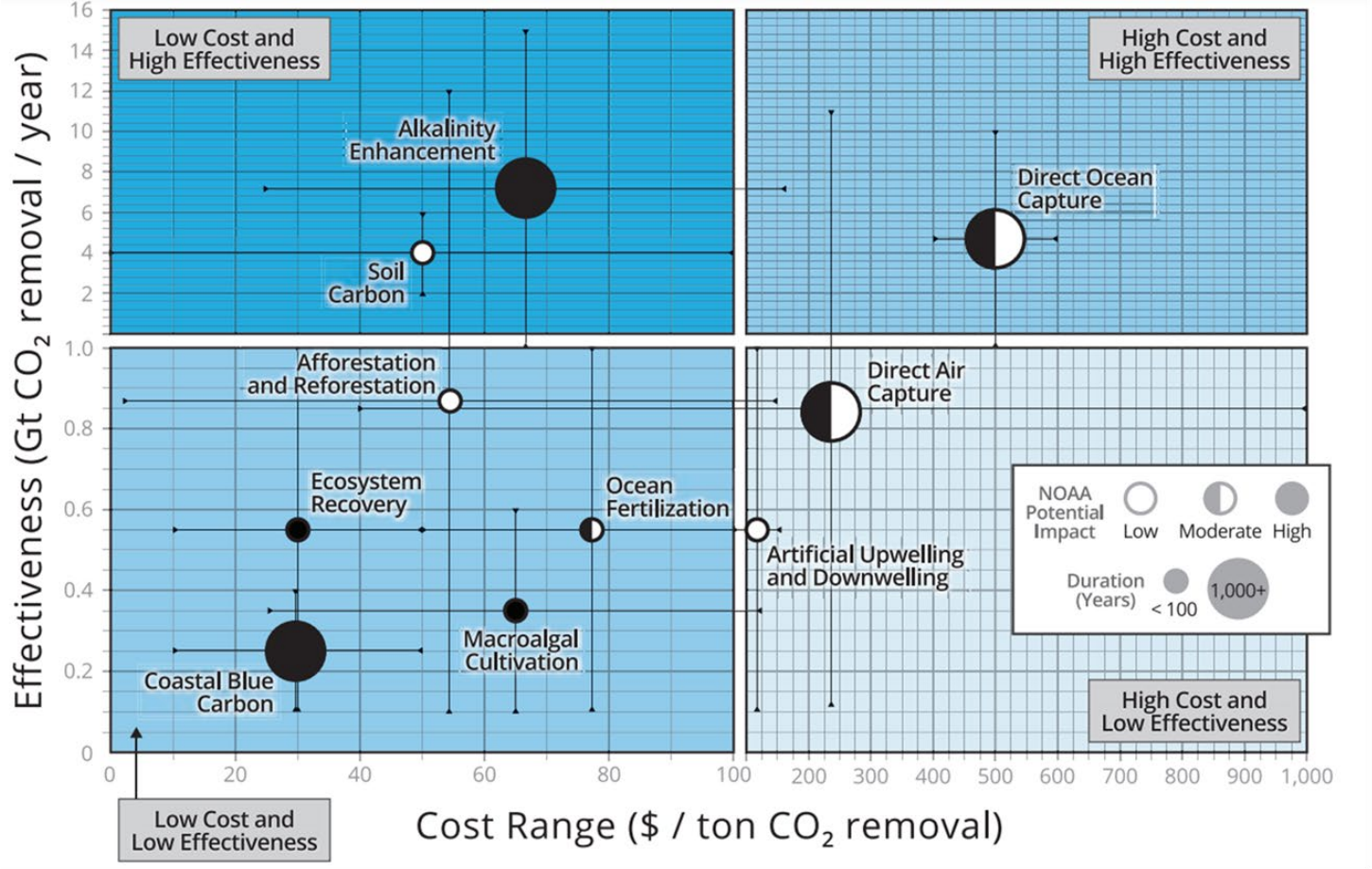
Portfolio of approaches to scale



Terrestrial CDR:
- Direct air capture (DAC)
- Bioenergy with carbon capture and storage (BECCS)
- Restoration, management (forests, soils, rangeland)

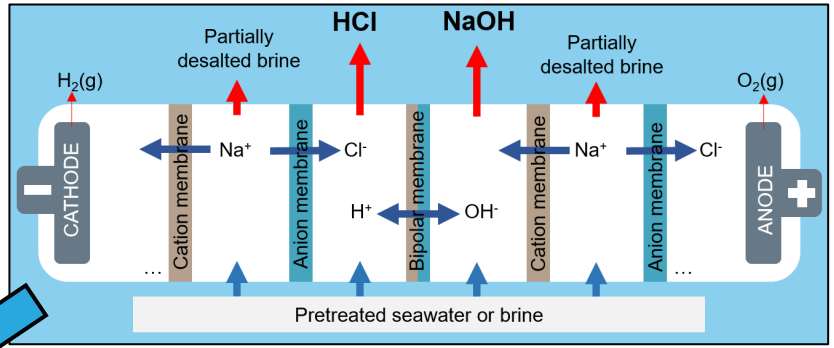
Marine (mCDR):
- Direct ocean capture (DAC)
- Macroalgae cultivation
- Ecosystem recovery
- Nutrient fertilization
- Artificial upwelling/downwelling
- Ocean alkalinity enhancement (OAE)

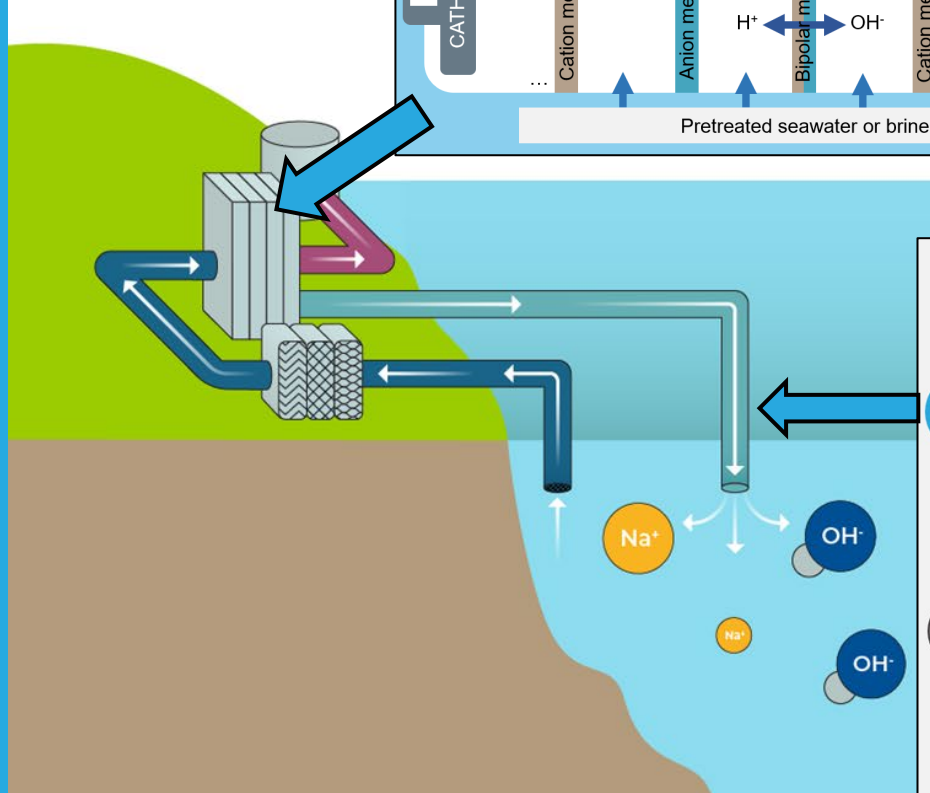
Portfolio of approaches to scale

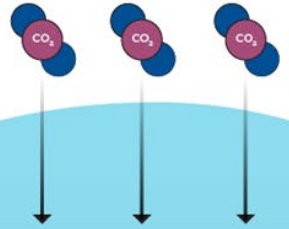


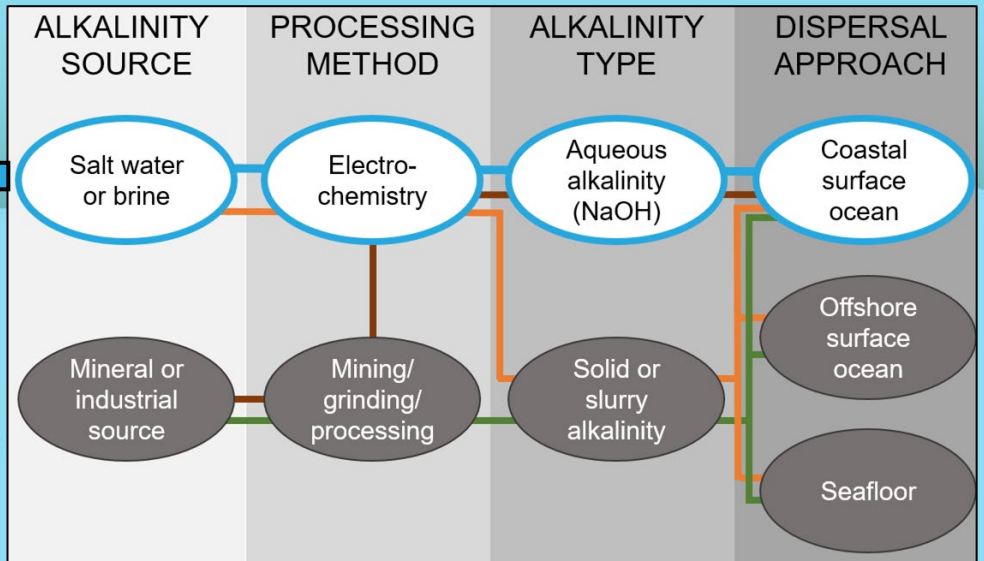
NOAA May 2023 Strategy for NOAA Carbon Dioxide Removal Research

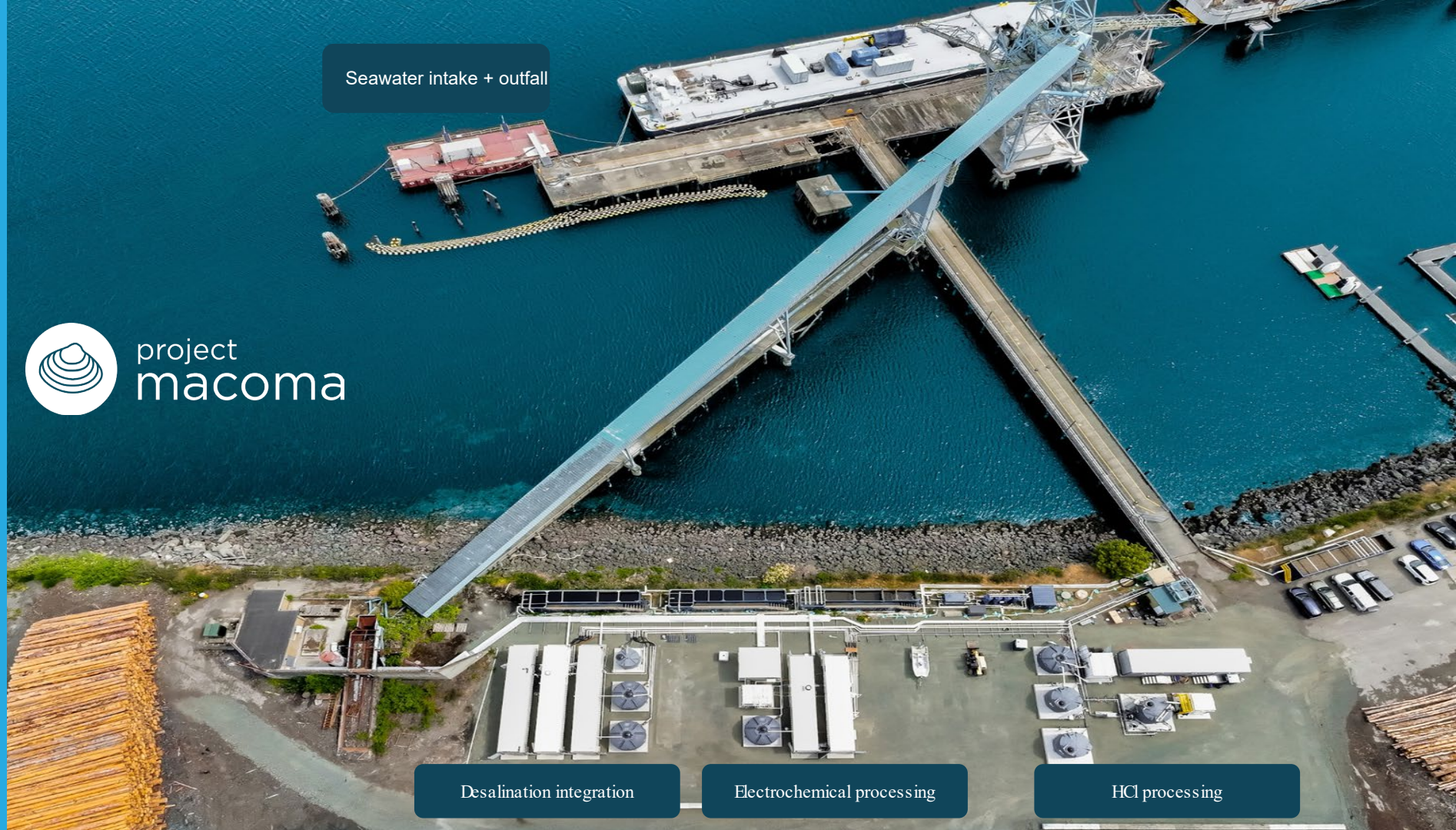
Electrochemical Ocean Alkalinity Enhancement

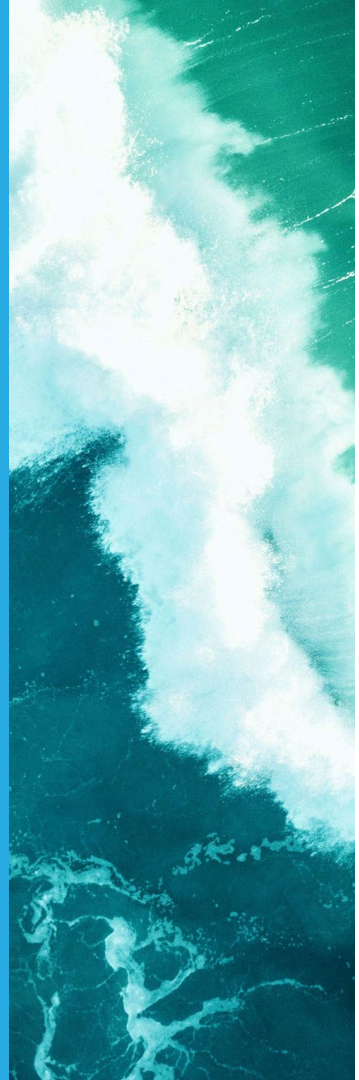









Seawater intake + outfall
project
macoma
Desalination integration
Electrochemical processing
HCl processing



Measurement, Reporting, and Verification

Rigorous, trustworthy quantification and delivery of atmospheric CO_2 removal and storage in the ocean to make an impact on climate change.

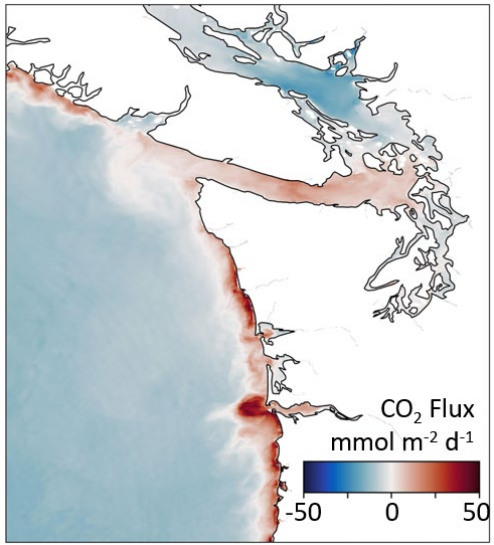
Includes:

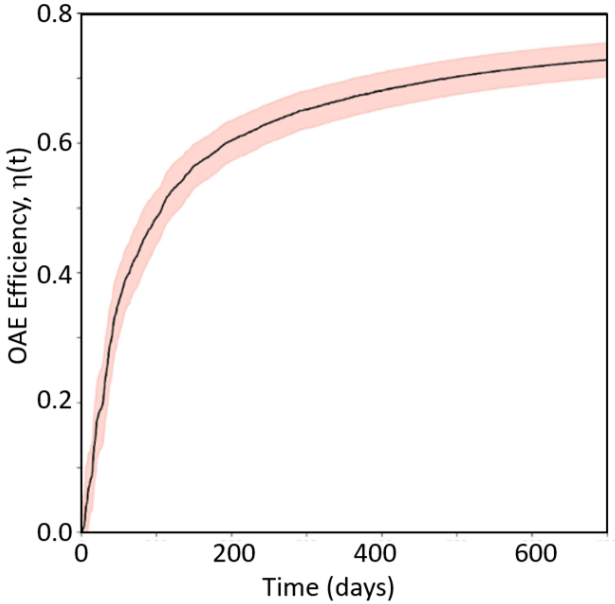
- Ecological safety
- Environmental data management
- Co-benefits
- CDR quantification
- Reporting and verification in partnership with best in class independent third parties

Gross CDR Quantification

- Ocean regions have predictable, linear CDR response to OAE
- Alkalinity release is simulated at the project site over different seasons and years to characterize CDR and uncertainty

- This lets us forecast CDR for planned alkalinity releases:
  Gross CDR =
  Amount of alkalinity released * CDR efficiency





Safe and Responsible Deployment

01

Permits and Regulatory Approval

Meet or exceeding all regulations safeguarding human and environmental health

02

Ecological Safety

Designed to honor the unique ecology and cultural significance of the project site

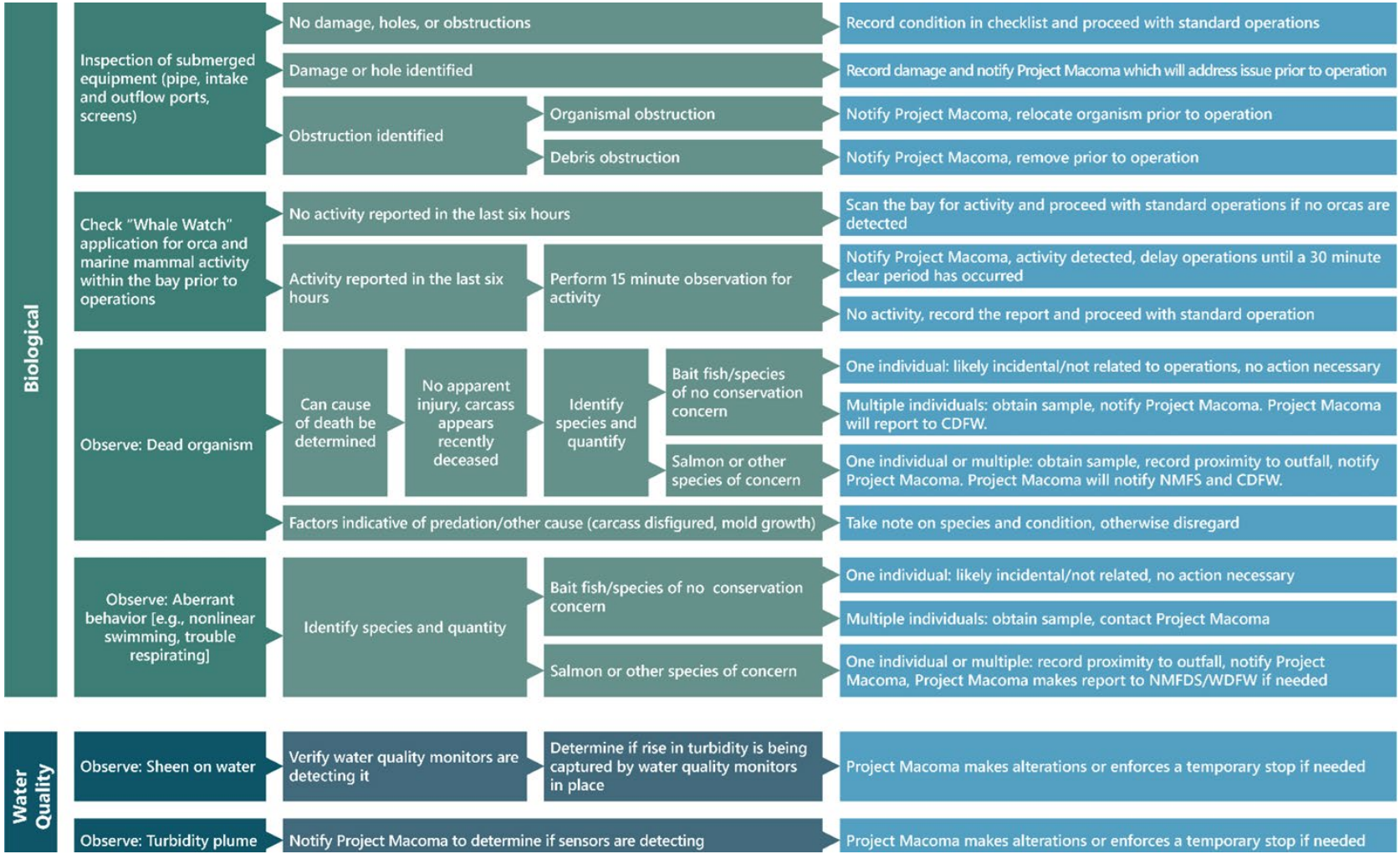
03

Stakeholder Engagement

Early, often and ongoing engagement with diverse stakeholders to learn from and meet community needs

Stakeholder Engagement

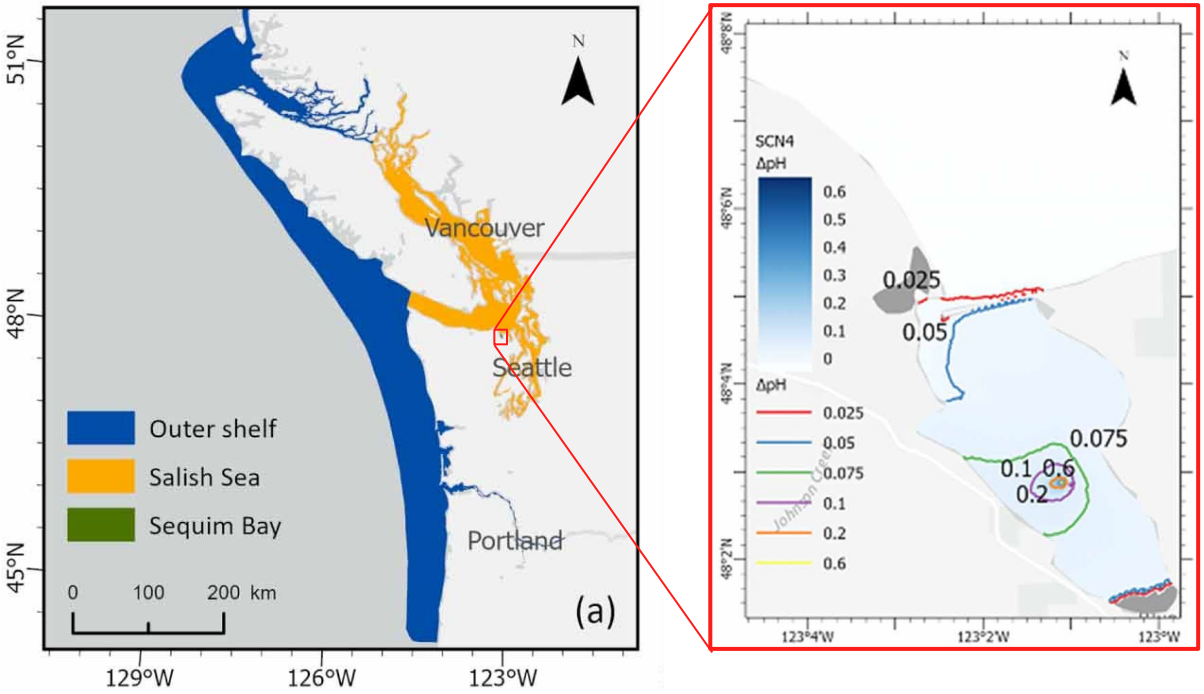
Ecological Safety Methodology: Adaptive Management



Co-benefits

Khangaonkar et al., 2024:

- FVCOM-based simulation of Ebb's alkalinity discharge and carbon dioxide removal at various scales
- Indicates potential bay-scale improvement in seawater pH via OAE



Carbon credit delivery process