

Project Design Document: Planetary's Nova Scotia Mineral OAE Project Template

Version 1.4

This PDD follows the Isometric standard template. . Please refer to the [Isometric Standard](#) for more information on how PDDs are used as part of the procedures of the Isometric Registry.

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Section A – Key Project Data

Title

Please provide the title of your Project. This will be displayed as your Project's name on the Isometric Registry and all related documentation.

Nova Scotia Mineral OAE Project

Description

Please provide a brief description (50-100 words) of your carbon removal Project. A more detailed written technical description must be provided later.

A mineral-based alkaline slurry will be dosed into a cooling water outfall at the Tufts Cove Power Generation Station located in Halifax Harbour. The mineral, a semi-calcined Magnesium Oxide, is transported from Spain to Halifax, and is mixed with seawater from the cooling loop to create a Magnesium Hydroxide slurry. The slurry is pumped back into the cooling loop, which flows into Halifax Harbour. An array of sensors, regular water, slurry, and feedstock sampling, alongside multiple numerical models, are used to ensure environmental safety, regulatory compliance, and to calculate carbon removal and its associated uncertainties.

Project Location(s)

- *Please submit at least one Address and/or specific geo-coordinates for the project.*
- *You may submit multiple Project locations – please specify what role each location plays in the Project.*

For summary on registry, the project location can be labelled as Nova Scotia, Canada. Exact locations provided below.

Magnesite mining: Eugi Quarry, Navarre, Spain (43°00'09.9"N 1°30'52.5"W)

Magnesite processing: Zona Industrial Magnesitas de Navarra, Av. de Roncesvalles Orreagako Etorbidea, 31630 Zubiri, Navarra, Spain (42°55'16.1"N 1°30'41.4"W)

Alkalinity addition: Nova Scotia Power - Tufts Cove Generating Station, 315 Windmill Rd, Dartmouth, NS B3A 1H5, Canada (44°40'30.3"N 63°35'43.9"W)

Project Participants

Please provide a complete list of organizations participating in the project, with a contact person for each organization.

(Please duplicate the below rows for each additional organization you wish to add)

Company registration number *(Unique business identification number in your country of registration)*:

Organization Name: Planetary Technologies

Organization Address: Unit 24-1A/B, 24 Orion Court, Dartmouth Nova Scotia B2Y 4W6, Canada

Contact Person: Will Burt

Contact Email Address: will@planetarytech.com

Contact Phone Number:

Organization role in Project: Supply and test feedstock, dose alkalinity, calculate removals

Organization Name: Nova Scotia Power

Organization Address: 315 Windmill Rd, Dartmouth, NS B3A 1H5, Canada

Contact Person: Kyle Ryan

Contact Email Address: Kyle.Ryan@nspower.ca

Contact Phone Number:

Organization role in Project: provide access to facility and cooling water loop

Organization Name: Dalhousie University

Organization Address: 1355 Oxford St. PO Box 15000. Halifax, NS, B3H 4R2.

Contact Person: Katja Fennel

Contact Email Address: Katja.Fennel@dal.ca

Contact Phone Number:

Organization role in Project: Collaborate on ocean sampling activities and conduct independent research on the impacts of the project.

Legal ownership of carbon removal claims

Please provide reasoning and evidence for legal ownership over the rights to all removals that will be claimed from the Project and refer to Section 3.1 "Ownership" of the Isometric Standard.

Planetary Technologies are the sole owners of these removals.

Technical description of Project activity

Please provide a brief technical description of your carbon removal Project activity in accessible language. This should include information on facilities and equipment, the age and average lifespan of equipment, and all further information essential to understanding how carbon removal is achieved by the Project.

Planetary sources and tests an alkaline feedstock, transports the feedstock to a coastal site with an ocean outfall, hydrates the feedstock into an alkaline slurry, and doses it into the ocean. Once dissolved in the ocean, the reactive alkalinity within the feedstock neutralizes dissolved CO₂ to form stable bicarbonate and carbonate ions, and the resulting decrease in CO₂ partial pressure creates a net transport of CO₂ from the atmosphere to the ocean.

For this project, the alkaline feedstock used is a semi-calcined magnesium oxide produced in Spain. The material is loaded into a series of weighed supersacks, and ultimately transported to the Tufts Cove Power Generation Station located in Dartmouth, Nova Scotia. In a mixing tank, seawater redirected from one of the power stations cooling loops is combined with the alkaline feedstock to create a slurry, which is concurrently pumped out of the mixing tank and back into the cooling loop directly before it exits into the ocean. The monitoring system consists of 4 main components: 1) boat-based sampling of the surrounding ocean environment, 2) a moored sensor platform located in the receiving waters near the addition point, 3) continuous flow-through sensor packages monitoring the effluent properties both up and downstream of alkalinity addition, and 4) monitoring systems of the slurry dosing system.

The CDR calculation involves 4 steps: first, the amount of reactive alkalinity dosed is calculated by multiplying the mass of feedstock added by the amount of reactive alkalinity present in the material, determined using detailed feedstock characterization assays. Second, the dosed alkalinity is inputted into a series of numerical models that utilize local and regional ocean conditions to simulate the gross CDR achieved as a result of the alkalinity addition. Third, a cradle-to-grave life-cycle GHG assessment is used to calculate total project emissions, which is subtracted from the gross CDR to estimate net CDR. Finally, the total propagated uncertainty across all calculations is used to generate a CDR volume (termed CDR holdback) that is subtracted from net CDR to calculate a high-confidence creditable CDR value.

Declaration of exclusive registration

Please confirm that your Project may only claim credits for activities that are exclusively registered with the Isometric Registry.

- I confirm the Project for which I aim to generate credits under the Isometric Standard is not registered with any other voluntary or compliance scheme.

Public funding

Please describe briefly whether your Project has received any public funding, e.g., grants or subsidies

Planetary received funding from NRC (Federal funding) through their IRAP and Graduate Hire program which reimburses a portion of salaries for two of our team members working on our Tufts Cove project. The total value of this funding is approximately CAD \$93,000

Estimated carbon removal capacity

Please give an estimate of the net carbon removal capacity of this project in the coming years (metric tonnes)

Year	Estimated carbon removal capacity (metric tonnes)
2023	
2024	1000
2025	9,400
2026	20,000
2027	60,000
2028	>100,000

Section B – Protocol and Monitoring Data

Selected Certified Protocol

Please select the Isometric Certified Protocol you wish to use for this Project.

Please note that, as per the Isometric Standard, you must use the latest available version of a Certified Protocol, unless a grace period has been explicitly specified by Isometric, whereby a former version of a Protocol may continue to be used for a defined time period.

Protocol Name: Ocean Alkalinity Enhancement from Coastal Outfalls v1.0

Protocol Version Number:

- I confirm that I am using the most recent available Certified Protocol version, or that a grace period has been explicitly specified allowing the use of an earlier protocol version.

Project Eligibility

Please explain why this Project is eligible under the selected Protocol.

This is a mineral alkalinity addition from a coastal outfall

Acknowledgement of responsibility for providing notification of changes to operations

Please confirm that you acknowledge responsibility for notifying Isometric of changes to operations which deviate from this submitted PDD

- I acknowledge responsibility for notifying Isometric of any changes to operations

Project Boundary

Please provide a description of the project boundary and complete the below table, including all GHGs considered across all Sources, Sinks and Reservoirs (SSRs) in both the Project and Baseline scenario. An appropriate level of detail on the scope of each individual GHG SSR that was studied should be clearly set out. Robust justification and appropriate evidence must be provided for any GHG SSRs that have been excluded from the project boundary. Evidence may be documented here or appended to the GHG Statement or PDD separately.

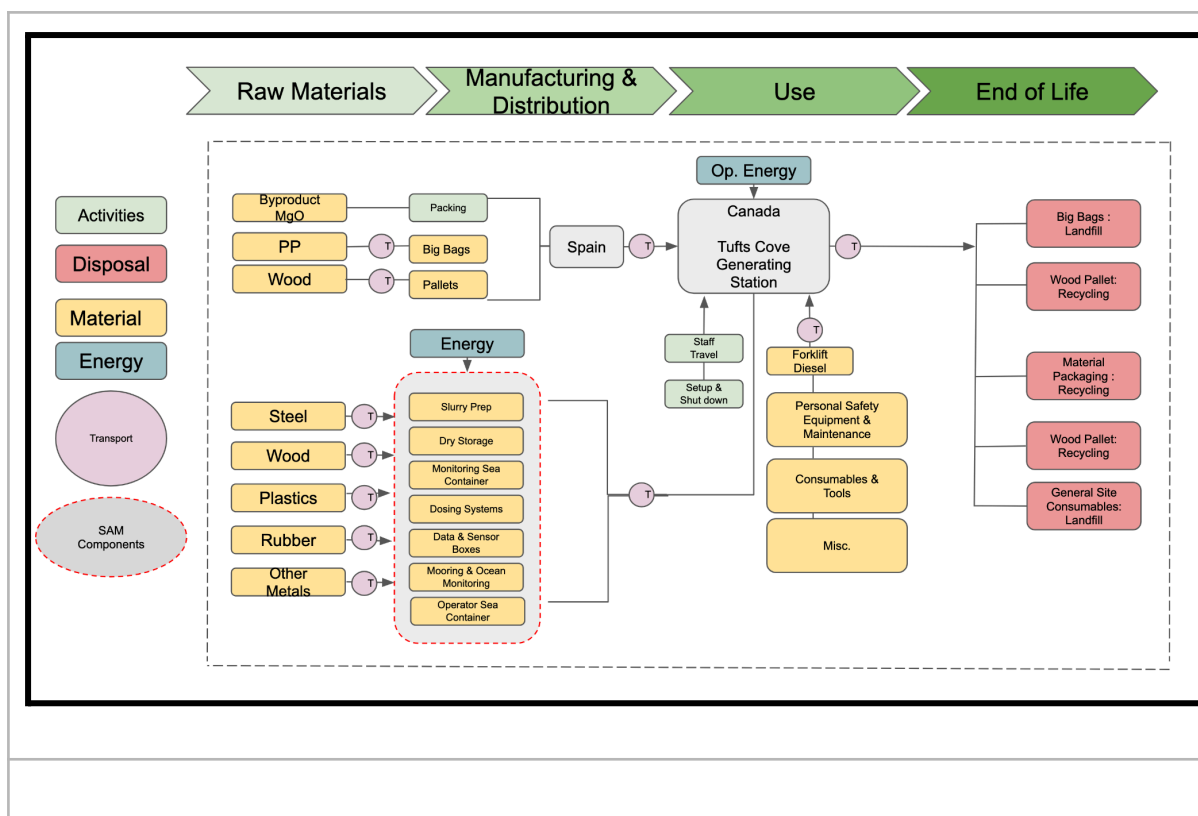
Additionally, you may also provide a diagram of the project boundary.

Planetary projects begin with the identification of an existing wastewater or seawater outfall system. This system is considered the “on site” location.

On site, the relevant sources, sinks, and reservoirs (SSR’s) are identified as part of the baselining activity. This includes the organizations that maintain operational control of these systems reporting for items such as its rate of discharge and energy consumption.

Off site, any activities related to the delivery of the project are accounted for in the baseline as having not generated reductions or emissions prior to the project Initiation.

Regarding the counterfactual scenario for emissions accounting, on site the ocean system is considered to be in steady state with no significant contribution as either a source or a sink of CO₂e prior to the project being initiated.



Baseline / Project	Carbon Flux / Emission Source	Included/ excluded from project boundary?	Greenhouse Gas(es)	Justification/description
<i>Example row follows...</i>				
Project	Electricity Use from feedstock transport	Included	CO ₂ , CH ₄ , NO ₂	CO ₂ included as the primary emission from electricity generation. CH ₄ and NO ₂ included for completeness as may also be released during electricity generation.

Baseline scenario

Please describe the baseline scenario of what would have happened if your Project did not take place (refer to Section 2.5.2 “Baselines” of the Isometric Standard and the requirements outlined in the relevant Protocol). Projects will only be credited for Removals above this counterfactual baseline.

The offsite counterfactual baseline is MgO byproduct feedstock remains at the production facility in Spain with limited use for up to 40,000 metric tonnes, and no materials are added to the cooling loop of Halifax Harbour.

Leakage Assessment

Please give a robust assessment of how you have considered potential increases in GHG emissions outside the defined Project boundary that occur as a result of the Project activity. Where the potential for such Leakage is identified, it must be quantified and deducted from the CO₂ Removals in accordance with the relevant Protocol. Please refer to Section 2.5.4 “Leakage” of the Isometric Standard.

Activities within the project boundary do not interact with any existing upstream or downstream activities or markets outside the project boundary. As such, no potential for leakage has been identified.

Demonstration of Additionality: Financial Additionality

Please describe and provide evidence for how your Project is financially additional. Refer to Section 2.5.3. “Additionality” of the Isometric Standard and the requirements outlined in the relevant Protocol.

Carbon removals are the main purpose of the project. Any other sources of revenue would not yield a positive IRR without carbon financing.

Demonstration of Additionality: Environmental Additionality

Please describe and provide evidence for how your Project is environmentally additional. Refer to Section 2.5.3. “Additionality” of the Isometric Standard and the requirements outlined in the relevant Protocol.

The climate impact of the project is net negative when compared to the counterfactual scenario, using a cradle-to-grave life-cycle GHG assessment.

Demonstration of Additionality: Regulatory Additionality

Please describe and provide evidence for how your Project is regulatorily additional. Refer to Section 2.5.3. “Additionality” of the Isometric Standard and the requirements outlined in the relevant Protocol.

The project is not a requirement under any regulation, policy, or other legal instrument.

Durability Assessment

Please confirm that the durability of your chosen sequestration pathway is at least 1000 years, in accordance with the Isometric Standard, and provide justification for how the Project adheres to the durability requirements outlined in the selected Protocol. This may include references to published literature or internal research. You may further expand on the Monitoring approach used to support the claimed Durability assessment in the “Overview of monitoring for durability” section of the next section.

- I confirm that the durability of carbon removed through this Project is at least 1000 years, in accordance with the Isometric Standard.

Assessment: The 1000+ year durability of ocean alkalinity enhancement is widely-accepted (see Middleburg et al., 2020 for example).

Middelburg, J.J., Soetaert, K. and Hagens, M., 2020. Ocean alkalinity, buffering and biogeochemical processes. Reviews of Geophysics, 58(3), p.e2019RG000681.

Monitoring Plan

Please specify whether this Project will follow the default Monitoring Plan, following the requirements specified in the “Monitoring Plan Requirements” appendix of the relevant Protocol and its associated modules (Option A), or whether a Monitoring Plan will be submitted which may contain additional or modified monitored parameters (Option B).

Additionally, please give an overview of how monitored parameters and/or models will be used to support the assessment of durability. You may also provide any additional information here about how Project monitoring will be conducted.

- A – I confirm this Project will follow the default Monitoring Plan, following the requirements specified in the “Monitoring Plan Requirements” appendix of the relevant Protocol and its associated modules
- **B – I have submitted a Monitoring Plan, which meets the requirements specified in the “Monitoring Plan Requirements” appendix of the relevant Protocol and its associated modules, and which describes any additional or modified parameters monitored which deviate from the default Monitoring Plan**

Overview of how monitored parameters or models will be used to support assessment of durability. If Option B was selected, please give details of how the monitoring plan adds to or differs from the default monitoring requirements outlined in the Protocol:

Please refer to [Appendix 1](#), [section 1.4](#) for details on Planetary’s monitoring plan.

[Optional] Additional information on Project monitoring:

Data collection and storage

Please describe the data collection and storage approach taken, including:

- *How data is transmitted and collected*
- *How data is stored*
- *Length of time for which records are archived*
- *Backup procedures and strategies for identifying and coping with lost or poor-quality data.*
- *Person(s) / organization(s) responsible for measurement and data collection*

Planetary's general approach to data collection is as follows:

- Data collected digitally (e.g., sensor-based measurements) will be stored on-device or in Planetary's cloud-based MRV system, on both internal and external drives, with physical access restricted only to authorized personnel.
- Data collected physically (e.g., discrete bottle-based measurements) will be stored securely on-site or in Planetary's laboratory facilities, with physical access restricted only to authorized personnel.
- Data collected physically will be transmitted securely to Planetary's cloud-based MRV system on an appropriate time frame, ranging from 5 minutes to 1 week, depending on the collection frequency and use case.

Planetary will employ sensors for continuous recording of critical measurements and manual data collection where sensors are currently unavailable, and for verifying the continuous data records.

Storage and Archiving

In general, Planetary will adopt the following guidelines:

- All data will be backed up regularly to Planetary-controlled secure cloud storage.
- Planetary's cloud-based MRV system will be backed up on a daily basis.
- Data will be archived indefinitely. Where regulatory, safety, and crediting requirements conflict with this policy, the archive period will be adjusted to satisfy the requirements.

Data are analyzed for multiple purposes, including safety, regulatory compliance, equipment (re-)calibration, and crediting.

Reversals

Please complete a reversal risk assessment for your Project, including consideration of the guidance in the Risk of Reversal Questionnaire below. [Questionnaire not needed if risk is already stated in protocol.](#)

Overall risk of reversal (based on risk reversal questionnaire score; please select one):

Very low (0)

Low (1-3)

Medium (4-5)
High (>6)

[Optional] Additional details/assessment of reversal risk mechanisms: **Reversal risks are discussed in Planetary's MRV Protocol (V3, Section 2.4.2)**

#	Question	If answered "Yes"	If answered "No"	Response
1	Is a reversal directly observable with a physical or chemical measurement as opposed to a modeled result?	Proceed to questions 2-8	Proceed to questions 7-8	No
2	Is the carbon being stored in a closed or impermeable system? (e.g., salt cavern)	Proceed to questions 10-11	Proceed to questions 3-11	N/A
3	Is the carbon being stored organic?	Add 1 to Risk Score		N/A
4	Does scientific consensus suggest that the carbon storage reservoir has a less than 10,000 year durability?	Add 1 to Risk Score		N/A
5	Is methane production a Project risk?	Add 1 to Risk Score		N/A
6	Does this approach have a material risk of reversal due to natural disasters including, but not limited to, floods, storms, earthquakes, fires, etc.?	Add 1 to Risk Score		N/A
7	Does this approach have a material risk of reversal due to human-induced events from outside actors, such as change in farming practices, change in ownership and management of Project sites, or similar?	Add 1 to Risk Score		No

8	[Applicable only for subsurface storage] Is the carbon being stored in the deep subsurface with multiple trapping mechanisms preventing reversals? (e.g., multiple confining layers, CO ₂ dissolves or solidifies)	Minus 1 to risk (unless 0)		N/A
9	Is there 10+ years of monitoring and/or lab data demonstrating low project risk?	Minus 1 to risk (unless 0)		No
10	Does this pathway have a documented history of reversals?	Please consider the frequency and severity of previous reversals, and the shared characteristics between documented reversals and the present project. For pathways with no documented history of reversals, add 0 to the Risk Score. For pathways with a history of frequent reversal, add 2 to Risk Score. For pathways with a limited history of reversals, add 1 to Risk Score.		No
11	Is there one or more Project-specific factors that merit a high risk level?	Please consider the number and severity of risks identified. If one low or medium severity risk is identified, add 1 to Risk Score. If multiple risks are identified, or if any high severity risks are identified, add 2 to Risk Score		No

Total Risk Score	0
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Uncertainty assessment

Specify how uncertainty is considered, and how removals are to be conservatively estimated, in accordance with Section 2.5.7 “Uncertainty” of the Isometric Standard.

Please specify which option(s) were used in consideration of uncertainty (one or multiple options).

- Conservative estimate of input parameters
- Variance propagation
- Monte Carlo Simulations

Please provide a sensitivity analysis.

- I have uploaded a sensitivity analysis in accordance with the guidance in the Isometric Standard

Justification for your choice of uncertainty approach:

Uncertainties in each of the inputs to the CDRnet calculation are determined as follows;

- Mass of feedstock; measured super sack weights and calibrated scale’s measurement uncertainty
- Feedstock alkalinity content; chemical analysis of samples with uncertainty derived from the statistics of the sample results
- Gross CDR; determined from ocean models with uncertainty derived from an ensemble of sensitivity runs
- Life-cycle emissions; uncertainty derived either by variance propagation or Monte Carlo simulation using the LCA model.

The overall probability distribution of CDRnet is then determined either by simple variance propagation (if all the uncertainties are represented by simple normal distributions) or by Monte Carlo simulation otherwise. The conservative estimate of removals is taken from this distribution at the 84% exceedance probability level, equivalent to one standard deviation below the mean for a normal distribution.

Use of Models

Please describe your use of models (if any) for quantification, monitoring, and meeting specified Protocol requirements. Describe the specific model and simulations used, with enough detail so that the work could be replicated.

Please provide model validation results to demonstrate model accuracy, and include an assessment of model uncertainty.

Processes important for OAE span ~10 orders of magnitude, from particle-fluid interactions at the micron scale to ocean circulation and air-sea gas exchange at the 100-1000 km scale. The key challenges are;

1. To assess the spatial and temporal distribution of alkalinity released during the advection, sinking and dissolution of a mass of alkaline particles with a broad particle size distribution.
2. To assess the extent to which the resulting mass of pCO₂ depleted water remains in contact with the ocean's surface mixed layer (ML), allowing pCO₂ equilibration through air-sea gas exchange over a decadal timescale.
3. To assess the overall uncertainty in the resulting CDR estimate arising from uncertainty in a broad range of input parameters, without excessive computational expense.

A multi-level modeling strategy is required to address these challenges [1], and its implementation in the current project (TC24) is described below and in section 1.5. Briefly, we quantify ex-post CDR for a given reporting period using biogeochemical (BGC) coastal (or 'near-field') and global (or 'far-field') ocean model simulations designed specifically for the project. These simulations are forced with past climatology and the observed alkalinity dosing time series (or equivalent upscaled alkalinity in the case of the global model; see section 1.5). The uncertainty around each ex-post estimate is then quantified using a simplified 1D diffusivity model, which has been calibrated against an ensemble of coastal and global BGC ocean model simulations.

i. Calculating CDR_{gross} and its uncertainty

The workflow used to quantify ex-post CDR from an OAE project follows the sequential steps described below, and is shown schematically in Figure 1:

- Quantify dilution rates near the outfall with multiple tracer studies.
- A 1-D alkalinity release model simplifies the full particle size distribution into a two-phase particle size distribution for forcing the coastal model.
- The initial alkalinity dispersion and local CO₂ uptake is characterized in the near-field using a suite of biogeochemical coastal model (ROMS) simulations. The coastal model ensemble is designed to capture the leading sources of uncertainty, including feedstock sensitivity, seabed losses, seasonality and interannual variability. This library of coastal model simulations produces a set of coastal uptake curves (η_{ROMS}).
- The global sensitivity of CO₂ uptake is characterized by a suite of simulations using ECCO/MITgcm global ocean state estimate. The global model ensemble is designed to characterize uncertainty in seasonality and interannual variability, focusing on variability in wind speed, mixed layer depth (MLD), SST and SSS in the region over which the added alkalinity disperses. Alkalinity is added to the global model following the horizontal and vertical distribution of alkalinity leaving the coastal model domain. The library of global model simulations produces a set of global uptake curves (η_{ECCO}).
- The two sets of coastal and global uptake curves, η_{ROMS} and η_{ECCO} , are used to calibrate a 1D diffusivity model. The calibrated 1D diffusivity model is used to characterize the uncertainties targeted by the ROMS and ECCO ensembles, and to expand the sampled parameter space of η .
- Once project activities are complete, a coastal ROMS simulation will be run with past climatology and with the observed alkalinity dosing time series prescribed.

Added alkalinity that has not equilibrated with the atmosphere within the model domain during the coastal model simulation is then upscaled and input to a global model ECCO simulation (see section 1.5). This provides a (ROMS+ECCO) CDR curve for the project using the actual dosed alkalinity. The timing of these simulations will be chosen to be most representative based on observed weather data during the projects dosing activities to minimize uncertainty generated by interannual variability.

- The uncertainty in ex post estimates of CDR_{cred} (see Section 1.3) is quantified using the simplified 1D approach, allowing for quantification of total project CDR and its uncertainty without the need for additional ROMS/ECCO model integrations.

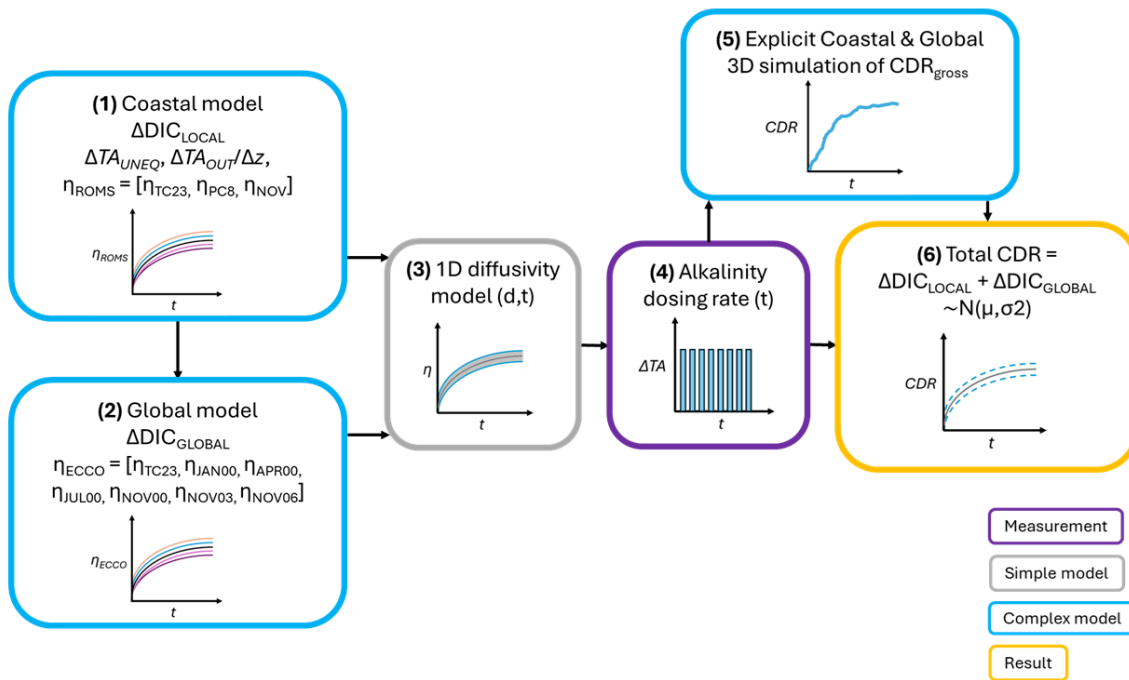


Figure 1: Modeling workflow to quantify ex-post CDR from an OAE project. The ensembles of coastal (1) and global (2) model simulations are used to calibrate the 1D diffusivity model (3), which then generates a series of additional sensitivities for uncertainty assessment, (4) the coastal and global model simulations are combined, using the observed alkalinity dosing time series, upscaled alkalinity and representative climatology (5) to provide an ex-post estimate of CDR_{cred} (6). ΔTA is the time series of added alkalinity; t is time; ΔDIC is the change in the ocean Dissolved Inorganic Carbon reservoir, split into its global and local components by the global and coastal models, respectively; ΔTA_{UNEQ} is the unequilibrated fraction of the added alkalinity at the end of the coastal model simulation; $\Delta TA_{OUT}/\Delta z$ is the vertical distribution of added alkalinity leaving the open boundaries of the coastal model domain; η_{ROMS} and η_{ECCO} are sets of uptake efficiency curves generated from the ensemble of coastal (ROMS) and global (ECCO) model simulations, respectively, with simulations designed to assess uptake seasonality (e.g. starting in Jan, Apr, Jul and Nov) and interannual variability (e.g. starting in years '00, '03 and '06, see subsequent section); CDR is the tonnes of CO_2 removed from the atmosphere by a project.

ii. 1D calibration ensemble

A list of the coastal and global model simulations performed to generate η_{ROMS} and η_{ECCO} and calibrate the 1D diffusivity model are provided in Table 1.

#	Model	Start date	Duration	ΔTA	Description
1	ROMS	Oct, 2023	6-months	TC24	Past climatology with actual TC24 dosing time series and feedstock-specific parameters
2	ROMS	Oct, 2023	6-months	TC23; 221 t	TC23 basecase with feedstock-specific parameters
3	ROMS	Feb, 2023	6-months	TC23	Seasonal sensitivity to Feb release
4	ROMS	Apr, 2023	6-months	TC23	Seasonal sensitivity to April release
5	ROMS	Jul, 2023	6-months	TC23	Seasonal sensitivity to July release
6	ROMS	Oct, 2023	6-months	TC23	Sensitivity to 2x dissolution rate
7	ROMS	Oct, 2023	6-months	TC23	Sensitivity to particulate feedstock
8	ROMS	Oct, 2023	6-months	TC23	Sensitivity to dissolved feedstock
9	ROMS	Oct, 2023	6-months	TC23	Seabed loss sensitivity
10	ROMS	Oct, 2023	6-months	TC23	Sensitivity to air-sea flux plus 15%
11	ROMS	Oct, 2023	6-months	TC23	Sensitivity to air-sea flux minus 15%
12	ROMS	Oct, 2023	6-months	500 t	Nominal November dose using 2023 climatological forcing and TC24 feedstock parameters
13	ROMS	Oct, 2003	6-months	500 t	Additional years to characterize interannual variability.
14	ROMS	Oct, 2006	6-months	500 t	Additional years to characterize interannual variability.
15	ROMS	Oct, 2007	6-months	500 t	Additional years to characterize interannual variability. One hurricane impacted Nova Scotia during November, 2007.
16	ROMS	Oct, 2009	6-months	500 t	Additional years to characterize interannual variability.
17	ROMS	Oct, 2012	6-months	500 t	Additional years to characterize interannual variability. Two hurricanes impacted Canada's Atlantic coast during 2012.
18	ROMS	Oct, 2016	6-months	500 t	Additional years to characterize interannual variability.
19	ECCO	Jan, 1992	26-years	N/A	Baseline
20	ECCO	Feb, 2000, 2007, 2012	10-years	TC24	Upscaled alkalinity from ROMS TC24 basecase simulation. Start dates are Feb, 2000, 2007 & 2012
21	ECCO	Apr, 2000	5-years	TC23; 119.63 t	TC23 upscaled alkalinity forcing, 2000 start year
22	ECCO	Apr, 2003	8-years	TC23; 119.63 t	TC23 upscaled alkalinity forcing, 2003 start year
23	ECCO	Apr, 2006	4-years	TC23; 119.63 t	TC23 upscaled alkalinity forcing, 2006 start year
24	ECCO	Apr, 2000	2-years	100 t	Sensitivity of CDR to the magnitude of ΔTA
25	ECCO	Apr, 2000	2-years	5,000 t	Sensitivity of CDR to the magnitude of ΔTA

26	ECCO	Apr, 2000	2-years	500 t	Seasonal and scale sensitivity for April, 2000
27	ECCO	Jul, 2000	2-years	500 t	Seasonal sensitivity for July, 2000
28	ECCO	Oct, 2000	2-years	500 t	Seasonal sensitivity for Oct, 2000
29	ECCO	Jan, 2001	10-years	500 t	Seasonal sensitivity for January, 2001
30	ECCO	Apr, 2003	10-years	500 t	Interannual sensitivity for April, 2003 (1 hurricane)
31	ECCO	Apr, 2006	2-years	500 t	Interannual sensitivity for April, 2006 (no hurricanes)
32	ECCO	Apr, 2007	10-years	500 t	Interannual sensitivity for April, 2007 (1 hurricane)
33	ECCO	Apr, 2012	2-years	500 t	Interannual sensitivity for April, 2012 (2 hurricanes)
34	ECCO	Apr, 2015	2-years	500 t	Interannual sensitivity for April, 2015 (no hurricanes)

Table 1: List of model simulations used to calculate CDR_{gross} and build the ensemble of uptake curves, η_{ROMS} and η_{ECCO} . TC23 indicates the Tufts Cove 2023 project alkalinity dosing profile using a slower dissolving feedstock. All other ΔTA values refer to simulations with the faster dissolving 2024 feedstock parameters. TC24 indicates simulations run with the observed 2024 project dosing time series. Start years were chosen to span extremes in interannual variability, including the number of hurricanes impacting the Atlantic/Nova Scotian coast of Canada, derived from: https://en.wikipedia.org/wiki/List_of_hurricanes_in_Canada#2000%E2%80%93present.

iii. Complex forward modeling validation

Periodically, and at the end of the crediting period, these estimates will be further validated using the full ROMS + ECCO modelling workflow (box 5 in Figure 1), similar to the methodology used to credit the 2023 dosing activities in Halifax (TC23). This approach uses representative climatology and the observed alkalinity dosing time series to force a 6-month high-resolution coastal ROMS simulation. At the end of the 6-month simulation, the remaining unequilibrated fraction of added alkalinity is upscaled for input to an ensemble of global ECCO simulations, so it can be tracked to eventual equilibrium over a decadal timescale. More details on the Alkalinity Upscaling approach are given in section 1.5. This forward modeling approach is significantly more time consuming due to the need to wait for a representative time period after dosing activities have finished for air-sea CO₂ flux to occur in the near-field domain (usually a minimum of 3-months post dosing), and for model boundary forcing to be updated before any CDR modeling can begin. This combined ROMS + ECCO modelling workflow provides an estimate of CDR_{cred} under ‘realistic’ boundary conditions.

iv. 1D alkalinity release model

The 1D alkalinity release “model” simulates the dissolution and sinking of feedstock particles across the full particle size distribution. The lab-determined dissolution rate (mol/m²/s) and sinking velocities calculated from Stokes’ Law are used to generate a profile of alkalinity release versus depth. A total water depth is specified and particles that reach the bed are assumed to dissolve there. Since ROMS cannot explicitly model particles, this profile is approximated using a 2-phase proxy, with a percentage of the alkalinity released in the surface layers and the remainder released with the sinking and

dissolution of a single particle size. The dissolution rate of these particles is represented by a simple decline rate (Note; for UM10, used in the 2023 pilot, 35% was released as dissolved, the remainder as 12 μm particles, with a mass decline rate of 1.5% per day.) Figure 2 shows the release profile for three full feedstock-specific particle size distributions (psds) and the fit to the 2-phase proxy. For input to ROMS, 90% of the feedstock is assumed fully dissolved on release, while the remaining 10%, released as 90 μm particles, declines (i.e. releases alkalinity) at 1.7% per minute, in line with the rapid dissolution rate (see Figure 3).

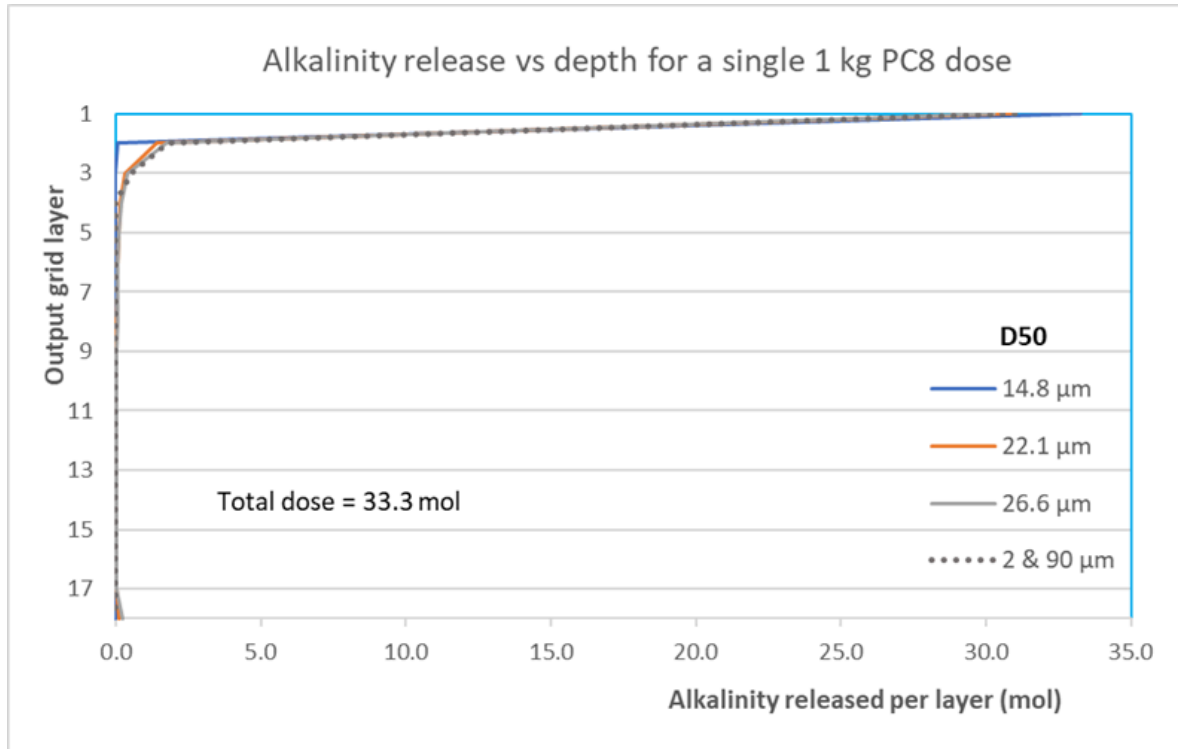


Figure 2: Vertical alkalinity release profile for three full psds (D50 = 14.8, 22.1, and 26.6 μm) and for the 2-phase proxy comprising 2 and 90 μm particles.

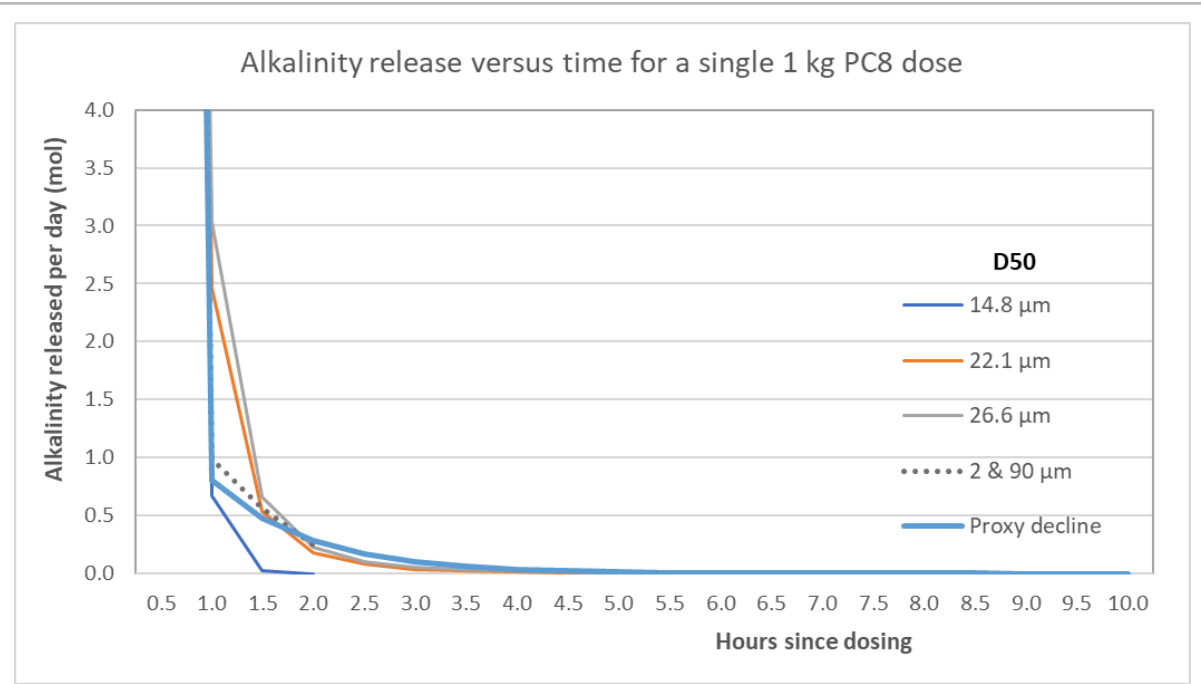


Figure 3: Alkalinity release time series for three full psds (D50 = 14.8, 22.1, and 26.6 µm) and for the 2-phase proxy comprising 2 and 90 µm particles.

[1] Fennel, K., Long, M.C., Algar, C., et al., 2023. Modeling considerations for research on Ocean Alkalinity Enhancement (OAE). State of the Planet Discussions, 2023, 1-47.

Section C – Duration & Crediting Period

Project timeline

Please indicate the projected start date of your Project and, if applicable, its expected operational closure date.

Start date of Project: Project initiation: February 1st, 2024.
Dosing period: July 2024 until December-January 2025

[Optional] Expected operational closure date of Project: N/A

Project closure

Please describe the conditions under which the Project will be considered closed, and describe the Project Closure Plan – outlining any post-cessation actions that will be undertaken upon Closure of the Project.

Definition of Project cessation: Dosing at Tufts Cove has ceased, with no future dosing plans in place.

If dosing at Tufts Cove has altogether ceased, all equipment and infrastructure will be removed from the Nova Scotia Power site, and the site will be remediated back to its original condition (e.g. ground leveled, appropriate disposal of any traces of alkaline feedstock).

Crediting Period

Please indicate the planned start date and duration of your crediting period. The crediting start date may either be your Project's start date or up to two years prior to design submission, whichever is later. Unless otherwise specified in the relevant Protocol, the maximum crediting period is 5 years.

Start date of crediting period: Start date is the first day of alkalinity dosing, currently set for 6th August, 2024 (exact date to be confirmed).

For the alkalinity dosing conducted during this project, credit generation is anticipated over a 10-year period, based on the results of air-sea gas exchange modelling. This is in accordance with Section 6.0 of the Air-Sea gas exchange module (<https://registry.isometric.com/module/air-sea-gas-exchange/1.0#footnote-label>).

Section D – Environmental and social impacts

Analysis of environmental and social impacts

Please provide an assessment of the environmental and social impacts of the Project, in accordance with Section 3.7 “Environmental and Social Impacts” of the Isometric Standard.

For each aspect of the assessment, demonstrate how the risks have been assessed and if applicable, what mitigation plan is in place to prevent them. If some aspects are not applicable to your project, justify how you determined it.

A full Environmental and/or Social Impact Assessment (EIA and/or SIA) is only required if impacts are considered significant and/or if required by the host jurisdiction.

- ~~[Optional] I have attached a full EIA document.~~

- ~~[Optional] I have attached a full SIA document.~~

YES	I acknowledge responsibility for reporting potential environmental and social impacts identified to Isometric and environmental regulators
Please see the following sections for assessment of risks. If relevant, the risks have been assessed on a five point scale, ranging from 1 (minimal), 2 (low), 3 (medium), 4 (high), 5 (extremely high), based on both the likelihood and severity of occurrence. For more significant risks, a score is presented for both original (unmitigated) and mitigated risk level.	
Environmental Impacts	
Resource efficiency and pollution prevention, including pollutant emissions to air, pollutant discharges to water, noise and vibration, generation of waste and release of hazardous materials, chemical pesticides and fertilizers.	
YES	Above risks are applicable to this Project
With the exception of the release of chemical pesticides and fertilizers, which have been scoped out, these risks are all considered applicable to some extent for the project. <u>Discharge of pollutants/hazardous materials to water</u> The most significant risk identified in this section relates to the possibility of pollutants discharging into water as a result of trace metal impurities or organic compounds present in the alkaline feedstocks, which could have deleterious effects in the marine environment (e.g. Renforth et al., 2019; Cyronak et al., 2023) and some of which may be classed as hazardous materials (e.g. mercury and cadmium). A key focus of the alkaline feedstock characterisation process is the determination of impurity levels, which are then screened against site-specific parameters such as outfall flow-rate, relevant water quality guidelines for a given jurisdiction and background levels of trace metals using a purpose-built screening tool. This process establishes the feasibility of safely using a given feedstock at a project site, and is used to derive indicative maximum alkalinity addition rates. A key pillar of the monitoring programme (see section 1.4) is to establish baseline levels of trace metals in water and sediments and then to continually monitor them throughout the alkalinity addition, in order to validate that Planetary's operations do not result in the accumulation of impurities and/or the exceedances of the relevant guideline values. The stop-triggers set out in section 1.2 set out a clear protocol to be followed in the event of any exceedances of trace metal threshold limits either in seawater or sediments. All materials, mixing operations and slurry storage will be contained in an impermeable bund, with a capacity in excess of the maximum volume of all storage tanks on the project site at any time. The risk of an uncontrolled spill event is therefore considered low. In the absence of any control and mitigation measures, the potential risk for deleterious levels of pollutant discharge to water is considered high (4). However, given the mitigation	

measures contained in the feedstock characterisation and monitoring programme, the mitigated risk of pollutant discharge is assessed as **low (2)**.

Pollutant emissions to air

The risk of pollutant emissions to air is overall considered to be low. Some direct emissions of CO₂, NO_x, CH₄, and SO₂ will occur, as a consequence of the transport of the alkalinity feedstock material to site and mechanized materials handling operations during the project. While a full account of all these emissions will be included in the independently audited post-project carbon accounting, the scale of these emissions will be orders of magnitude lower than background air pollution in the project environs, which are urban and industrial. Nevertheless, all possible efficiencies will be sought to reduce vehicular emissions on the project site.

Given that the alkaline feedstock material is finely ground, there exists some risk of dust pollution during materials handling operations, which is likely to be particularly problematic in windy conditions. A number of mitigation strategies are included in operational planning, including the use of dust curtains and tarpaulins during materials handling operations, restrictions on materials handling during windy conditions and rapid containment and cleanup procedures in the event of a dry material spill.

Overall, the risk of pollutant emissions to air is assessed as **minimal (1)**, after mitigation measures.

Noise contamination, light pollution and vibration

During operation, the project machinery and vehicles will create a low level of additional noise, light and vibration. However, this is considered negligible within the context of the baseline noise, light and vibration from the Tufts Cove thermal power plant, which is the host facility for the project and has extensive machinery immediately adjacent to the project site.

Overall, this risk is assessed as **minimal (1)**.

Generation of waste

The principal source of waste during the project will be the packing materials for the alkaline feedstock, which consist of empty super sacks and pallets. These will be disposed of in accordance with municipal protocols in Nova Scotia, through a licenced and accredited contractor.

Overall this risk is assessed as **minimal (1)**.

References:

Cyronak, T., Albright, R., & Bach, L. (2023). *Field experiments in ocean alkalinity enhancement research*. <https://doi.org/10.5194/sp-2023-9>

Renforth, P., and Henderson, G. (2017). *Assessing ocean alkalinity for carbon sequestration*. *Rev. Geophys.* 55, 636–674. doi: 10.1002/2016RG000533

Biodiversity conservation and sustainable management of living natural resources, including terrestrial & marine biodiversity and ecosystems, protecting habitats of rare & endangered species, avoiding conversion of natural forests, grasslands or wetlands, minimizing soil degradation or erosion, minimizing water consumption and stress.

YES	Above risks are applicable to this Project
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Of the above risks, soil degradation and erosion is not considered relevant to Planetary's OAE project. Similarly, water consumption and stress is also considered a negligible risk, given that the water used for slurry preparation and mixing is estuarine rather than fresh, with the system intake situated in the Bedford Basin.

The risk posed to valuable natural habitats in the vicinity of the project site is also considered low. The risk outlined above considers natural forests, grasslands and wetlands as examples of valuable habitat; of these, given the nature of OAE, only wetlands are considered to be potentially at risk. In order to ascertain the distribution of sensitive habitats in the vicinity of the project site, the project location was screened against the Nova Scotia database for Significant Habitats, which defines Significant Habitats as the following:

1. sites where species at risk or other species of conservation concern can be found and/or;
2. sites where unusually large concentrations of wildlife occur and/or;
3. habitats that are rare in the province.

The results of the Nova Scotia significant habitat screening are shown in Figure 1 below, which also shows the project location in Tufts Cove (denoted by red triangle). The habitats identified in the vicinity are important sites for migratory birds (in light blue) and several areas classed as significant other habitat (in purple) correspond to wetland areas. Based on the predicted extent of the alkalinity plume informed by current modelling work, all significant habitats shown would not experience any detectable impacts from the project.



Figure 1: Nova Scotia Significant Habitats identified around the project location

The project location was also screened against the UN Environment Programme World Conservation Monitoring Centre's (UNEP-WCMC) Global Critical Habitat Screening layer. The UNEP-WCMC screening layer shows the global spatial distribution of likely or potential Critical Habitat, as defined by the International Finance Corporation's Performance Standard 6 (IFC PS6) criteria, which focus on areas with high biodiversity value, as defined by one or more of the following criteria:

- Criterion 1 – habitat of significant important to Critically Endangered (CR) and/or Endangered (E) species
- Criterion 2 – habitat of significant importance to endemic and/or restricted-range species
- Criterion 3 – habitat supporting globally significant concentrations of migratory species and/or congregatory species
- Criterion 4 – highly threatened and/or unique ecosystems
- Criterion 5 – areas associated with key evolutionary processes.

Where Critical Habitats are defined, net gain of biodiversity features is a requirement for developers or project proponents. The UNEP-WCMC layer uses a 1km x 1km gridded approach to categorize grid cells either as unclassified, as potential critical habitat or as likely critical habitat (corresponding to the red grid cells in Figure 2 below). As is evident, the nearest area of likely critical habitat is approximately 15 km away from the project location to the south-east. Given the distances of identified sensitive habitat from the

project location and the rapid dilution of the alkalinity plume as informed by the monitoring work, the overall risk of disruption to these areas is assessed as **minimal (1)**.

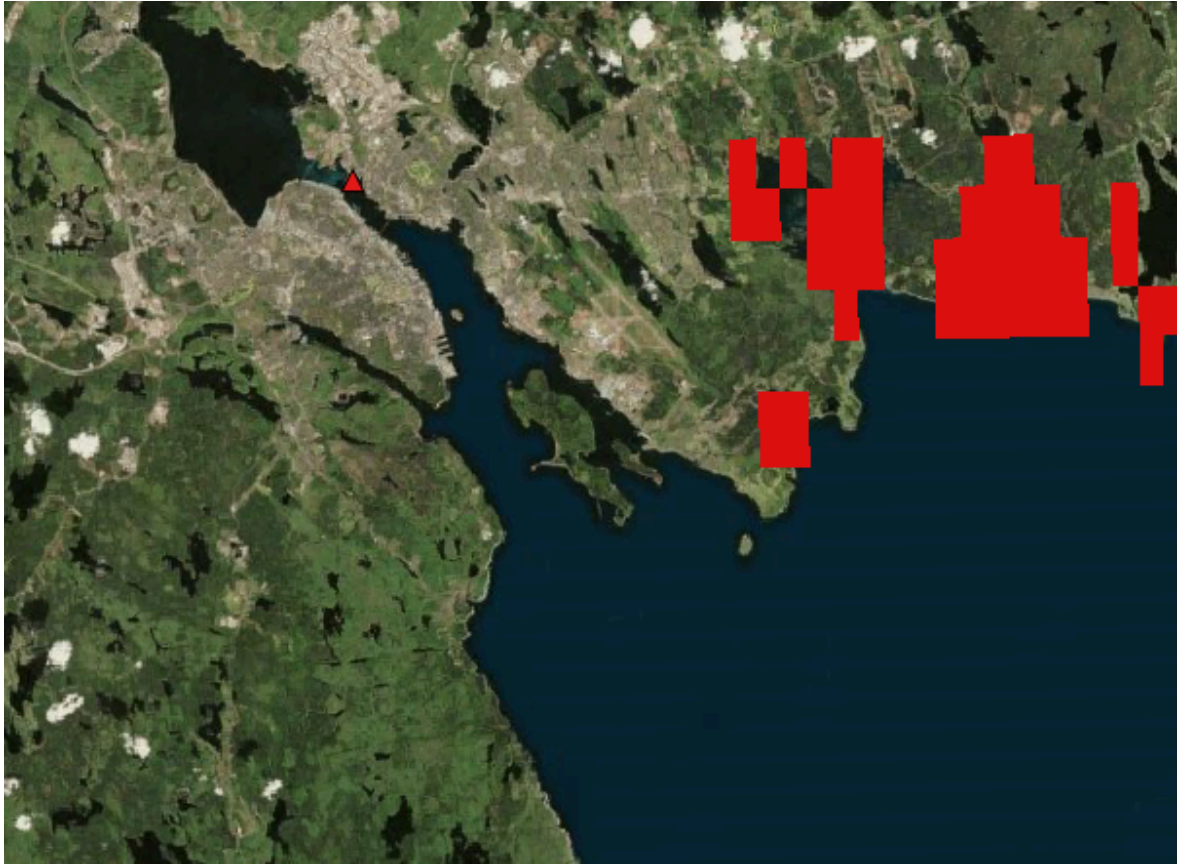


Figure 2: Likely Critical Habitat identified in the vicinity of the project area based on screening through UNEP-WCMC layer

However, the project also has an obligation to consider all marine biodiversity as opposed to solely nationally and internationally recognised habitats that have been designated as particularly sensitive. This pertains to the first objective of the risk guidance above – the conservation and sustainable management of natural living resources, including marine biodiversity and ecosystems – and this requirement has been a key factor in the design of the project monitoring programme.

An important precursor to an effective environmental monitoring programme is the identification of all biological receptors in the marine environment, together with consideration of all adverse impacts they might experience from alkalinity addition.

Iglesias-Rodríguez et al. (2023) note that, when considering those organisms most likely to be affected by OAE, special attention should be paid to those species that (1) significantly impact or respond biogeochemically to chemical changes caused by alkalinity addition (e.g., possibly calcifiers, photosynthetic organisms); (2) keystone organisms (e.g., corals, toxin-producing phytoplankton); and (3) organisms/functional groups of known vulnerability to climate change (corals, sea urchins).

The following is a core list of receptors for consideration:

- Benthic epifauna (invertebrates) and epiflora (algae)
- Benthic infauna
- Benthic microbial communities
- Phytoplankton
- Zooplankton, including larvae of fish and invertebrates
- Fish & shellfish
- Avifauna
- Higher trophic level organisms, such as marine mammals

At the most fundamental level, alkalinity addition to coastal environments could affect the physical and chemical properties of the water column and/or the marine sediments. Whilst these impacts may then interact with the biological receptors identified above through a variety of mechanisms, the root causes of all impacts should be traceable back to alteration of these physical or chemical properties of water and sediments. The following is a list of some of the potential impacts which have been identified and considered, which also incorporates the risks presented by Isometric in their MRV and best practice standard for effecting Ocean Alkalinity Enhancement through Coastal Outfalls (v1.0).

Physical Perturbations

- Undissolved particles of mineral added alkalinity accumulate on seabed around alkalinity addition point, resulting in physical impacts to benthic environment and concomitant impacts upon benthic ecosystems.
- Added alkalinity particles lead to an increase in total suspended solids (and hence turbidity). This can have various impacts, including: reducing the natural light penetration through the water column and impacting primary productivity of both pelagic and benthic photosynthesisers; particle ingestion by filter feeding biota; and increased flocculation leading to the formation of residues
- Suspended particulate matter causes physical damage such as abrasion prior to dissolution
- On projects with seawater intake pipes, marine biota is adversely impacted by impingement, entrainment and entrapment from pumping, pre-treatment and electrochemical treatment.

Chemical Perturbations

- Reduction in aqueous CO₂ around the addition point, which impacts photosynthesising primary producers (phytoplankton/algae)
- Changes in ambient water quality (pH, alkalinity) affect zooplankton, including survival and recruitment of commercially important shellfish or finfish larvae.
- Addition of alkaline substances to seawater causes localised increase in salinity, which can have negative impacts on marine organisms that are hypersensitive to salinity fluctuations

- Changes in the carbonate chemistry of seawater around the addition point, which could impact marine ecosystems and biogeochemical cycles, such as the cycling of carbon, oxygen, and nutrients, and may have a particular effect on calcifying organisms.
- Disturbance to the natural concentrations of macro- or micronutrients through dissolution by-products
- Reduction in water or sediment quality around the addition point due to the presence of trace metal impurities present as dissolution by-products in the added alkalinity, which may then bioaccumulate through trophic levels. .
- Shock to the ecosystem due to rapid or sudden changes in alkalinity dosing
- Increased pH could directly help or harm aquatic life depending on the magnitude of pH shift
- If silica accompanies the alkalinity addition as a product of feedstock dissolution, changes in silicate concentrations could alter diatom growth rates and shift diatom community composition
- Removal of inorganic nutrients due to secondary precipitation could drive nutrient limitation, resulting in a decrease in biological productivity or shift in ecosystem composition

The monitoring programme seeks to mitigate the risks presented by the chemical and physical perturbations listed above in relation to the biological receptors identified. It is evident that, whilst individual risks have been set out above, multiple risks relate to the same chemical or physical perturbation. For instance, undissolved suspended alkaline feedstock particles are the cause of the first three risks related to physical perturbations, and the majority of the risks related to chemical perturbations are linked to changes in marine water chemistry. As such, the monitoring programme has been principally structured around the following key risks:

- 1) Increased suspended particle loads in the water column. In the absence of any mitigation and control measures, this risk is assessed as **high (4)**. However, given that ameliorating this risk is a key focus of the monitoring programme which will inform the adaptive management of the project, the mitigated risk is assessed as **low (2)**.
- 2) Accumulation of undissolved particles on the benthos. In the absence of any mitigation and control measures, this risk is assessed as **moderate (3)**. That said, given that this risk is also a key focus of the monitoring programme which feeds into the adaptive management of the project, the mitigated risk is assessed as **low (2)**.
- 3) Chemical reductions in marine water quality. In the absence of any mitigation and control measures, this risk is assessed as **low (2)**; this is largely due to the rapid dilution of the alkalinity plume and the frequent flushing through the basin, which is likely to prevent any impurities present in the alkalinity reaching concentrations that could cause deleterious effects. Given the mitigation and control measures set out in the monitoring programme and alkalinity feedstock characterisation process, the mitigated risk is assessed as **minimal (1)**.
- 4) Chemical reductions in marine sediment quality. In the absence of any mitigation and control measures, this risk is assessed as **high (4)**; unlike marine water, which

is a transient medium by definition, marine sediments are more (but not entirely) static, which means that accumulation of any impurities present in the alkalinity could occur over time. This makes it more likely that contaminant levels in marine sediments could exceed thresholds that might entail adverse effects for marine ecosystems. However, the mitigation and control measures set out in the monitoring programme and alkalinity feedstock characterisation process have been explicitly structured to minimize this risk. The mitigated risk is assessed as **low (2)**.

Biological metrics, such as plankton community composition, are also a key part of the monitoring programme but any change induced in these receptors is likely to arise as a consequence of the above perturbations. It should be noted that the biota receptors listed above encompass a wide range of trophic levels, from the bottom of the food web (phytoplankton and microbes) to the top (marine mammals). Any direct impacts arising from alkalinity addition will be most easily detected in lower trophic level organisms, as a result of shorter generation times and increased sensitivity to physical or chemical changes to the water and sediment, which are the mechanisms by which biota would be affected by alkalinity addition. As such, in order to maximise the possibility of detecting any impact, it is reasonable that a monitoring programme be primarily aimed at water column and benthic particle loading, together with impacts upon water and sediment quality. This does not mean that higher trophic level organisms should be considered excluded from the scope; in fact, these organisms depend upon primary producers at the base of the food web and are most likely to be impacted by second-order effects, such as disruption to lower trophic level organisms resulting in the altered availability of prey species. Closely monitoring the base of the food web (e.g. through plankton sampling) alongside water quality metrics (e.g., suspended solids and trace metals) will help understand whether any risk exists to higher trophic level animals that ingest water, particles, or lower trophic level organisms. In other words, by monitoring water quality and lower trophic levels, a monitoring programme will provide a signal as to any potential cascading second-order impacts upon organisms higher in the food web.

Direct impacts upon higher trophic level organisms such as marine mammals are not considered likely, given that natural spatial and temporal variation in pH and total alkalinity across the ranges of these species and across seasons typically greatly exceed any differences modelled at the proposed addition rates (e.g. Howland et al., 2000; Humphreys et al., 2020).

References:

Howland, R. J. M., Tappin, A. D., Uncles, R. J., Plummer, D. H., & Bloomer, N. J. (2000). Distributions and seasonal variability of pH and alkalinity in the Tweed Estuary, UK. *Science of the Total Environment*, 251(252), 125–138. [https://doi.org/10.1016/S0048-9697\(00\)00406-X](https://doi.org/10.1016/S0048-9697(00)00406-X)

Humphreys, M. P., Artioli, Y., Bakker, D. C. E., Hartman, S. E., León, P., Wakelin, S., Walsham, P., & Williamson, P. (2020). Air–sea CO₂ exchange and ocean acidification in UK seas and adjacent waters. *MCCIP Science Review 2020*, 54–75. <https://doi.org/10.14465/2020.arc03.oac>

Iglesias-Rodríguez, M. D., Rickaby, R. E. M., Singh, A., and Gately, J. A.: Laboratory experiments in ocean alkalinity enhancement research, in: Guide to Best Practices in Ocean Alkalinity

Enhancement Research, edited by: Oschlies, A., Stevenson, A., Bach, L. T., Fennel, K., Rickaby, R. E. M., Satterfield, T., Webb, R., and Gattuso, J.-P., Copernicus Publications, State Planet, 2-oae2023, 5, <https://doi.org/10.5194/sp-2-oae2023-5-2023>, 2023.

Social Impacts

Labor rights and working conditions, including providing safe & healthy working conditions for employees, fair treatment and equal opportunities in your organization; considerations of prevention of forced labor, child labour or trafficked persons protecting workers employed by third parties.

This is required for all Projects.

Yes	Above risks are applicable to this Project
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Planetary has included labor rights and working conditions directly into our organizational objectives and HR policies. Our top most objective has a strong focus on safety to ensure not only ocean safety but worker safety. We have stop-triggers in place and thorough training practices to ensure workers have the knowledge to act safely. This is coupled with a transparent culture where we encourage psychological safety so all team members can bring forward change or suggestions.

Planetary's HR policies further outline benefits and safeguards to protect the team. This includes paid time off, sick/ wellness time off, paid parental leave and a wellness benefit. We are also working on salary transparency to encourage fairness. We have also included policies around whistleblowing and conflict of interest. Our [Code of Conduct](#) is posted publicly on our website so that we can be held accountable.

Planetary is also actively pursuing B Corp certification and has been working to implement further working condition improvements and a supplier checklist.

Land acquisition and involuntary resettlement in the context of your deployment site selection

No	Not applicable to this Project
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Planetary uses existing infrastructure with the selection of our outfall sites. In Halifax, we are using the existing infrastructure from Nova Scotia Power.

Environmental and social justice and gender equality (equal opportunities and pay), as it relates specifically to deployment site selection.

•	Above risks are applicable to this Project
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Recognizing that we have a responsibility to address both social and environmental impacts of our work, Planetary has been actively pursuing [B Corp Certification](#) and, through this process, have adopted the three pillars of focus to support our JEDI strategy.

Under racial equity, we have adopted key practices addressing diversity in recruitment as well as awareness and education of Planetary talent (e.g. addressing key topics like intersectionality). Under distribution of power, we have invested deeply in people and systems that enable self-management and empowerment (e.g. salary transparency, promotion and performance reviews, coaching support etc.). Under accountability, we have developed and published a public code of conduct and aim to offer transparency across all of our active projects - both by sharing openly what we are up to and by engaging directly with the communities in which we operate.

Human rights, and in particular gender-based violence, including sexual harassment, human trafficking, slavery, imprisonment, physical and mental drudgery, and punishment or coercion.

- Not applicable to this Project

Confirm whether there are **indigenous land rights, ancestral or customary rights or equivalent claims** pertaining to the area in which the project intends to operate. Outline any measures being taken to mitigate any negative impacts on rights-holders, indigenous peoples and local communities.

- Applicable to this Project (please provide details below)

Planetary's Halifax project will operate in a commercial harbor within the ancestral territory of the Mi'kmaq people.

We have been proactive in our approach and reached out to the indigenous communities at the outset of our project plans to both build awareness and to invite their perspectives into our planning process. In essence, it's our high goal to both understand and co-create the conditions under which the project could be scaled in the region over time by surfacing topmost material concerns from these groups.

We have also been working through community engagement practices with community groups as described in Section E. Beyond understanding and integrating / mitigating the topmost material concerns raised in the community into our project plans and are working towards benefits sharing agreement as we scale.

Additional risks

In addition to the above areas of environmental and social impacts, I attest that further risks of potential harm arising from the Project have been assessed, and [please select one below option]:

- | | |
|-----|--|
| YES | A) No such additional risks have been identified |
| • | ~~B) For any such risks identified, appropriate risk mitigations have been put in place and are detailed below.~~ |

Please describe any such risks identified, and the corresponding risk mitigations which have been put in place.

Sustainable Development Impact

Please explain in the below table, where relevant, which Sustainable Development Goals (SDGs) other than SDG13 ("Climate Action") your Project has a positive impact and how this is consistent with the SDG objectives of all jurisdictions in which you operate. If applicable, please include information on any data and parameters monitored before or during the crediting period.

Please see [here](#) for a full list and details of all 17 SDGs.

#SDG with name	Description of project impact	Description of alignment with goals of jurisdiction(s), if relevant and applicable	If applicable, unit of measurement (e.g. removal credits, MWh)
SDG14 - Life Below Water	Minimize and address the impacts of ocean acidification, including through enhanced scientific cooperation at all levels	Aligns with the Nova Scotia Sustainable Development Goals Act , section 6, items (c) and (f)	
SDG9 - Industry, Innovation and Infrastructure	Collaborate with academic, industrial and mCDR peers to collectively advance this novel technology.	Aligns with the Nova Scotia Climate Change Plan for Clean Growth - Accelerating the integration of sustainable and innovative technologies and approaches	
SDG8 - Decent Work and Economic Growth	Planetary has ambitious plans for growth which will create jobs, in	This aligns with the ambitions set out in the Nova Scotia Sustainable Development Goals Act to	

	accordance with the code of conduct referenced above ("Social Impacts).	achieve sustainable prosperity: item 4 (a).	
<i>Please explain whether you assessed the SDG impact of your project prior to this qualitative reasoning. If so, please describe if and which standardized assessment tools and methods you relied on.</i>			
Not formally assessed prior to this evaluation.			

Section E – Stakeholder Input Process

Stakeholder Input Process Summary

Please provide a description and documentation of how comments by local stakeholders have been invited and compiled, a summary of comments received, and report on how due account was taken of comments received. Refer to Section 3.5 "Stakeholder Input Process" of the Isometric Standard for full requirements.

Stakeholder Input Process & Documentation

Planetary has undertaken a comprehensive and strategic process to ensure that all relevant stakeholders and rights holders, including Indigenous Peoples and Local Communities (IPLCs), land-tenure rights holders, policymakers, NGOs, and governmental bodies, are informed and consulted throughout the development and ongoing operation of the project.

Our engagement strategy follows a clear, best-practice framework: *Inform, Consult, Involve, Collaborate and Empower* with transparency as a guiding principle (IAP2 International). This approach ensures meaningful inclusion of diverse voices and perspectives, while fostering shared ownership and empowerment.

This engagement process has been iterative, accessible, transparent, and responsive to stakeholder feedback, in accordance with the Isometric Standard Section 3.5 "Stakeholder Input Process."

1. Invitation of Feedback

Planetary has actively invited stakeholder input through a multi-faceted engagement process designed to maximize accessibility, inclusivity, and responsiveness.

- *Engagement with Local Knowledge Keepers:* Integrating traditional knowledge and perspectives to enhance cultural relevance, respect, and authenticity in project planning and decision-making.

- *Consultation with Indigenous Groups and Organizations:* Ongoing meetings and collaborations with Indigenous communities through representative bodies and collaborative groups. This approach emphasizes relationship-building and sustained dialogue, rather than one-time consultations.
- *Collaboration with Key Community Organizations:* Partnering with various groups to align project activities with local priorities and cultural considerations.
- *Youth Engagement Initiatives:* Creating opportunities for young voices to contribute meaningfully to the project, fostering intergenerational learning and leadership.
- *Outreach to Regulatory Bodies:* Engaging with relevant agencies at multiple levels of governance to ensure compliance, transparency, and alignment with broader environmental policies.
- *Public Awareness & Education Efforts:* Utilizing diverse communication platforms such as websites, newsletters, social media outreach, and public speaker series to enhance understanding and encourage participation.
- *Highlighting Local Voices:* Launching initiatives to amplify underrepresented perspectives through dedicated forums, speaker series, and inclusive outreach activities.
- *Broad Community Engagement:* Consulting with a wide range of community groups, promoting inclusive dialogue, and fostering a sense of shared purpose.
- *Impact Reporting & Transparency:* Regularly sharing progress reports and updates through accessible channels to maintain open communication.
- *Joint Learning Initiatives:* Establishing collaborative learning opportunities with local researchers and stakeholders to support mutual learning, capacity-building, and innovative problem-solving.

2. Summary of Comments Received

Through our engagement efforts, a diverse range of perspectives have been gathered. Feedback and comments primarily were:

- Concerns about the impact of alkalinity additions on fishing and marine life, emphasizing the importance of implementing robust environmental safeguards.
- Questions about the sourcing, safety, and transparency of alkalinity, including potential toxicity, supplier practices, and long-term environmental impacts.
- Interest in how the project's approach to carbon removal compares to carbon reduction, including how the methods align with broader climate goals.
- Concerns about historical water pollution in the area and how the project's interventions might interact with existing environmental issues.
- Curiosity about the scalability of the project and how it can be expanded effectively without compromising safety or environmental integrity.
- Recognition of technological advancements and interest in how these innovations could positively impact both local and global environmental challenges.
- Appreciation for efforts to engage community groups and maintain clear, accessible communication channels.
- Requests for deeper, ongoing collaboration to ensure diverse voices are meaningfully included throughout the project's lifespan.

- Interest in the project's potential to provide economic benefits and contribute to sustainable growth.
- Acknowledgment of our' commitment to transparency, with encouragement to continue providing updates and inviting constructive feedback.

3. Consideration of Feedback & Integration into Project Plans

Planetary has actively integrated feedback from stakeholders into its project goals and planning processes through a process of adaptation, innovation, and collaboration:

- *Conducting Biological Safety Testing:* Responding to community feedback by implementing lobster larvae eco-testing to ensure the safety of alkalinity additions, demonstrating a commitment to precautionary principles.
- *Collaborative Educational Development:* Partnering with relevant organizations to co-develop educational materials that align with local priorities and values, promoting knowledge-sharing and skills development.
- *Innovation & Policy Engagement:* Establishing platforms for broader advocacy and policy discussions, including the creation of new partnerships aimed at influencing environmental and economic policies on a national level.
- *Enhanced Transparency:* Ensuring that stakeholder concerns are addressed through accessible online resources, including project FAQs and public reports.

4. Transparency & Accessibility

Planetary Technologies has prioritized transparency and accessibility throughout the engagement process by:

- *Regularly Updating Project Information:* Providing ongoing, accurate information on the project's progress through public platforms, ensuring stakeholders remain informed and engaged.
- *Maintaining Publicly Available Documentation:* Making reports, updates, and relevant materials accessible to ensure accountability and build public trust.
- *Providing Consistent Communication Channels:* Ensuring stakeholders can easily submit inquiries, provide feedback, and receive timely responses.
- *Cultural & Religious Considerations:* When scheduling meetings or engagement activities, consideration is given to cultural and religious practices to enhance inclusivity and participation.

Grievance Mechanism

Please outline the mechanism for stakeholders to voice, process and resolve grievances.

- Submission Channels: Concerns can be submitted through email, website forms, consultation meetings, or written correspondence.
- Acknowledgment & Resolution: Processes are designed to ensure that any and all concerns are acknowledged within 14 days and addressed within 60 days. If additional review is required, they are escalated appropriately.
- Documentation & Transparency: Records of feedback are maintained and available upon request to ensure accountability.
- Reporting to Isometric: No major grievances have been reported to date. The mechanism is designed to inform Isometric within 14 days if any are received.

Section F – Project Changes

Summary of changes

Please provide details of the proposed or actual changes to the implementation, operation or monitoring of the project activity description submitted to Isometric.

Project Proponents must determine whether the proposed or actual changes are temporary deviations or permanent changes

If there are temporary changes or deviations which are only relevant to a specific Reporting Period, please note this instead in Section C in the corresponding GHG Statement Report.

(Kindly note that this section may not be applicable during the initial validation. If so, kindly leave the section blank and mention "Section is intentionally left blank.")

July 2025:

In the Models section of the PDD, references highlighting use of models in scientific literature were added, and minor wording and formatting changes were made to improve clarity.

Slight alterations made to the Stop Trigger Framework. The key change is introducing additional steps in the assessment of stop triggers. This was put in place after consulting with both the provincial regulatory body (NS-ECC) and local environmental consultants (Dillon Consulting). In particular, exceedances in the ocean or sediment now trigger a sample reanalysis to confirm the initial result. This is common practice, as it helps avoid false-positives due to analytical error and sample heterogeneity.

Impact of changes

Please provide details on the impact of the proposed or actual changes (temporary/permanent) on the following sections of the project:

- Additionality*
- Applicability of Protocol/ Module*
- Quantification of the carbon removals*
- Any other (stakeholder consultation, safeguard assessment etc.)*

(Kindly note that this section may not be applicable during the initial validation. If so, kindly leave the section blank and mention "Section is intentionally left blank.")

July 2025:

Small clarifications and addition of references in the Use of Models section has no impacts.

Changes in the Stop Trigger Framework may require additional safeguard assessment.

History of changes

Please provide the summary of the changes in the table

(Kindly note that this section may not be applicable during the initial validation. If so, kindly leave the section blank and mention "Section is intentionally left blank.")

<i>Date of change</i>	<i>Nature of change</i>	<i>Impact of change</i>	<i>Corresponding version of the PDD</i>
July, 2025	Updates to stop trigger framework	Slight adjustment in how environmental safeguards are monitored and managed.	

Appendix 1: Marine Carbon Dioxide Removal Projects

This appendix should be completed for projects credited using the Ocean Alkalinity Enhancement from Coastal Outfalls protocol. Throughout this appendix, please include citations to any published data sources that were used or referenced.

Section 1.1 – Pre-deployment

Pre-deployment requirements

Please provide an in-depth site description of coastal discharge dynamics according to [Section 9](#) of the protocol.

The site for alkalinity addition is Tufts Cove, a small inlet within Halifax Harbour adjacent to the Tufts Cove Power Generation Station (see Figure 1.4.1 in Appendix 1). In general, Halifax and Halifax Harbour are subject to very strong seasonal variability. Average air temperatures range from -8 to 0 °C in January, and about 15 to 23 °C in August (Environment Canada), while sea surface temperatures in the region range from approximately 1 to 18 °C (Burt et al., 2013; [Bedford Institute of Oceanography](#)). Salinities range from ~28.5 to 30.5, with typically weak seasonality.

Halifax Harbour exhibits typical estuarine circulation, characterized by offshore flow of surface waters driven primarily by Sackville River discharge at the head of Bedford Basin, and subsurface return from the Scotian Shelf (see Figure 1 below). Sackville River discharge typically peaks in spring and steadily decreases until late summer (August). The Sackville River accounts for approximately one-third of total freshwater input into Bedford Basin and Halifax Harbour, with smaller rivers, storm drains, and wastewater discharge contributing the remainder. Groundwater is not considered a significant source in this urbanized harbour.

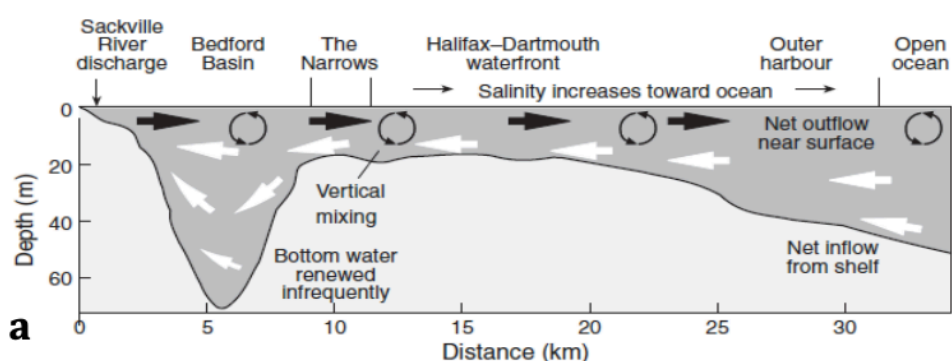


Figure 1: Simplified circulation pattern across Halifax Harbour (taken from Burt et al., 2013)

Tides and winds also play important roles in the circulation patterns and hydrodynamics (Shan et al., 2011). The Harbour experiences semi-diurnal tidal elevations (mean tidal range of 1.3 m, and up to 2 m). Tidal flows, and current speeds, generally, are strongest in the Narrows, a 300m-wide and 20-m deep channel in the central harbour, where Tufts

Cove is located. Clear tidally-driven variability is seen in the Narrows, but not elsewhere in the Harbour (Shan et al., 2011, as well as recent model runs, K. Fennel, pers. comm.). Local wind forcing can significantly alter the strength of the estuarine circulation, and based on observations in 2023 (particularly rhodamine dye releases), wind-induced currents are important in dictating the initial dispersion of an alkalinity plume from Tufts Cove. Winds are generally strong and vary seasonally, with stronger winter winds predominantly from the west/northwest, and weaker summer winds from the south/southwest. Overall, tides are the dominant driver of variability at the point of alkalinity addition. Throughout the broader Harbour, alkalinity dispersion is driven generally by the estuarine circulation. Winds impose significant localized and sporadic variability on the surface alkalinity dispersion. A comprehensive study of the oceanography of Halifax Harbour, particularly seasonal dynamics and circulation patterns, is given in Shan et al., 2011. As a result of recent OAE-driven research, described in the Monitoring Plan sections below, more updated peer-reviewed literature is in preparation. For example, general water-mass and circulation patterns across Halifax Harbour have been studied via monthly harbour-wide monitoring campaigns that began in 2022 (Yee et al., in prep.). Patterns in circulation and biogeochemistry have also been simulated using more up-to-date numerical modeling (see ROMS model described in detail below, Laurent et al., in prep.). Summaries of this work can be found in the form of conference abstracts (e.g., Atamanchuk et al., 2024, and Laurent et al., 2024 below), but at this point this relatively recent work has yet to be submitted for peer-reviewed publication.

Flushing times in the Harbour also vary by region and season. Generally, flushing times range from ~1 day in the Narrows to 2-5 days in the Outer Harbour. Longer residence times, ~40 days in the upper parts of Bedford Basin and ~90 days in the deeper Central Basin, result from the limited exchange of seawater over a shallow sill (~20 m deep) located at the intersection between the Basin and Narrows (Shan and Sheng, 2011). A more comprehensive analysis of spatiotemporal variability in flushing times using ROMS model output is currently underway, but preliminary results show similar results to prior work (Wang et al., in prep.).

In addition to these general patterns, a number of events can alter the biogeochemistry of Halifax Harbour. The region experiences significant storms throughout the year, particularly in winter, as well as tropical storms and hurricanes in fall, with the latter intensifying in recent years. During summer and fall, limited ventilation leads to pCO₂, DIC and nutrient accumulation and significant oxygen depletion in deeper waters of Bedford Basin. Deep water flushing events occur in most winters via convective mixing, and also via deep water intrusions of offshore waters that pour over the sill, typically in the fall (Burt et al., 2013). Primary productivity follows a typical temperate seasonal cycle, with a significant spring bloom around April, and a smaller autumn bloom typically in October (Li and Dickie, 2001). However, phytoplankton remain fairly productive (Chl *a* levels typically >2 mg/m³) throughout the summer, due largely to consistent nutrient inputs from wastewater and other runoff. The role of wastewater and urban runoff in altering biogeochemistry of the harbour is an active area of research. More recent work using microcosms in the inner Harbour has shown that Chl concentrations near the shore can change dramatically, possibly due to sporadic nutrient loading in these shallow nearshore areas (H. MacIntyre, pers. comm.).

The surface waters of Halifax Harbour warm throughout the spring and stratification is typically established from ~April-October, with strongest stratification typically occurring in September (Shan et al., 2011). Compared to other areas of the Basin and Harbour, the Narrows are well-mixed throughout the year due to the strong tidal mixing. As a result of this stronger mixing, sediment cover in the Narrows is limited to small patches, with the bulk of sediment deposition occurring in the deeper Bedford Basin where surface currents are typically weakest (K. Fennel, pers. comm.).

To-date, the vast majority of carbonate chemistry data has been collected at a single station in the central Bedford Basin. The primary known carbon fluxes in the Harbour are from the Sackville River, wastewater treatment, and primary production, and benthic flux rates of nutrients, DIC and alkalinity have been estimated by Burt et al. (2013). More recent data collected elsewhere across Halifax Harbour show a strong linear alkalinity-salinity relationship, and highly variable benthic flux rates that are generally comparable in magnitude to work by Burt et al. (2013) (C. Algar and D. Atamanchuk, pers. comm.). Significant Dalhousie-led research tied to the ongoing OAE project is underway to better elucidate benthic fluxes.

It is also notable that Halifax Harbour is an extremely busy port, and has been a highly industrialized water body for over a century. Currently, the Harbour hosts Canada's East Coast Navy fleet, a large ship-building port, one of Canada's largest commercial ports (~1500 ships annually), a large cruise ship industry (>150 cruise ships annually), and significant wastewater discharges (typically advanced primary treatment). Water quality has improved over the past 15 years due primarily to upgrades in wastewater treatment facilities. However, swimming in the harbour is not common, and 'no swimming advisories', resulting from waste- and/or stormwater leaks into the Harbour, are typical, particularly during the summer. Sediment sampling has taken place across the harbour for many decades, and legacy contamination of metals and organic compounds is well documented (e.g. Tay et al., 1992; Buckley, Smith & Winters 1995; Williams, 2010). In particular, concentrations of certain heavy metals (e.g. copper, silver, lead, mercury), have been, for many years, consistently above the probable effect threshold (PEL) for sediments at many locations throughout the harbour, according to the Canadian Environmental Quality Guidelines

Outside Halifax Harbour, the Nova Scotia coastal current runs southwest along the inner Scotian Shelf. Limited cross-shelf exchange occurs, thus alkalinized water that exits the Harbour will typically flow southeast toward the Bay of Fundy and Gulf of Maine.

References:

Atamanchuk, D., Laurent, A., Wang, B., Fennel, K., Musgrave, R., Wallace, D., Fradette, C., Izett, R., and Burt, W.: Detectability of alkalinity plumes during the OAE field trial: A Bedford Basin case study, EGU General Assembly 2024, Vienna, Austria, 14–19 Apr 2024, EGU24-12132, <https://doi.org/10.5194/egusphere-egu24-12132>, 2024.

Buckley, D.E, Smith, J.N and Winters, G.V. Accumulation of contaminant metals in marine sediments of Halifax Harbour, Nova Scotia: Environmental factors and historical trends: Applied Geochemistry, vol. 10, no. 2, pp. 175-195, 1995.

Burt, W. J., Thomas, H., Fennel, K., and Horne, E.: Sediment-water column fluxes of carbon, oxygen and nutrients in Bedford Basin, Nova Scotia, inferred from ²²⁴Ra measurements, Biogeosciences, 10, 53–66, <https://doi.org/10.5194/bg-10-53-2013>, 2013.

Laurent, A., Wang, B., Pei, Q., Ohashi, K., Sheng, J., Garcia Larez, E., Fradette, C., Rakshit, S., Atamanchuk, D., Azetsu-Scott, K., Algar, C., Wallace, D., Burt, W., and Fennel, K.: A high-resolution nested model to study the effects of alkalinity additions in a mid-latitude coastal fjord, EGU General Assembly 2024, Vienna, Austria, 14–19 Apr 2024, EGU24-6536, <https://doi.org/10.5194/egusphere-egu24-6536>, 2024.

Li, W. K. W., and Dickie, P. M.: Monitoring Phytoplankton, Bacterioplankton, and Virioplankton in a Coastal Inlet (Bedford Basin) by Flow Cytometry, Cytometry, 44, 236-246, [https://doi.org/10.1002/1097-0320\(20010701\)44:3<236::AID-CYTO1116>3.0.CO;2-5](https://doi.org/10.1002/1097-0320(20010701)44:3<236::AID-CYTO1116>3.0.CO;2-5), 2001.

Shan, S., Sheng, J., and Thompson, K. F.: Simulating the three dimensional circulation and hydrography of Halifax Harbour using a multi-nested coastal ocean circulation model, Ocean Dynam., 61, 951–976, 2011.

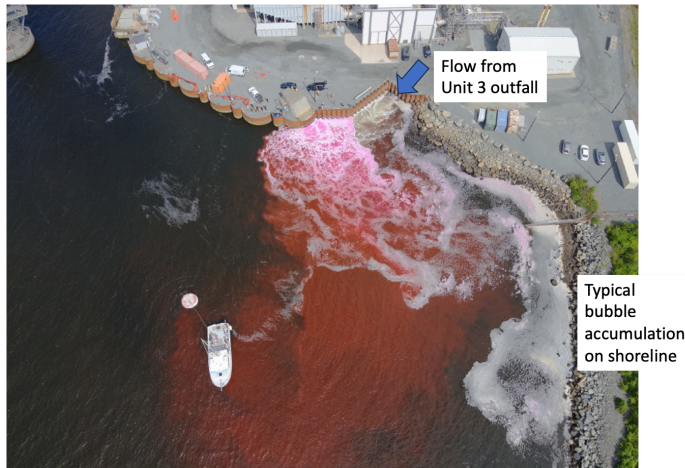
Tay K-L, Doe KG, Wade SJ, Vaughan DA, Berrigan RE, Moore MJ. 1992. Sediment bioassessment in Halifax harbour. *Environ Toxicol Chem* 11: 1567–1581.

Williams, G., Parsons, M.B., Hellou, J. and Scott, D.B. (2010). Evaluating the effects of wastewater treatment on marine sediment chemistry in Halifax Harbour, Nova Scotia. *Atlantic Geology*, 46 (1).

Please describe a conceptual model of alkaline plume transport and dispersion from the alkalinity release location. This may include results from a mixing zone model, regional model, and/or prior surveys on mixing and dispersion at the site. Describe how initial alkalinity dispersal estimates will inform the spatial extent of monitoring efforts according to [Section 9](#) of the protocol.

Dilution rates from the discharge point are calculated empirically using results from dye tracer releases conducted in 2023. This approach is preferred over typical plume modelling approaches (e.g. analytical plume models or CORMIX software) because of the unique nature of the Tufts Cove outfall. Specifically, waters from the pipe plunge into the receiving waters down a ‘waterfall’, rather than simply discharging from a pipe. Also, the Tufts Cove Unit 3 outfall (discharge rate higher than the Unit 6 outfall used for this project) is less than ~20m away from the Unit 6 outfall, creating a complex mixed plume that will be extremely difficult to model accurately using industry standard tools. Three releases were conducted (August, September, October). The drone image below shows the August

release, and the influence of the unit 3 outfall on the initial dye dispersion.



The dilution factor (D) at a given distance (x) from the discharge point is calculated as:

$$D(x) = C_0/C_x$$

Where C_0 is the initial dye concentration in the outfall, and C_x is the measured concentration at a given location. Preliminary results from the Dalhousie team show that near the addition point (within ~100m), dilution factors vary considerably (on the order of 10s-100s). The plume is then mixed/advected away, creating dye filaments (confirmed by drone imagery) that result in highly variable dye concentrations at further distances from the plume. These results highlight that: 1) dilution factors here can vary significantly in both time and space, making accurate dilution factor estimates via boats or moorings difficult, and 2) typical plume modelling techniques (e.g. via CORMIX) in this complex system will be hugely challenging. Nevertheless, data from the dye releases provide bounds for the concentrations of important parameters (e.g. alkalinity) that we can expect near the addition point. For example, the lowest bound of these estimates (dilution factor of 10) is used to predict the maximum pH, alkalinity, and total metals concentrations expected in the receiving waters, which is then used to further ensure the choice of safe dosing rates. These preliminary results are also used to inform the monitoring plan outlined in section 1.4. Specifically, these analyses help define the spatial extent of the 'plume', which in turn informs placement of both the boat-based sampling stations used to measure 'in-plume' and 'out of plume' characteristics, as well as the placement of the moored sensor package. Comprehensive analysis of these dilution factors is currently underway by the Dalhousie team.

Based on the significant methodological and operational learnings from the 2023 dye experiment, additional dye releases are planned for the 2024 project described here. The timing and scope of these releases are not yet confirmed.

Please outline your alkalinity dosing rates, and justify how modeling has been used to determine that alkalinity release that adheres to relevant safety thresholds and minimizes water contamination and accumulation on the sea bed, according to [Section 9](#) of the protocol.

During the 2023 OAE field trial, Planetary safely dosed alkaline feedstock into the receiving waters of Halifax Harbour at rates ranging from 7 to 21 kg/min. A basal (1x) dosing rate of 7 kg/min was selected based on preliminary modeling work performed by Dalhousie University that revealed that such a dosing rate would be necessary to measure a detectable pH and TA spike in the receiving waters of Tufts Cove. In 2024, we will adopt the same initial 1x dose rate, but will select a new, nominal dose rate based on an early-trial experimental phase. Indeed, Planetary is proposing to conduct the 2024 alkalinity release trial in two phases (Fig. 1.1.1) consisting of (1) an intense, 2-week ramping phase, followed by (2) nominal 5-day/week dosing. The trial will begin in mid-summer (July/August), and will end in winter (late 2024 or early 2025).

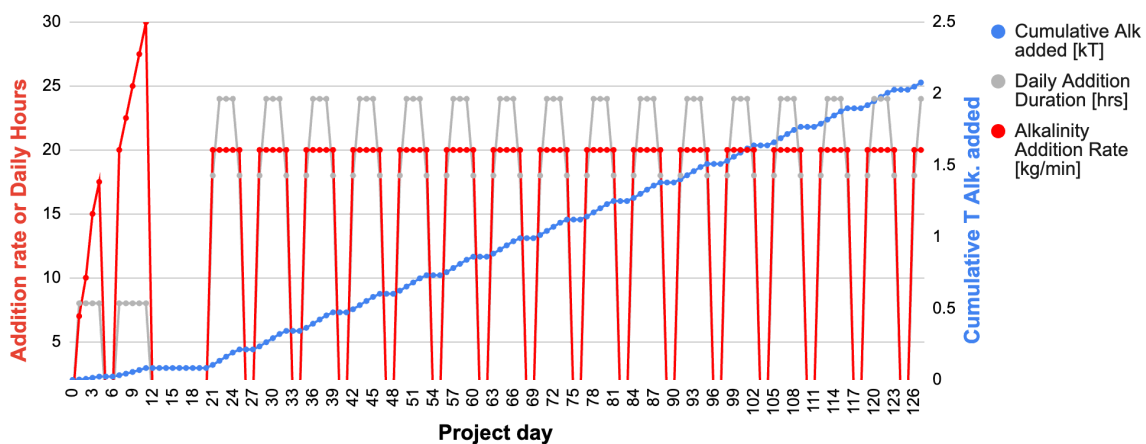


Figure 1.1.1 Proposed alkalinity dosing schedule showing a proposed ramping phased (days 1-14), followed by a nominal continuous dosing period. Short breaks represent weekends. Breaks for holidays, maintenance shut-downs, or pauses in the event of a stop-trigger being breached are not currently scheduled.

The goal of the ramping period will be to ascertain a safe, nominal dosing rate that we are confident will not result in an exceedance of a stop-trigger threshold (see section 1.2 below). This period will comprise the following:

- Alkaline feedstock delivery rates will be increased incrementally from ~7 kg/min (start of week one) to as high as ~40 kg/min (end of week two, exact max rate TBD, max shown in image above is 30 kg/min)
- Each prescribed dosing rate will be sustained for 8 hours (9a-5p), and the rate will be increased by 2.5-5 kg/min on each subsequent day.
- Planetary will conduct extensive monitoring of the effluent and ocean receiving waters (see details in Appendix 1, section 1.4), and will pause dosing operations for at least one week afterwards to analyze the resulting data.

Note that Planetary will immediately reduce dosing rates or pause the ramping phase in the event that a stop-trigger threshold is reached (e.g., effluent pH > 9).

During the nominal dosing period, we will maintain a constant dosing rate each week until the end of the trial. Notwithstanding holidays, maintenance shut-downs, or pauses in the event of a stop-trigger being breached, dosing will commence at approximately 6am on Monday mornings and will end at 6pm on Friday evenings. Dosing rates will remain

constant during that time, unless a stop-trigger is reached; in such an event, we will reassess the nominal dose rate based on our most up-to-date learnings.

The dosing schedule proposed in Fig. 1.1.1 will be used to conduct a pre-trial modeling simulation (using the ROMS model described elsewhere, and including dissolution and sinking parameters chosen based on feedstock testing). This simulation may be used to refine our monitoring plan (see section 2.6, below), by providing insights into optimal sampling locations and timing.

Section 1.2 – Additional details on Environmental & Social Safeguarding

Additional details on Environmental & Social Safeguarding

Note: In Section D “Analysis of environmental and social impacts” above, please include a description of mitigation plan & accompanying robust monitoring plan as described in [section 6.3](#) of the protocol.

Please outline details of all relevant permitting for the marine CDR project, according to [section 6.2](#) of the protocol. Include here what permits have been acquired for project siting, what discharge and other limits are set by the permit, and any monitoring requirements (frequency and duration) you must adhere to under the permit.

The project falls within the jurisdiction of the Province of Nova Scotia and is regulated under the [Environment Act, S.N.S. 1994-95, c.1 s.1](#) (“Environment Act”).

Planetary was granted approval (Approval No. 2023-3366981-00) to operate a Dangerous Goods - Chemical Storage Facility from September 6, 2023 to September 6, 2025 at 315 Windmill Road, Dartmouth, Nova Scotia, B3A 1H5 (Property Identification Number - PID: 41380395).

Paragraph 9 of the approval restricts the site to the use of Magnesium Hydroxide ($Mg(OH)_2$) while paragraph 12 details monitoring and reporting requirements. Section 6.2 of this document outlines our monitoring program which ensures compliance with the Monitoring and Recording section (copied below for ease of reference)

12. Monitoring and Recording

- a. The outfall Environmental Monitoring conducted at the outfall to measure Dissolved Inorganic Carbon (DIC), Total Alkalinity (TA), pH and TSS shall be recorded and provided to the Department after each addition phase.*
- b. The Environmental Monitoring conducted at the mooring station to measure Dissolved Inorganic Carbon (DIC), Total Alkalinity (TA), pH and TSS shall be recorded and provided to the Department after each addition phase.*
- c. The outfall shall be monitored continuously during the $Mg(OH)_2$ addition phases, the monitoring compliance limits are as follows:*
 - i. Suspended Solids shall not exceed 40 mg/L.*

sii. pH - 6.5 to 9

An amendment to the approval was submitted to the Nova Scotia Department of Environment and Climate Change (NS-ECC) in spring 2024. The amendment, which includes updates to the alkaline feedstock, dosing system, and contingency plans as detailed in this document, was approved by NS-ECC in May, 2024.

Please outline how you undertook an environmental justice review, including who conducted this, what information it took into account, and how it considered the historical inequities in the distribution of coastal amenities and disamenities prior to site selection, according to [section 6.4](#) of the protocol.

Community engagement activities and goals have been well outlined in prior questions, so that (to avoid repetition here) we'll focus here on "environmental justice" efforts undertaken by the team at Planetary. To inspire our thinking and approach we have focused on B-Corp standards and practices as well as integrated thoughts from leaders in the community like Carbon180. There is a complex question to be answered around what "social MRV" looks like in relation to our work and we are working towards the same through:

1. Understanding what benefits sharing looks like in the communities in which we operate with a goal of understanding the socio economic consequences of our projects (alongside technology and scientific concerns).
2. Identifying and engaging with vulnerable and under-represented groups (e.g. Indigenous peoples) in the communities in which we operate.
3. Having safeguards in place to minimize harm done and ensure that adverse impacts are not borne by vulnerable and disadvantaged groups in the communities in which we operate.
4. Holding both a temporal and spatial view on our projects - considering both geographic location and "over time" impacts of our work as it scales in both space and time.

We are also actively engaged with social scientists to better understand these questions and to explore how best to approach such questions that touch environmental justice from an MRV perspective.

Please include a description of the adaptive management plan for information sharing, emergency response and conditions for stopping or pausing a deployment, according to [section 6.6](#) of the protocol.

Planetary has developed the concept of 'stop-triggers', whereby a variety of different measurements can cause a 'STOP' in the dosing activity. These triggers will be made publicly available and will be strictly adhered to during the project:

Stop-triggers

Predosing feedstock characterization and quality assurance is the main safeguard, marine sampling is the confirmation of that assumption. In-pipe measurement of pH and TSS is a regulatory requirement.

Type	Trigger / threshold	Stop action ^(A)	Resumption requirements
Manual	Personnel injury	Stop dosing immediately	- First aid administered to the injured worker (if necessary), and preventative measures put in place to ensure no repeat injury - Sufficient number of fit operators on-site
	Equipment malfunction resulting in unsafe working conditions (e.g., leaks, sparks), un-monitored dosing or loss of dosing data	Stop dosing immediately	Equipment fixed and safety-tested
	Spill occurs	- Stop dosing immediately - Inform environmental regulator.	- Spill cleaned up - Regulator informed of cleanup
	Inclement weather (realized or forecasted)	Stop dosing immediately	Inclement weather subsides
Effluent	pH: rolling hourly-median value >9 or <6.5	Stop dosing immediately	- Reduce dosing rate - Demonstrate values at lower dosing rate no longer exceed - Regulator report sent within 48hrs of event
	TSS: rolling hourly-median difference between up- and downstream stations >40 mg/L		
	TA: total alkalinity >1000 umol/kg above background ^(C)		
Ocean^(B)	pH: any measurement outside 7-8.7 range or >0.2 units above background when background exceeds that range ^(C)	Initiate follow-up sampling and analysis to verify observed exceedance. Stop dosing if link to Planetary is established.	- Dosing will resume at a reduced rate, and will be gradually increased to the previous rate. Increasing the dose rate will only occur when subsequent sampling demonstrates safe thresholds for all measured variables. - Regulator report sent within 48hrs of event
	TSS: >25 mg/L difference between in- and out-of-plume		
	Dissolved oxygen: A) < 10% below background concentration range ^(C) in the alkalized plume when DO >8mg/L; or B) below natural DO when DO		

	<8mg/L		
	Total metals: in-plume concentration > EQS limit ^(D) when out-of-plume concentration < EQS limit		
Sed.^(B)	Total metals: Sediment metals concentrations for any of 9 metals (Ag, As, Cd, Cr, Cu, Hg, Ni, Pb, Zn) exceed stop-trigger thresholds determined as statistical outliers in long-term average comparable dataset for Tufts Cove and immediate area.	Initiate follow-up sampling and analysis to verify observed exceedance. Stop dosing if link to Planetary is established	- Dosing will resume at a reduced rate, and will be gradually increased to the previous rate. Increasing the dose rate will only occur when subsequent sampling demonstrates safe thresholds for all measured variables. - Regulator report sent within 48hrs of event
Bio./Eco.	Abnormal wildlife activity observed	Stop dosing immediately	- Once wildlife activity ends, dosing can resume at equal or reduced rate. - Closely monitor the area, and if wildlife activity resumes soon after restart, dosing must stop until further analysis can be completed - Activity must be noted in regular weekly regulator reports

(A) “stopping dosing immediately” is to be done ONLY when it is deemed safe to do so (e.g., if injury has occurred, the injured person must first be secured before taking further action). Stopping dosing must also be communicated clearly to the broader team via Slack.

(B) Ocean and sediment thresholds closely follow guidelines imparted by [CCME](#). The 9 metals parameters selected are those which CCME identifies as being of particular environmental concern and therefore provides guideline thresholds for marine sediments. Comparable data is defined as using similar sampling and analysis (e.g. digestion) techniques.

(C) Background conditions primarily determined from various baseline data sources (see Pre-deployment monitoring, section 1.4), including long-standing time-series of Bedford Basin and Planetary monitoring activities. Out of plume data (derived from three additional stations located over 300 m away from the Tufts Cove plume) are also used to assess OAE impacts during dosing periods.

(D) EQS limits for metals are defined by [CCME](#) and the US-EPA when CCME definitions are not available.

Section 1.3 – Quantification approach

Net carbon removal quantification approach

Please describe how net carbon removal is quantified for this project, following Equation 1 in [Section 7.4.1](#) of the protocol. This should include additional equations if applicable, definition of terms, emissions allocation method and how the time-evolution of CO₂ uptake is accounted for.

Planetary's quantification methodology for CO₂e removals is fully documented in the MRV3 protocol,[1] and is briefly summarised here.

Gross, net, and creditable removals

Conceptually, gross removals are quantified using equation 1;

$$\text{CDR}_{\text{GROSS}} = \text{ALK} \times \text{CDR}/\text{ALK} \times \eta \quad (1)$$

where ALK is a quantity of reactive alkalinity discharged to the sea (tonnes), determined from the mass of feedstock and its wt% reactive alkalinity content (EQOH), the latter as described in Appendix 2C; Assessment of CO₂ removal potential,

CDR/ALK is the theoretical CDR per tonne of ALK (tonnes CO₂/tonne ALK), and

η is the discharge location specific CDR efficiency (fraction).

In practice, $\text{CDR}_{\text{GROSS}}$ is directly determined from the ocean modelling approach described in Section 4, and the efficiency term η is back calculated using equation 1. As discussed in the Isometric Protocol (Section 7.3), the counterfactual against which $\text{CDR}_{\text{GROSS}}$ is determined is the prevailing ocean state, including the natural background ocean uptake and outgassing of CO₂ over the same domain during the reporting period, without the project's alkalinity addition.

Net removals are then calculated according to equation 2;

$$\text{CDR}_{\text{NET}} = \text{CDR}_{\text{GROSS}} - E_{\text{LCA}} \quad (2)$$

where E_{LCA} is the total lifecycle embedded CO₂e emissions associated with the quantity of added ALK (tonnes CO₂e), determined as described elsewhere.

The calculated CDR_{NET} is subject to the following uncertainties;

- the mass of feedstock added to the ocean,
- the reactive alkalinity content of the feedstock,
- parametric and systemic uncertainty in the ocean model, and

- the inputs to the quantification of E_{LCA} .

These uncertainties are quantified as probability density functions (pdfs), which are combined using Monte Carlo simulation to determine an overall pdf for CDR_{NET} . The creditable CDR quantity (CDR_{CRED} , tonnes CO_2) is determined from the CDR_{NET} cumulative probability curve for an exceedance probability of 84%, equivalent to one standard deviation below the mean for a normal distribution.

The discount from CDR_{NET} to CDR_{CRED} is termed the holdback CDR_{HBACK} , so that;

$$CDR_{CRED} = CDR_{NET} - CDR_{HBACK} \quad (3)$$

Ex post and ex ante estimates

CDR_{NET} and CDR_{CRED} may be determined for a specific quantity of alkalinity addition either *ex ante* – removals up to a specified future time – or *ex post* – removals up to the time of the estimate. The Isometric OAE protocol specifies that removals credits will only be issued *ex post*, in which case it is appropriate to replace E_{LCA} in equation 2 with the proportion of these total emissions embedded in the fraction of added alkalinity that has resulted in the CDR achieved at the estimate date. Thus;

$$CDR_{NET.XP}(t) = ALK \times CDR / ALK \times \eta(t) - E_{LCA} \times \eta(t) / \eta_{10} \quad (4)$$

$$CDR_{CRED.XP}(t) = CDR_{NET.XP}(t) - CDR_{HBACK.XP}(t) \quad (5)$$

where $\eta(t)$ is determined at the estimate date, and η_{10} is the efficiency achieved at the end of a 10-year forecast (see next section). Equation 5 essentially allocates E_{LCA} across the full CDR profile resulting from the ALK addition.

While not required for credit issuance, an *ex ante* estimate is essential for business planning, and a forecast for the 10-year period from the start of dosing (using equations 1 and 2) is also presented here.

[1] Available at <https://github.com/Planetary-Technologies/MRV/releases/tag/v3.0>

Please describe the strategy (measurements and methods) used to quantify processes relevant to the calculation of gross CO_2e removal, cross-referenced with relevant standards where applicable following [Appendix 1](#) of the protocol. This section should also describe the risk of and strategy for alkalinity losses, following [Section 7.4.2](#).

Mitigation and quantification of potential alkalinity losses

The Isometric OAE protocol notes that, upon alkalinity discharge, losses of TA leading to reduced OAE efficiency can arise due to secondary precipitation, enhanced biotic calcification, or changes in counterfactual alkalinity release as a result of sediment interactions. The mitigation and/or quantification approach for each of these potential losses is discussed below.

Alkalinity loss from secondary precipitation

The latest research on this topic clearly demonstrates that compliance with regulatory pH limits (for this project, $\text{pH} < 9$ at the end of pipe) is sufficient to prevent the initiation of secondary precipitation.[1] Standard operational monitoring of the alkalinity discharge to ensure regulatory compliance will ensure that this risk is avoided.

Prior to alkalinity discharge, secondary precipitation may occur in the seawater-based slurry if this is kept in a holding tank for several days. Here, the residence time of the slurry tank will be on the order of minutes-to-hours. In the event that slurry is kept in the tank for several days, the quantitative impact of precipitation in the tank is minimal due to the small volume of seawater affected, and this can be quantified for any affected volumes by calculating the TA loss and related CO_2 emissions assuming the complete precipitation of all carbonate in the mixing water.

Alkalinity loss from biocalcification

Planetary follows the mitigation strategy noted in the Isometric Protocol, of setting pH and TA guardrails at $\text{pH} < 9$ and $\Delta\text{TA} < 1000 \mu\text{mol/kg}$ in effluent pipe prior to discharge, these being lower than the perturbations in published studies that showed no significant increase in biologically produced CaCO_3 . [2]

Alkalinity loss from sediment interactions

Early research suggests that OAE may reduce natural alkalinity fluxes from sediments (i.e., ‘additionality problem’, Bach et al., 2023).[3] This risk may be exacerbated by mineral OAE projects which result in alkalinity enrichment in sediments, and the potential impacts on the net removal calculation remains an active area of research.

A recommended avoidance strategy for mineral OAE projects is to limit accumulation of alkalinity on the sea bed through careful selection of rapidly dissolving feedstock, dosing rate and project sites with full water column mixing and/or sufficient resuspension due to shear forces at the sea bed. Based on the estimated dissolution rates, and the model simulations that incorporate that dissolution in the harbour, the risk of seabed accumulation is very low. Regardless, sediment sampling will help understand whether any accumulation is occurring. Finally, benchtop incubation experiments using Halifax Harbour sediments alongside the feedstock can test whether accumulation does result in a depression of sediment alkalinity fluxes, and these are planned over the coming months.

[1] Suitner, N., Faucher, G., Lim, C., et al., 2023. Ocean alkalinity enhancement approaches and the predictability of runaway precipitation processes—Results of an experimental study to determine critical alkalinity ranges for safe and sustainable application scenarios. *EGUsphere*, 2023, 1-35.

[2] Subhas, A.V., Marx, L., Reynolds, S., et al., 2022. Microbial ecosystem responses to alkalinity enhancement in the North Atlantic Subtropical Gyre. *Frontiers in Climate*, 4, p.784997.

[3] Bach, L. T.: The additionality problem of ocean alkalinity enhancement, *Biogeosciences*, 21, 261–277, <https://doi.org/10.5194/bg-21-261-2024>, 2024.

For each term in the net carbon removal equation, please describe how the uncertainty is quantified.

Uncertainty in alkalinity addition

Note: Complete details of the uncertainty propagation cannot be finalized because the details of the ocean modelling approach are not yet finalized. Accordingly, a complete uncertainty analysis will be provided with the final CDR quantification documents. The parts that are known, and general statements regarding the approach, are provided below.

The uncertainty in the quantity of reactive alkalinity added to the discharge has two components, uncertainty in the total tonnage of raw material added and uncertainty in the reactive alkalinity content of each tonne of raw material.

Dry feed mass uncertainty

The feedstock mass is weighed prior to dosing using a calibrated scale, with the uncertainty associated with these weights determined during the scale calibration process.

Reactive alkalinity content uncertainty

The reactive alkalinity content of the feedstock (EQOH) is determined as described in Appendix 2C. Heterogeneity of this EQOH value, and thus the feedstock itself, is determined through consistent analysis of the feedstock throughout the operation, following the sampling procedures described in Appendix 2D. The standard deviation of the resulting EQOH values provides the uncertainty of the reactive alkalinity content.

Uncertainty in CDR_{GROSS}

This will be assessed using an ensemble of sensitivity runs of the near- and far-field models, supplemented by additional runs using a calibrated 1D model.

Uncertainty in life-cycle emissions

This will be assessed based on uncertainties in the input factors contributing to the major life-cycle emissions components, such as the uncertainty in the carbon intensity of ocean container shipping. [4]

[4] Cepowski, T. and Drozd, A., 2023. Measurement-based relationships between container ship operating parameters and fuel consumption. Applied Energy, 347, p.121315.

Section 1.4 – Monitoring Plan

Refer to [Appendix 2](#) of the protocol for guidance and resources on high quality observational data collection.

Description of Monitoring Plan

Please provide a summary of the full monitoring plan, including any maps of monitoring locations, tables summarizing measurements that will be taken and how they will be reported and used.

Overview

Planetary will conduct monitoring activities of the ocean receiving waters in Halifax Harbour (Fig. 1.4.1) and outfall prior to, during and after the proposed trial. These activities have been developed in accordance with the standards identified in Section 10 of the Isometric OAE protocol V1.0. Additionally, Planetary has established a list of ‘stop-triggers’ to further ensure regulatory compliance and environmental safety throughout the trial (see section 1.2 above).

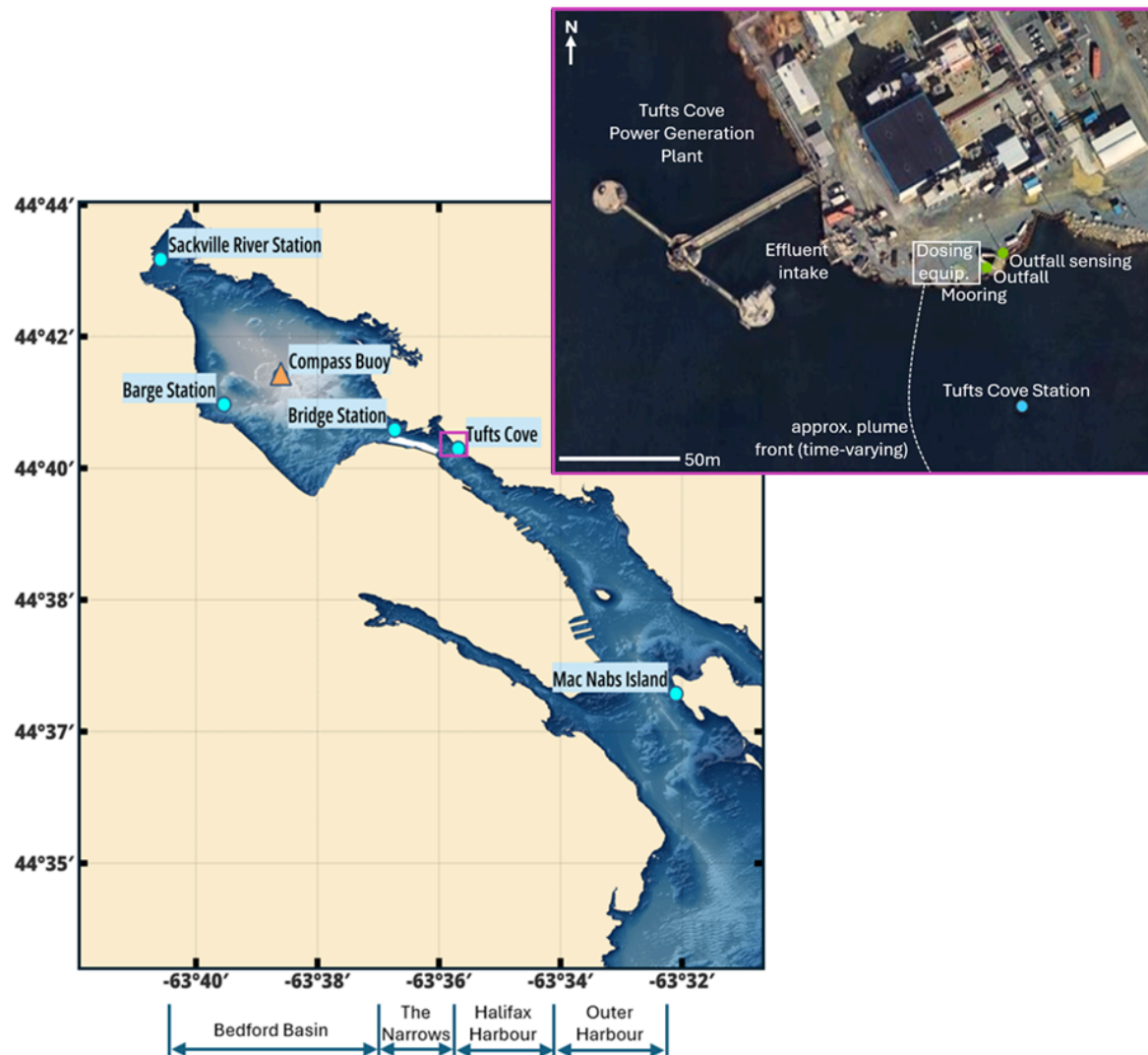
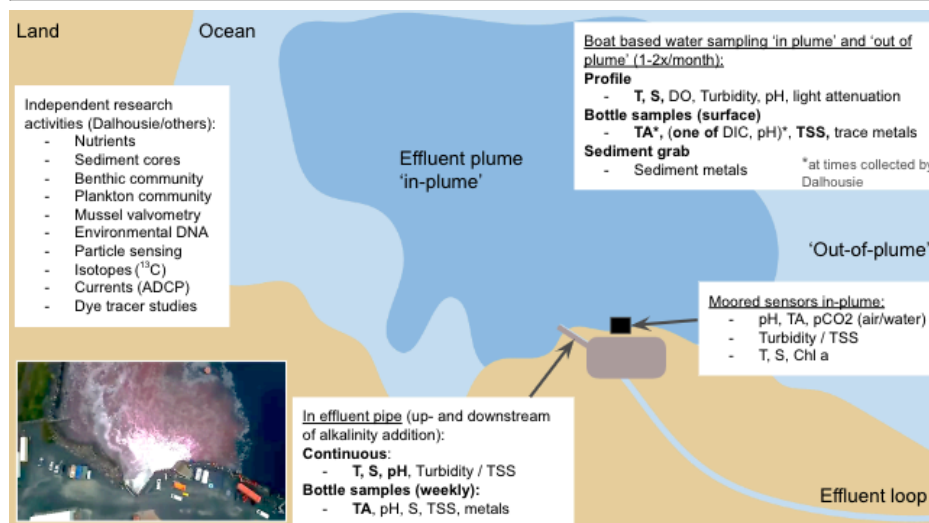
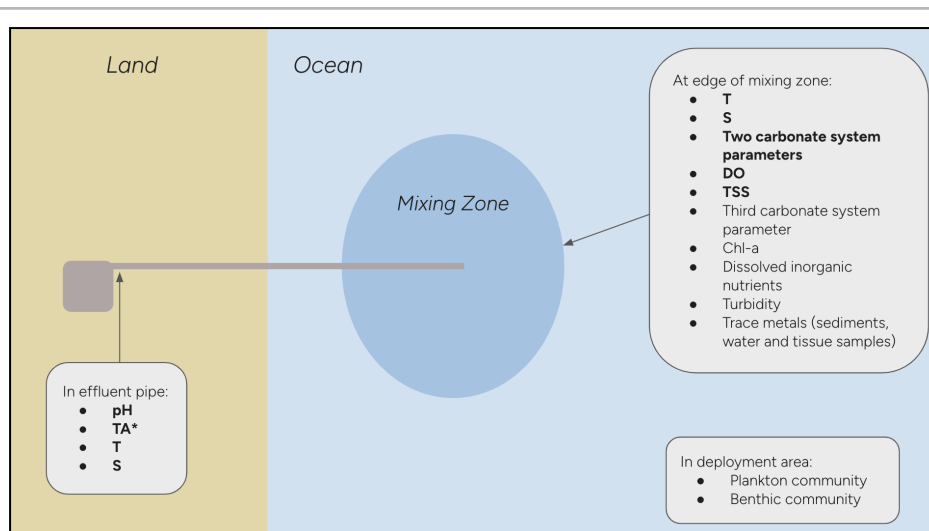


Figure 1.4.1 Map of Bedford Basin and Halifax Harbour. Blue markers and the orange triangle represent the regularly sampled ocean monitoring stations.

Note that the typical 'mixing zone' concept used in the protocol is not applied here as no mixing zone has been established here previously. At this site, the effluent plunges into the receiving waters down a waterfall, creating a visible bubble-rich area referred to here as the 'plume'. Therefore, we focus on measuring the clearest impacts of our OAE deployment 'in-plume', and compare against measurements taken 'out-of-plume' (out of plume refers to all stations except the Tufts Cove station). See Figure 1.4.2 below.



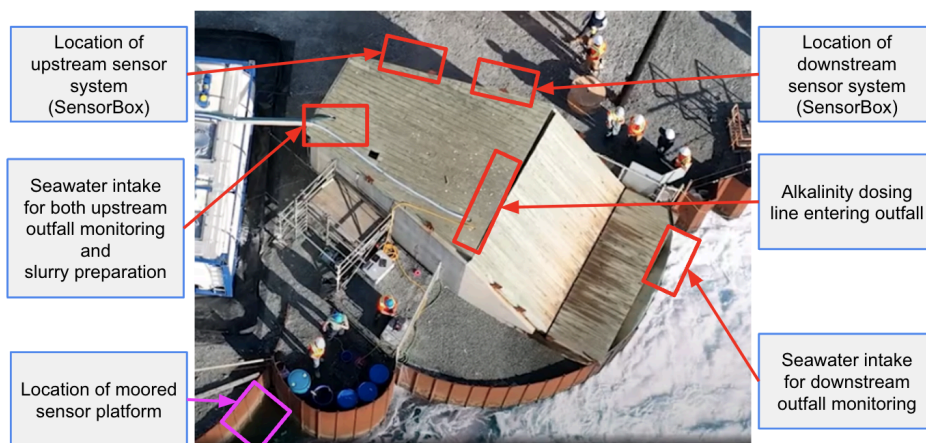


Figure 1.4.2 (TOP 2 PANELS) Plan view from Isometric V1.0 OAE protocol Section 10.2 Monitoring Locations above, with Planetary's plan view at Tufts Cove (aerial image inset) below. Required measurements are shown in bold. **(BOTTOM 2 PANELS)** Zoomed-out images showing the time-varying plume location relative to the OAE discharge, and below, zoomed-in image of the ocean outfall with locations of sensors arrays, seawater intakes, and alkalinity dosing point.

As shown in Figure 1.4.2, monitoring systems are in place for all ocean parameters required by the Isometric protocol. Additionally, all recommended parameters are collected, either by Planetary or through collaborative research conducted by external academic groups (namely Dalhousie University).

Monitoring can be categorized into four areas:

1. Boat surveys of the Halifax Harbour and Bedford Basin will be conducted at monthly (pre- and post-trial) and approximately bi-weekly (during trial; dependent on weather and boat availability) intervals.
2. A moored sensor package installed adjacent to the ocean outfall and within the effluent plume. These are continuous measurements collected from the initial deployment (~1 month prior to the onset of the dosing period), until the end of the dosing period. Since the moored package is a prototype, and susceptible to data incursions resulting from bio-fouling, sensor testing/malfunction and other anomalous events, data collected from the mooring will be primarily used for exploratory R&D, rather than for crediting purposes.
3. Effluent monitoring using sensor packages installed up- and downstream of the dosing location (see image in Figure 1.4.2)
4. Dosing system and feedstock parameters required to calculate the amount of reactive alkalinity delivered to the outfall during the dosing period.

Please describe the pre-deployment monitoring plan following [section 9](#) of the protocol, including the frequency and duration of measurements, instruments and methods used and justification for choices made.

Pre-deployment monitoring

The survey area has been well-baselined through biogeochemical time-series monitoring programs of central Bedford Basin (orange triangle in Fig. 1.4.1) conducted by the [Department of Fisheries and Oceans](#) (weekly since 1992) and [Dalhousie University](#) (since 2008). Carbonate system parameters (pH, total inorganic carbon, total alkalinity) have

been measured at this site since 2016. Additional surveying of the region occurred through a [water quality monitoring program](#) that reported on temperature, salinity, dissolved oxygen, water metal content and total suspended solids levels in Halifax Harbour and Bedford Basin between 2004-2010. Substantial sediment sampling has taken place throughout the harbour over many decades. To date, we have compiled sediment metals data from 4 campaigns (references below) dating back to 1986, totalling over 2000 data points. Earlier data is available from Bedford Basin, but the focus to date has been on more recent data, given changes in analytical techniques over time.

Prior to Planetary's first OAE field trial in 2023, monthly biogeochemical surveys across Halifax Harbour and Bedford Basin began in spring, 2022. These surveys - led by Dalhousie University, Department of Oceanography - included measurements of physical (e.g. "tow-yo" underway vertical profile surveys of temperature and salinity) and carbonate system parameters. Sediment coring near the Tufts Cove site, both for surface sediment metals sampling and for external research, began in spring 2023 and continued through the fall in alignment with the 2023 field trial.

Additional monitoring began in summer 2023, which included the installation of a mooring ~60 m offshore of the Tufts Cove dosing location (jointly administered by Planetary and Dalhousie) and the inclusion of water column and sediment metal content and eDNA (water only) sampling on monthly boat surveys (both Dalhousie-led). The mooring contained sensors to measure pH, TA, temperature and salinity continuously from June-December, 2023, yielding pre-dosing baseline data (June-August) and observations during Planetary's 2023 OAE field trial (Sep.-Dec.). Dalhousie also installed an ADCP approximately 100 m northwest of the 2023 OAE discharge site.

These prior monitoring efforts are summarized in Table 1.4.1 below.

Table 1.4.1. Summary of monitoring activities that have taken place in Halifax Harbour and Bedford Basin prior to the beginning of the proposed 2024 trial. Additional details are provided for survey activities that have occurred in 2024. HH = Halifax Harbour; BB = Bedford Basin

Time period	Activity	Data generated
1986 - 1988	Three different sediment sampling campaigns using grabs and cores throughout Halifax Harbour (Buckley, Winters and Smith, 1995).	- Metals (Al, Ca, Cd, Cr, Cu, Fe, Hg, K, Li, Mg, Mn, Ni, Pb, Ti) - Grain size data (% gravel, silt, clay, sand, kurtosis, skewness) - Water content, CaCO₃, organic carbon
1990	Sediment metals sampling in Halifax Harbour (Tay, 1992)	Metals (As, Cd, Cu, Hg, Pb, Zn)
1992 - present	Weekly boat survey of central Bedford Basin by Department of Fisheries and Oceans Canada (1992-present) and Dalhousie University (2008-present)	- Temperature, salinity, oxygen, pH, Chl-a fluorescence and PAR profiles at central Bedford station - Depth-resolved carbonate system samples (DIC, pH, TA) (2016-present) at central Bedford station
2007	Sediment metals sampling	Metals (Al, As, Ba, Be, Cd, Co,

	during marine environmental baseline survey at Tufts Cove (Jacques Whitford, 2008).	Cr, Cu, Fe, Mn, Mo, Ni, Pb, Se, Sn, Sr, Tl, U, V, Zn)
2008 - 2009	Sediment sampling throughout Halifax Harbour (Williams et al., 2010).	- Metals (Cd, Co, Cr, Cu, Fe, Hg, Li, Mn, Ni, Pb, Zn) - Organic carbon
Spring 2022 - Dec. 2023	Monthly boat surveys of HH & BB (Fig. 1.4.1)	Surface and bottom water pH, DIC, TA and eDNA at four stations
Aug., Sep., Oct. 2023	Dye release from OAE discharge location	4D rhodamine tracer distribution in HH & BB
Aug. - Dec. 2023	Ocean mooring installation at Tufts Cove	Surface pH, TA, temperature and salinity time-series
Sep. - Dec. 2023	Planetary 2023 OAE pilot trial	- Effluent pH, TSS, TA, DIC (3x weekly at up- and downstream locations) - Effluent metals (1x weekly at up- and downstream locations) - Effluent phytoplankton (5x weekly and up- and downstream locations for ~1 month)
May, 2023; Sep. 2023; Jan. 2024	Sediment cores	Sediment metal content at Tufts Cove station
Jan. 2024 - Dec. 2024	Monthly (Jan.-May) and bi-weekly (May-Dec.) boat surveys	- Planetary details in Tables 1.4.2 and 1.4.3 - Dalhousie sampling described in 'independent research' section below.

Since January 2024, Planetary has participated in the monthly boat surveys, by obtaining biogeochemical observations at up to five stations throughout the survey area (blue markers in Fig. 1.4.1). One station is located within the outfall plume ("Tufts Cove" station), and the rest are outside. The measurements made to-date, and those planned for future surveys are summarized in Tables 1.4.2 and 1.4.3 below.

- Profiles of pH, turbidity, dissolved oxygen, temperature and salinity obtained at all stations using a profiling sensor package.
- Discrete surface samples for total suspended solids (TSS) determinations obtained from four stations. When possible, bottom water samples are also collected, but these are not considered part of the core monitoring program.
- Discrete surface water and sediment grab samples for metals content analyses, obtained from two stations (locations vary based on logistics and pre-trial model simulation). Note that water column metal sampling began in April, 2024.

Note that some variables have not been collected at all stations or on all monthly surveys since Jan. 2024 due to various logistical constraints (e.g., weather) and technical (e.g. instrument malfunction) problems. The purpose of the pre-trial surveys was to collect background data to supplement the observations that have been made in the region since 1992 (see above).

Table 1.4.2 Summary of Planetary's boat survey work. TC = Tufts Cove station (in-plume); Br = Bridge Station, Ba = Barge Station, CB = Central Basin / Compass Buoy, MI = McNabs Island Station (see Fig. 1.4.1)

	CTD profile	pH profile	Turb. profile	O2 profile	TSS sample	Sed. metals	Water metals
Jan. 2024	TC, Br, Ba, MI				TC, Br, Ba, MI		
Feb. 2024	TC, Br, Ba, MI	TC, Br, Ba, MI			TC, Br, Ba, MI	TC, MI	
Mar. 2024	TC, Br, Ba, MI	TC, Br, Ba, MI			TC, Br, Ba, MI	TC	
Apr. 2024	TC, Br, Ba, MI	TC, Br, Ba, MI			TC, Br, Ba, MI (surf. + bottom)	TC, Ba	TC, Ba (surf. + bottom)
May. 2024	TC, Br, Ba, CB, MI	TC, Br, Ba, CB, MI	TC, Br, Ba, CB, MI	TC, Br, Ba, CB, MI	TC, CB (surf + bottom), Br, Ba, MI (bottom)	TC, CB	TC, CB (surf + bottom)
June - end of project (large surveys; 1x/month)	TC, Br, Ba, CB, MI	TC, Br, Ba, CB, MI	TC, Br, Ba, CB, MI	TC, Br, Ba, CB, MI	TC, CB (surf + bottom), Br, Ba, MI (surf only)	TC, CB	TC, CB (surf + bottom)
June - end of project (small surveys; 1x/month)	TC, CB	TC, CB	TC, CB	TC, CB	TC, CB (surf)		

*note: bottle samples for carbonate system parameters (TA, pH) are not listed because they are collected by Dalhousie during the monthly sampling campaigns. For the additional boat surveys during the dosing period, carbonate system samples will be collected by the Planetary team, or by Dalhousie (depending on the scope of the particular survey).

Both the moored sensor package and the effluent sensing systems were installed approximately 1 month prior to dosing to adequately test the systems and to collect background data. More details regarding these sensor packages are provided in the subsequent section.

References:

Buckley, D.E, Smith, J.N and Winters, G.V. Accumulation of contaminant metals in marine sediments of Halifax Harbour, Nova Scotia: Environmental factors and historical trends: *Applied Geochemistry*, vol. 10, no. 2, pp. 175-195, 1995.

Tay K-L, Doe KG, Wade SJ, Vaughan DA, Berrigan RE, Moore MJ. 1992. Sediment bioassessment in Halifax harbour. *Environ Toxicol Chem* 11: 1567–1581.

Williams, G., Parsons, M.B., Hellou, J. and Scott, D.B. (2010). Evaluating the effects of wastewater treatment on marine sediment chemistry in Halifax Harbour, Nova Scotia. *Atlantic Geology*, 46 (1).

Please describe the ongoing monitoring plan for the duration of the project operation, following [section 10](#), including the frequency and duration of measurements, instruments and methods used and justification for choices made.

Core operational measurements and monitoring program

As mentioned above, Planetary’s monitoring activities fall into 4 specific areas (boat-sampling, moored sensors, effluent sampling, dosing systems). Details of sampling within each area, including the measurement frequency, and instruments used, are shown in Table 1.4.3 and described below. This program will be followed for the duration of the trial. However, slight adjustments may be made to address specific observations or results from ongoing modeling work.

Boat-sampling:

Throughout the dosing period, boat surveys are scheduled to occur bi-weekly (weather pending) as alternating “larger” and “smaller” surveys. During the larger monthly survey, Planetary collects measurements at five stations (Table 1.4.2), and Dalhousie collects measurements at all six stations shown in Fig. 1.4.1 (see “Independent research activities” below). Planetary does not typically sample at the Sackville River station. During the smaller surveys, Planetary samples at least two of the same stations without Dalhousie support. Bottle samples are collected at surface and bottom depths on the larger surveys, and only in surface waters on the smaller surveys. The majority of these surveys are organized and primarily crewed by the Dalhousie team, in collaboration with our internal science team.

Moored Sensors:

We aim to deploy the moored sensor package continuously throughout the dosing period, with periodic down-time for cleaning and maintenance. As is clear in Figure 1.4.2 and Table 1.4.3, the data collected by these sensors are used for general MRV development, and to enhance our oceanographic understanding of the system. This distinction is important because maintaining high-quality data from this array will be challenging, especially given the extreme biofouling that tends to occur in these waters.

The mooring will continuously (frequency ~30-120 min) measure TA (DOT Alkalinity sensor), pCO₂ in both air and water (ProOceanus Pro-ATM), and pH, turbidity, total suspended solids (TSS; derived from turbidity), Chlorophyll *a* (Chl *a*) fluorescence, temperature and salinity (all using a multiparameter sonde). The data will be logged continuously on the respective sensors and retrieved and analyzed weekly throughout the duration of the alkalinity release. The mooring will be installed at a fixed location that is nominally within the outfall plume (Fig. 1.4.2), however, the tidal cycle and prevailing winds at Tufts Cove will result in transient periods where the package is outside of the plume.

Effluent sampling:

Planetary will install custom-built sensor packages (“SensorBoxes”) at locations up and downstream of the alkalinity dosing point (see Fig. 1.4.2, bottom image). The SensorBoxes will continuously monitor (frequency ~5 min) the outfall water for pH, turbidity, TSS (derived from turbidity), temperature and salinity (all using a multiparameter sonde). This data, particularly the downstream data, which is located at ‘end of pipe’, is an essential part of our regulatory compliance (both for Isometric and provincial regulators).

We have elected to exclude a pCO₂ sensor from the present SensorBox array due to a number of logistical constraints that make data collection and interpretation of a dissolved gas signal challenging. Namely, the downstream water stream is exceedingly bubble-laden (see plume in Fig. 1.4.2), which makes gas measurement challenging. Signal interpretation is also made difficult because the distance between up- and downstream locations is very short (~5 m), and because the downstream sample point is in the ocean (whereas the upstream point is ‘in-pipe’). However, Planetary will collect weekly discrete carbonate parameter samples from the up- and downstream locations throughout the trial. Discrete bottle samples for pH, TA, TSS, and metal content will be obtained from both measurement locations once per week, during nominal dosing operations. The frequency of sample collection will increase during ramping periods. The carbonate parameters will be measured by Dalhousie, and the metals by an independent third party laboratory. Planetary will analyze the TSS samples (see below).

Dosing System:

In addition to the ocean and outfall monitoring described here, Planetary will install an alkalinity dosing platform on the Tufts Cove site that will be used to dose alkalinity into the ocean outfall at a controlled and prescribed rate. The dosing skid consists of a tank, and a series of pumps and valves housed in a sea container. The slurry concentration and density can be calculated using the weights of each supersack of dry material and the measured volume of seawater added to the tank. Periodic slurry samples are then used to ensure slurry densities follow the expected values. Dosing flow rate will be quantified from the change in tank volume over time, and the addition rate (feedstock kg/min) will be calculated from the cycle time it takes to dose each sack of material.

Planetary site operators will also collect dry alkalinity sub-samples from each supersack bag of dry alkalinity. These individual samples will be combined into composite samples for each alkalinity ‘batch’, and subsequently analyzed for metals content (see Appendix 2 for more details).

Data analysis techniques, and quality control:

All data will be analyzed in-house on a weekly basis in order to assess if any regulatory or environmental thresholds are exceeded in a timely manner.

Data processing from the ocean profiling sensor package includes regular QA/QC produces such as sensor post-processing, including comparison to discrete samples (for pH, TSS, and salinity) collected during each survey. Discrete samples for carbonate system parameters (TA and pH) are filtered (<1 micron) during collection to remove any undissolved feedstock, as well as phytoplankton (mercuric chloride not used due to logistical challenges that arise from safety concerns). These samples are analyzed by Dalhousie University using well-established methods.

TSS analyses are done in-house using pre-combusted and pre-weighed 1.6 µm filters. After sample collection and filtration, the filters are rinsed with deionized water to avoid salt buildup. Although TSS measurements by an independent 3rd party is preferred, it is not practical because labs require delivery of a water sample for subsequent filtering. Here, the targeted particulates (in this case, from the feedstock) dissolve rapidly within the water sample, meaning any delay in filtering will compromise the measurement. As a result, Planetary operators filter samples immediately on-site after water collection.

Metal samples are collected by Planetary and sent to a third party laboratory for processing and analysis (done via strong acid digestion and ICP-MS analysis). The resulting data are analyzed by Planetary, and evaluated against the limits defined in our stop-triggers protocol.

The moored sensor package will be serviced weekly, involving recovery and data retrieval, as well as cleaning and battery/reagent changes (if necessary). Weekly water sampling from beside the mooring (TA, pH, salinity, Chl *a*, and TSS) are used to regularly validate the continuous data streams from the corresponding sensors. Aside from TSS, these validation samples will be measured by various labs at Dalhousie University. Chl *a* analysis is done following the Welschmeyer (non acidification) method. Similarly, regular servicing, calibration and collection of validation data samples from the SensorBoxes (TSS, pH, salinity) will occur.

Independent research activities:

A significant amount of independent research is being conducted in alignment with this project. Much of this work is led by Dalhousie University, but also includes researchers from other institutions. Research that includes measuring parameters that are 'recommended' under the Isometric Protocol are mentioned below in **bold**. Planetary does not replicate these measurements as part of our own monitoring for this project. However, the timing or details of this sampling (e.g. QA/QC procedures), or the nature or timing of data delivery, are not driven by Planetary, and thus cannot be detailed here. Given the collaborative nature of this work, and the obligation of academic researchers to share data publicly, we anticipate reporting these results, but not as part of the project verification procedures.

To the best of our knowledge, monitoring activities that fall under this category include, but are not limited to:

- Sampling during boat surveys, including:
 - Discrete samples for pH, TA, DIC, **phytoplankton biomass and community composition**, environmental DNA (eDNA), **macronutrients** and salinity
 - deployments of a towed, profiling ecoCTD for underway vertical profile surveys of temperature, salinity and dissolved oxygen
- Dye tracer studies. These 'tracer dispersion experiments' use Rhodamine dye that is deployed adjacent to the alkaline slurry within the Tufts Cove outfall. Confirmation of these studies, including their timing and frequency, are not yet available.
- Deployment of autonomous vehicles (e.g. gliders and surface vehicles). Specifically, a surface vehicle called a Blue boat is typically deployed to map changes in surface water parameters.
- Sediment coring at various stations, including near Tufts Cove and within Bedford Basin. Analyses could include: pore-water profiling, core incubations, or sampling for sediment metals.
- Sediment collection to assess **benthic community composition**

- Benthic lander studies at various locations, including near Tufts Cove, to quantify in-situ chemical fluxes.
- Mussel valvometry study. This involves the installation of a moored array of mussel cages. Small probes are attached to each mussel that collect constant readings of shell movement. Changes in the rates of shell opening/closing are used as a proxy for physiological stress.
- Installation of acoustic doppler current profilers (ADCPs) near the OAE discharge site. These are used primarily to understand ocean currents and mixing of the discharge with ambient seawater near the discharge site, but can also provide information on relative water turbidity and particle dynamics.
- A sensor to monitor particle dynamics and settling, deployed on Planetary's moored sensor platform adjacent to the dosing location.

Please describe the post-deployment monitoring plan following [section 10](#), including the frequency and duration of measurements, instruments and methods used and justification for choices made.

Post-deployment monitoring

Dosing activities at Tufts Cove are anticipated to progress for multiple years beyond the completion of the 2024 trial. As a result, all monitoring activities described above are expected to continued into 2025. Any updates to these monitoring plans following the 2024 trial will be provided in an amended PDD.

Data reporting following [section 5.6](#): Please note where measurements and supporting documentation (such as calibration certificates) will be made available, and where deployment data relevant to scientific research will be publicly disseminated.

As described above (Section B), Planetary will archive all project data to a secure and private cloud storage location. Data, discrete sample records, audit logs, and inventory trackers will be archived indefinitely. Cleaned time series data sets and summary reports will be made available. Select data will also be made available for export to authorized personnel for further ad-hoc analysis.

Data collected by Dalhousie University will be made freely available on a public repository as it is processed. The primary purpose of data generated by Dalhousie University will be for the publication of research results in peer-reviewed journals. However, once made freely available shortly after collection and processing, the data will be used by Planetary to support the project activities.

Table 1.4.3 Summary of Planetary's ocean outfall and dosing monitoring plans. Required measurements are shown in **bold**.

Area	Parameter	Requirement & Purpose	Instrument	Location	Timing and frequency
Boat sampling	pH (depth profile)	Regulatory compliance and MRV	RBR-Maestro	Two-Five stations in BB & HH (number of stations sampled may be weather-dependent)	Monthly pre/post-trial; bi-weekly during trial (bottle samples monthly, only)
	Turbidity (depth profile).	Regulatory compliance and MRV	RBR-Maestro		
	Temperature, Salinity (depth profile)	Regulatory compliance and MRV	RBR-Maestro		
	Dissolved oxygen (depth profile)	Regulatory compliance and MRV	RBR-Maestro		
	Bottle samples (surface) TA, (one of DIC, pH), salinity, TSS, trace metals	Sensor calibration; Regulatory compliance, MRV	TA - autotitrator pH - spec-pH TSS - filter weight Salinity - salinometer Metals - ICP-MS	Tufts Cove + Central Bedford Basin	
	Sediment trace metals	Regulatory compliance and MRV	Sampler - Ponar grab Analysis - ICP-MS (3rd party laboratory)		
Moored Sensors	pH, turbidity, salinity, temperature, Chl fluorescence	R&D	Multiparameter sonde	~10 m adjacent to outfall ~1.5m depth. Nominally within plume	Continuous during trial
	TA	R&D	DOT-TA		
	pCO2 (air and water)	R&D	Pro-Oceanus CO2-Pro ATM		
	Bottle samples (at mooring) pH, TA, salinity, TSS, Chl <i>a</i>	Sensor calibration	TA - autotitrator pH - spec-pH TSS - filter weights Salinity - salinometer Chl <i>a</i> - Turner fluorometer	weekly	

Outfall - effluent	pH, turbidity, temperature, salinity	Regulatory compliance and MRV	Multiparameter sonde	Up- and downstream outfall	Continuous during trial (5-15-min frequency)
	Bottle samples TA, pH, salinity, TSS, trace metals	Regulatory compliance and MRV	TA - autotitrator pH - Spec-pH + hand-held probe TSS - filter weight Salinity - salinometer Metals - ICP-MS	Up- and downstream outfall	1x weekly during trial
Dosing system	Alk. dosing rate	MRV and CDR calculation.	Feedstock weights and change in tank level	Dosing system	Per supersack (weights); continuous (smoothed 5-min.; flow rate)
	Power consumption	CDR calculation	Accuenergy ev300 meter	Upstream of all equipment	Cumulative
	Dry feedstock sub-sampling (mass, elemental composition)	MRV and CDR calc	Various instruments, including ICP-MS. Conducted by third-party lab	Alkalinity feedstock	Each supersack
	Outfall flow rate	CDR calc.; Required by IOAE	N/A	N/A	Constant, provided by power plant

Section 1.5 – Models

Model descriptions: Please provide the following information for each model that is used for quantifying net carbon removal. The boxes below can be copied and filled out for each model. Please refer to [Appendix 3](#) for requirements on mixing zone and coastal dynamics models used for alkalinity upscaling, and the [Air-sea CO₂ Uptake Module](#) for requirements on models used to quantify atmospheric removal of CO₂.

Model name: MITgcm ECCO	
<i>Is this model already validated and has a track record of use in science, industry, government or other applications?</i>	
•	Yes, this model meets the requirements outlined in air-sea CO₂ Uptake Module Section 4.1.1, and proof of track record of use is provided here Zhang, H., Menemenlis, D., and Fenty, I. G., 2018. ECCO LLC270 ocean-ice state estimate (Tech. Rep.). Jet Propulsion Laboratory. California Institute of Technology. Available at: http://hdl.handle.net/1721.1/119821 He, J. and Tyka, M. D., 2023. Limits and CO₂ equilibration of near-coast alkalinity enhancement. <i>Biogeosciences</i>, 20, 27–43. Carroll, D., Menemenlis, D., Adkins, J. F., et al., 2020. The ECCO-Darwin data-assimilative global ocean biogeochemistry model: Estimates of seasonal to multidecadal Surface Ocean pCO₂ and air-sea CO₂ flux. <i>Journal of Advances in Modeling Earth Systems</i>, 12(10), 1–28. Suselj, K., Carroll, D., Whitt, D., Samuels, B., Menemenlis, D., Zhang, H., et al. 2025. Quantifying marine carbon dioxide removal via alkalinity enhancement across circulation regimes using ECCO-Darwin and 1D models. <i>Journal of Advances in Modeling Earth Systems</i>, 17, e2024MS004847. https://doi.org/10.1029/2024MS004847
•	~~No, model validation will be attached. For guidelines, see Appendix 3 of the protocol and Air-sea CO₂ Uptake Module Section 4.1.2~~
<i>Description of model domain, physical processes represented, and biogeochemical processes represented (if applicable). If the model is used to quantify air-sea CO₂ uptake, please refer to sections 3.1.1 and 3.1.2 of the Air-sea CO₂ Uptake Module.</i>	
The “Estimating the Circulation and Climate of the Ocean” (ECCO) LLC270 global-ocean state estimate [1] assimilates physical observations using the adjoint method (i.e., 4-D-Var) [2] with the MITgcm ocean circulation model [3]. ECCO LLC270 has nominal 1/3° horizontal grid spacing, ranging from 7.3 km to 36.6 km between high and low latitudes. The model grid uses a Cartesian curvilinear coordinate system divided into 13 tiles, each consisting of 270x270 grid cells in the horizontal and 50 vertical levels. Mesoscale eddies, and their impact on large-scale ocean circulation, are parameterized using the Redi [4] and Gent and McWilliams [5] schemes and vertical mixing is parameterized using the	

scheme of Gaspar et al. [6]. We use the configuration described in He and Tyka [7]: specifically, the iteration-42 state estimate covering the years 1992–2017 [8]

- [1] Zhang, H., Menemenlis, D., and Fenty, I. G., 2018. ECCO LLC270 ocean-ice state estimate (Tech. Rep.). Jet Propulsion Laboratory. California Institute of Technology. Available at: <http://hdl.handle.net/1721.1/119821>
- [2] Wunsch, C., and Heimbach, P., 2013. Dynamically and kinematically consistent global ocean circulation and ice state estimates. In G. Siedler, S. M. Griffies, J. Gould, & J. A. Church (Eds.), *Ocean circulation and climate: A 21st century perspective* (Vol. 103, pp. 553–579). Academic Press.
- [3] Marshall, J., Adcroft, A., Hill, C., Perelman, L., and Heisey, C., 1997. A finite-volume, incompressible Navier Stokes model for studies of the ocean on parallel computers. *Journal of Geophysical Research: Oceans*, 102, 5753–5766.
- [4] Redi, M. H., 1982. Oceanic isopycnal mixing by coordinate rotation. *Journal of Physical Oceanography*, 12(10), 1154–1158.
- [5] Gent, P. R., and McWilliams, J. C., 1990. Isopycnal mixing in ocean circulation models. *Journal of Physical Oceanography*, 20(1), 150–155.
- [6] Gaspar, P., Grégoris, Y., and Lefevre, J.-M., 1990. A simple eddy kinetic energy model for simulations of the oceanic vertical mixing: Tests at station papa and long-term upper ocean study site. *Journal of Geophysical Research: Oceans*, 95(C9), 16179–16193.
- [7] He, J. and Tyka, M. D., 2023. Limits and CO₂ equilibration of near-coast alkalinity enhancement. *Biogeosciences*, 20, 27–43
- [8] Carroll, D., Menemenlis, D., Adkins, J. F., et al., 2020. The ECCO-Darwin data-assimilative global ocean biogeochemistry model: Estimates of seasonal to multidecadal Surface Ocean pCO₂ and air-sea CO₂ flux. *Journal of Advances in Modeling Earth Systems*, 12(10), 1–28.

Please describe the representation of the CDR approach in the model.

The ocean carbonate system is resolved using MITgcm's gchem and DIC packages. The ocean carbon model is based on Dutkiewicz et al. [1] and uses five biogeochemical tracers (DIC, alkalinity, phosphate, dissolved organic phosphorus, and oxygen), which are advected and mixed by the physical flow fields. The sources and sinks of DIC are the air-sea CO₂ flux, freshwater fluxes, biological production, and the formation of calcium carbonate shells. Biogeochemical tracers are initialized with contemporary data from GLODAPv2 mapped climatologies [2,3] or from Dutkiewicz et al. [1]. Atmospheric CO₂ is fixed at 415 μatm .

Alkalinity Upscaling:

As the feedstock used is fast dissolving, there is no remaining particle fraction at the end of the coastal model simulations run as part of the TC24 project, and all ΔTA added to the global model is added in dissolved form. The coastal model simulations indicate that >90% of the added alkalinity has left the coastal model domain over the 6-month simulation. Consequently, ΔTA is added to the global model over the month corresponding to the peak of ΔTA leaving the near-field domain, or to the end of the coastal model simulation for slower dissolving feedstock.

For the TC23 ECCO simulations the coastal model is used to generate a residual alkalinity forcing function that is input to the global model. The 'residual alkalinity function' is a 4-D, monthly varying time series of the magnitude and horizontal and vertical distribution of added alkalinity. The residual alkalinity forcing ($\Delta\text{TA}_{\text{RES}}$) is generated from the coastal

model and represents the unequilibrated fraction of the input alkalinity in tonnes (ΔTA_{UNEQ}). ΔTA_{UNEQ} is calculated as the total alkalinity added to the coastal model (ΔTA_{IN}) minus the equilibrated fraction of the added alkalinity (ΔTA_{EQ}). ΔTA_{UNEQ} includes the unequilibrated alkalinity that leaves the coastal domain at the open boundaries (ΔTA_{OUT}) and the alkalinity that remains within the coastal domain but has not equilibrated with the atmosphere by the end of the coastal model simulation. ΔTA_{EQ} is calculated as the total added alkalinity (ΔTA_{IN}) multiplied by the CDR efficiency (CDR_{eff}), where CDR_{eff} is the ratio of the net ΔCO_2 air-sea flux simulated during the coastal model simulation (ΔCO_{2SIM}) to the potential ΔCO_2 air-sea flux (ΔCO_{2POT}), calculated using CO2SYS and volume-averaged ocean conditions extracted from the coastal model simulation.

For the TC23 simulations, using a slower dissolving feedstock, we assume that all added alkalinity that leaves the coastal domain has dissolved by the end of the simulation. This assumption is supported by the consistency between the mass of particles that remain within the coastal model domain at the end of the simulation and the predicted remaining particle mass calculated using the applied feedstock dissolution rate of 1.5 %/day. The remaining particle mass ($\Delta TA_{UNEQ-part}$) is then the total mass of particles left within the coastal domain at the end of the coastal simulation. As particles are by definition unequilibrated, the dissolved fraction of the unequilibrated alkalinity ($\Delta TA_{UNEQ-diss}$) can be calculated as the total unequilibrated alkalinity minus the particle fraction ($\Delta TA_{UNEQ-part}$). Each component of ΔTA_{UNEQ} is converted from tonnes to moles for input to the global ECCO model.

$$CDR_{eff} = \Delta CO_{2SIM} / \Delta CO_{2POT} \quad (1)$$

$$\Delta TA_{EQ} = \Delta TA_{IN} * CDR_{eff} \quad (2)$$

$$\Delta TA_{UNEQ} = \Delta TA_{IN} - \Delta TA_{EQ} \quad (3)$$

$$\Delta TA_{UNEQ-diss} = \Delta TA_{UNEQ} - \Delta TA_{UNEQ-part} \quad (4)$$

For both the TC23 and TC24 simulations, the horizontal and vertical distribution of alkalinity added to the global ECCO model is calculated from the horizontal and vertical distribution of ΔTA_{OUT} ; i.e. the horizontal and vertical distribution of added alkalinity crossing the open boundaries of the coastal model, integrated onto the ECCO depth levels. For the TC23 simulations using the slower dissolving feedstock, the dissolved fraction of unequilibrated alkalinity, $\Delta TA_{UNEQ-diss}$, is added over the period of one month, corresponding to the last month of the coastal model simulation to maintain temporal continuity between the coastal and global models, i.e. if the coastal model simulation covers 6-months from October to March, $\Delta TA_{UNEQ-diss}$ is added in April. The particle fraction, $\Delta TA_{UNEQ-part}$, is added gradually over subsequent months following the particle dissolution rate of 1.5 %/day, integrated into monthly timesteps, until the remaining particle mass is equivalent to <100 moles of added alkalinity. For the TC24 simulations using a fast dissolving feedstock, all added alkalinity has dissolved before the end of the coastal model simulation and the particle dissolution step is not required for the global model.

[1] Dutkiewicz, S., Sokolov, A., Scott, J., and Stone, P., 2005. A three dimensional ocean-seaice-carbon cycle model and its coupling to a two dimensional atmospheric model: Uses in climate change studies. Report 122, MIT Joint Program on the Science and Policy of Global Change, <https://dspace.mit.edu/handle/1721.1/18091>.

[2] Lauvset, S. K., Key, R. M., Olsen, A., et al., 2016. A new global interior ocean mapped climatology: The 1° × 1° GLODAP version 2. *Earth System Science Data*, 8(2), 325–340.

[3] Olsen, A., Key, R. M., Lauvset, S. K., et al., 2017. Global Ocean Data Analysis Project, Version 2 (GLODAPv2) (NCEI Accession 0162565), NOAA [data set], <https://doi.org/10.7289/V5KW5D97>.

Please describe the simulations

ECCO provides approximately 30-years of historical ocean and atmosphere conditions (e.g. seawater temperatures, salinities, currents, mixed layer depths and wind speeds). Uncertainty in the water mass pathway of a specific alkalinity-containing water parcel will increase with time after dosing, and as properties are dispersed over ever larger spatial scales. We therefore characterize uncertainty in the dispersion of added alkalinity, and the temporal evolution of air-sea gas exchange, on the scale of months-to-years using an ensemble of ECCO simulations that sample the climatological variability provided by the ocean state estimate. This allows our ensemble to assess the influences of initial condition uncertainty and internal climate variability.

The ECCO simulations run as part of the TC24 project and used to calibrate the 1D model are listed in the Table below. The reference simulation is run for 26-years and represents the counterfactual baseline condition with no project activity. The dosing simulations are run over different time windows within the ECCO forcing period. The TC24 dosing simulations have a nominal 500 t dissolved feedstock added over one month, with the horizontal and vertical distribution of added alkalinity prescribed by the distribution of added alkalinity leaving the coastal model domain. Additional simulations are included with 500, 1000 and 5000 t of prescribed alkalinity to test linearity in the CDR response to the scale of added alkalinity. Note that the amount of alkalinity added to the 2023 global model simulations, calculated from the alkalinity upscaling approach described above, was approximately 221 t. The total area of ECCO grid cells with alkalinity forcing applied equals 657.48 km². The ensemble of ECCO dosing simulations are designed to characterize the seasonal and interannual variability in regional OAE deployment, by selecting different start months and years. Once dosing activities are complete, an additional ROMS and ECCO simulation are run, with the prescribed alkalinity to the ECCO simulation upscaled from the ROMS simulation, that uses the observed project dosing time series. The start year of this simulation is chosen to be most representative of the period of dosing activities based on observed meteorological data. The list of ECCO experiments is provided in the 'Use of Models' section above.

These simulations were run on a small MPI cluster (13 machines, 59 processes each) on Amazon Web Services (AWS) Cloud Computing Services.

Please describe the analysis of model output and how it was used in the project.

CDR is quantified as the anomaly in ocean DIC between the dosing and baseline simulations

Please describe how uncertainty of the model and model results is accounted for.

We perform an ensemble of simulations covering different time periods within the 26-year ocean state estimate window to incorporate interannual variability (e.g. wind forcing, SST etc.) and uncertainty in initial conditions.

- I confirm that the model results are reproducible and all model files and code needed to reproduce the results are available (see protocol section 14.6, and Air-sea CO₂ Uptake Module Section 5.0 for examples)

[insert link to model files and code, e.g. github repository]

We confirm that model files and code needed to reproduce results will be made available.

Code used in previous simulations provided below

<https://zenodo.org/records/7460358>

<https://github.com/ECCO-GROUP/ECCO-v4-Configurations/tree/master/ECCOv4%20Release%205>

Model name: ROMS

Is this model already validated and has a track record of use in science, industry, government or other applications?

- Yes, this model meets the requirements outlined in air-sea CO₂ Uptake Module Section 4.1.1, and proof of track record of use is provided here

Laurent et al., 2025. Preprint available here:
<https://egusphere.copernicus.org/preprints/2025/egusphere-2025-3361/>
In-depth model-data comparisons for both Halifax Harbour and the coastal shelf region are available in both main paper and supplement.
Model code for this publication are available here:
https://github.com/alaurent101/ROMS_OAE

Wang et al., 2025. Available here:
<https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2024EF005463>
This paper provides up-to-date information about the ROMS model, alongside some model-data comparisons.

Fennel, K., Wilkin, J., Levin, J., et al. 2006. Nitrogen cycling in the Middle Atlantic Bight: Results from a three-dimensional model and implications for the North Atlantic nitrogen budget, Global Biogeochemical Cycles, 20, GB3007.
- ~~No, model validation will be attached. For guidelines, see [Appendix 3](#) of the protocol and Air-sea CO₂ Uptake Module [Section 4.1.2](#)~~

Description of model domain, physical processes represented, and biogeochemical processes represented (if applicable). If the model is used to quantify air-sea CO₂ uptake, please refer to sections 3.1.1 and 3.1.2 of the Air-sea CO₂ Uptake Module.

The Regional Ocean Modeling System (ROMS) is a free-surface, terrain-following, primitive equation ocean model [1], that has been widely used by the scientific community for a diverse range of applications [2]. ROMS solves the Reynolds-averaged Navier–Stokes equations using the hydrostatic and Boussinesq assumptions [3,4]. ROMS includes several coupled models for biogeochemical, bio-optical, sediment, and sea ice applications.

The Halifax ROMS model used here for the near-field solution has been developed by Prof. Katja Fennel's group at Dalhousie University [5]. The domain has a horizontal resolution of ~150 m and 40 terrain-following vertical levels. The domain encompasses Bedford Basin and Halifax Harbor as well as the adjacent shelf. The bathymetry is generated with the NONNA-10 and NONNA-100 high resolution products from the Canadian Hydrographic Services

(<https://open.canada.ca/data/en/dataset/d3881c4c-650d-4070-bf9b-1e00aabf0a1d>), filled with GEBCO global bathymetry (<https://www.gebco.net>) where high resolution data are unavailable. This model is one-way nested inside a wider ROMS model with a horizontal resolution of 760 m, which itself is nested one-way within the data-assimilative global GLORYS reanalysis model [6]. The model uses the GLS vertical mixing scheme [7,8], 3rd-order upstream (horizontal) and 4th-order centered (vertical) advection schemes for physical tracers and the high-order spatial interpolation at the middle temporal level (HSIMT) advection scheme for biological tracers [9]. Atmospheric surface forcing is prescribed from the European Centre for Medium-Range Weather Forecasts (ECMWF) ERA5 global atmospheric reanalysis [10].

[1] Haidvogel, D. B., Arango, H., Budgell, W. P., et al. 2008. Ocean forecasting in terrain-following coordinates: Formulation and skill assessment of the Regional Ocean Modeling System, *Journal of computational physics*, 227, 3595–3624

[2] See <https://www.myroms.org> for examples and code availability.

[3] Haidvogel, D.B., Arango, H.G., Hedstroöm, K.S., et al. 2000. Model evaluation experiments in the North Atlantic Basin simulations in nonlinear terrain-following coordinates, *Dynamics of Atmospheres and Oceans*, 32, 239–281.

[4] Shchepetkin, J.C. McWilliams., 2005. The regional oceanic modeling system (ROMS) a split-explicit, free-surface, topography following-coordinate oceanic model, *Ocean Modelling* 9(4) 347–404.

[5] Laurent, A., Wang, B., Atamanchuk, D., et al. 2025. A high-resolution nested model to study the effects of alkalinity additions in Halifax Harbour, a mid-latitude coastal fjord, *Biogeosciences*, <https://doi.org/10.5194/egusphere-2025-3361>.

[6] Lellouche, J.-M., Greiner, E., Bourdallé-Badie, R., et al. 2021. The Copernicus Global 1/12° Oceanic and Sea Ice GLORYS12 Reanalysis, *Frontiers in Earth Science*, 9, 698876.

[7] Umlauf, L., and Burchard, H., 2003. A generic length-scale equation for geophysical turbulence models, *Journal of Marine Research*, 61, 235–265.

[8] Warner, J. C., Sherwood, C. R., Arango, H. G., and Signell, R. P., 2005. Performance of four turbulence closure models implemented using a generic length scale method, *Ocean Modelling*, 8, 81–113.

[9] Wu, H., and Zhu, J. 2010. Advection scheme with 3rd high-order spatial interpolation at the middle temporal level and its application to saltwater intrusion in the Changjiang Estuary, *Ocean Modelling*, 33, 33–51..

[10] Hersbach, H., Bell, B., Berrisford, P., et al., 2020. The ERA5 global reanalysis. *Quarterly Journal of the Royal Meteorological Society*, 146(730), 1999–2049.

Please describe the representation of the CDR approach in the model.

The biogeochemical model is part of ROMS v.3.9 and is described in the published work of Prof. Fennel's group [1]. Alkalinity dosing is prescribed following the dosing rate time-series, recorded during the trial in kg dry feed/hour, and using the 1D alkalinity release model, which calculates the alkalinity release for a given size distribution of mineral particles as they sink through a 1D water column (described earlier in the PDD). Alkalinity is added to ROMS as a point source to a single 150m resolution gridcell corresponding to the outfall location.

[1] Fennel, K., Wilkin, J., Levin, J., et al. 2006. Nitrogen cycling in the Middle Atlantic Bight: Results from a three-dimensional model and implications for the North Atlantic nitrogen budget, *Global Biogeochemical Cycles*, 20, GB3007

Please describe the simulations that were run

Simulations will include:

- baseline simulation with no alkalinity addition
- dosing simulation that includes the alkalinity additions using standard parameters
- a number of sensitivity experiments to test uncertainties in the input parameters. These may include, but are not limited to: interannual variability, seasonal variability (start dosing 3, 6, and/or 9 months before the actual start date), varying feedstock dissolution rates and varying windspeed.

All simulations use actual climatology (surface and open boundary forcing) and span, at minimum, the full dosing period.

Once dosing activities are complete, an additional ROMS simulation is performed using past climatology and the observed project dosing time series. The start year of this simulation is chosen to be most representative of the period of dosing activities based on observed meteorological data. The list of ROMS experiments is given in the 'Use of Models' section above.

Please describe the analysis of model output and how it was used in the project.

ROMS outputs total inorganic carbon (TIC) and air-sea CO₂ flux. Because both TA and TIC are lost at the open boundaries, total CDR is calculated as the net ΔCO_2 air-sea flux between the dosing and baseline simulations, which provides an accurate measure of how much CO₂ (or carbon) was absorbed during the experiment.

The method of calculating the residual alkalinity forcing ($\Delta\text{TA}_{\text{RES}}$), that was applied to the global model is described in the above section "*describe the representation of the CDR approach in the model*" for the global model.

Please describe how uncertainty of the model and model results is accounted for.

Sensitivity experiments are conducted to explore the leading sources of uncertainty (examples given above). The ensemble is used to provide an estimated uncertainty envelope on simulated CDR.

- I confirm that the model results are reproducible and all model files and code needed to reproduce the results are available (see protocol section 14.6, and Air-sea CO₂ Uptake Module Section 5.0 for examples)

[insert link to model files and code, e.g. github repository]

We confirm that model files and code needed to reproduce results will be made available.

Model name: 1D Diffusivity Model

Is this model already validated and has a track record of use in science, industry, government or other applications?

- ~~Yes, this model meets the requirements outlined in air-sea CO₂ Uptake Module Section 4.1.1, and proof of track record of use is provided here~~

- No, model validation will be attached. For guidelines, see [Appendix 3](#) of the protocol and Air-sea CO₂ Uptake Module [Section 4.1.2](#)

Description of the 1D model setup, and how the model is applied for this project, is provided below. Discussion of validation for the 1D diffusivity model has been provided in a report sent to the Isometric team.

Description of model domain, physical processes represented, and biogeochemical processes represented (if applicable). If the model is used to quantify air-sea CO₂ uptake, please refer to sections 3.1.1 and 3.1.2 of the Air-sea CO₂ Uptake Module.

Planetary's 1D diffusivity model has been developed in parallel with a similar project underway at Dalhousie University [1]. This simple model simulates the dispersion of released alkalinity and pCO₂ depleted water within a vertical water column, using the 1D diffusivity equation;

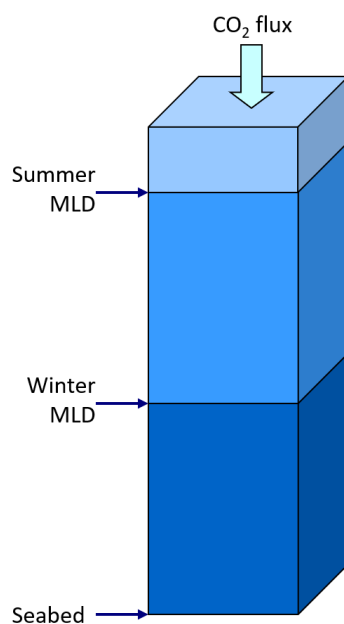
$$dC/dt = d/dx (kz \times dC/dx)$$

where C is concentration under investigation (e.g. TA, DIC), and kz is the vertical diffusivity (ks within the surface mixed layer, kd below the mixed layer depth).

The impact of increased alkalinity on the seawater carbonate system is calculated using the method of Follows et al. (see below), and subsequent $p\text{CO}_2$ equilibration through air-sea gas exchange is parameterized using the Wanninkhof (2014) relationship for CO_2 [2]. The baseline simulation has zero air-sea CO_2 flux throughout the simulation, and this is achieved by tuning the models carbonate system parameters (specifically the borate parameters B_{tot} and K_b) to match $p\text{CO}_{2\text{sea}}$ to $p\text{CO}_{2\text{air}}$.

The alkalinity input is calculated from the project dosing profile (kg feed/min), the particle size distribution, laboratory determined dissolution rate, and Stokes' sinking velocity. A shrinking core dissolution model is assumed and a particle-shape-dependent Stokes' drag factor (i.e. sinking velocity reduction factor) can be applied to reflect the non-spherical particle shapes observed on SEM photographs (see sensitivities below). A maximum settling depth for particles within the 300 m water column is specified at 40 m for this site, reflecting the depth profile of alkalinity export from the near-field ROMS domain.

The model is matched to location specific conditions by forcing the air-sea CO_2 flux using local wind speed data and by imposing a seasonally varying mixed layer depth, separating the high diffusivity surface from the lower diffusivity deep water column, based on regional ocean observations.



300 x 1 m layer model, nominal 1000 km² water column (~ one ECCO grid cell)

Seasonal MLD from Cai (2021) MLD climatology paper covering the Scotian Shelf

Diffusivity within and below mixed layer, based on similar DAL model

CO_2 flux from Wanninkhof's correlation for CO_2 , wind data from ROMS/Sable Island

TC23 dosing profile generates alkalinity release profile in (z,t) for 2-phase proxy or full PSD

[1] Yee, R., Musgrave, R., and Rackley, S., 2023. Simple models for carbon dioxide removal via ocean alkalinity enhancement in coastal environments. Presented at the Canadian Meteorological and Oceanographic Society (CMOS) congress, May 2023, St. John's, NL.

[2] Wanninkhof, R., 2014. Relationship between wind speed and gas exchange over the ocean revisited. *Limnology and Oceanography: Methods*, 12(6), 351-362.

Please describe the representation of the CDR approach in the model.

The seawater carbonate system response to increased TA is solved using the approximation reported by Follows et al. [1], and air-sea gas exchange is parameterized using the Wanninkhof relationship for CO₂. [2].

[1] Follows, M.J., Ito, T. and Dutkiewicz, S., 2006. On the solution of the carbonate chemistry system in ocean biogeochemistry models. *Ocean Modelling*, 12(3-4), 290-301.

[2] Wanninkhof, R., 2014. Relationship between wind speed and gas exchange over the ocean revisited. *Limnology and Oceanography: Methods*, 12(6), 351-362.

Please describe the simulations that were run

For the 2023 Halifax pilot;

- Wind data representative of the downstream shelf region was downloaded for the Sable Island meteorological station. The second exponent of the data (U_{10}^2) was computed at the raw 10-minute data frequency, and monthly averages were calculated to give $\langle U_{10}^2 \rangle$. 2002 was selected as an average windspeed year.
- Wanninkhof estimated a 20% uncertainty in the global average gas transfer velocity for air-sea exchange of CO₂. Low and high sensitivity cases were assessed by decreasing or increasing the gas exchange velocity by a slightly more conservative factor of 1.25.
- Mixed layer depth climatologies reported by Cai et al. [1] for the northeast US continental shelf were imposed on the model, with Southern Mid-Atlantic Bight (SMAB), Georges Bank (GB), and Western Gulf of Maine (WGOM) selected to represent shallow, mid, and deep MLD cases. MLD values within this range have also been reported for the Scotian Shelf, ca. 12 km offshore from Halifax [2]. MLD sensitivity was assessed using these shallow and deep cases, as well as by increasing/decreasing the mid-case MLD by a factor 1.5.
- The shallow and deep diffusivities were set at a typical ocean value of $1.9 \cdot 10^{-3} \text{ m}^2/\text{s}$ and $10^{-4} \text{ m}^2/\text{s}$ resp. Sensitivity cases were taken to be a factor of 2x higher or lower for the deep, and 1.25x for the shallow diffusivity, a larger “shallow” factor being impossible due to numerical instability

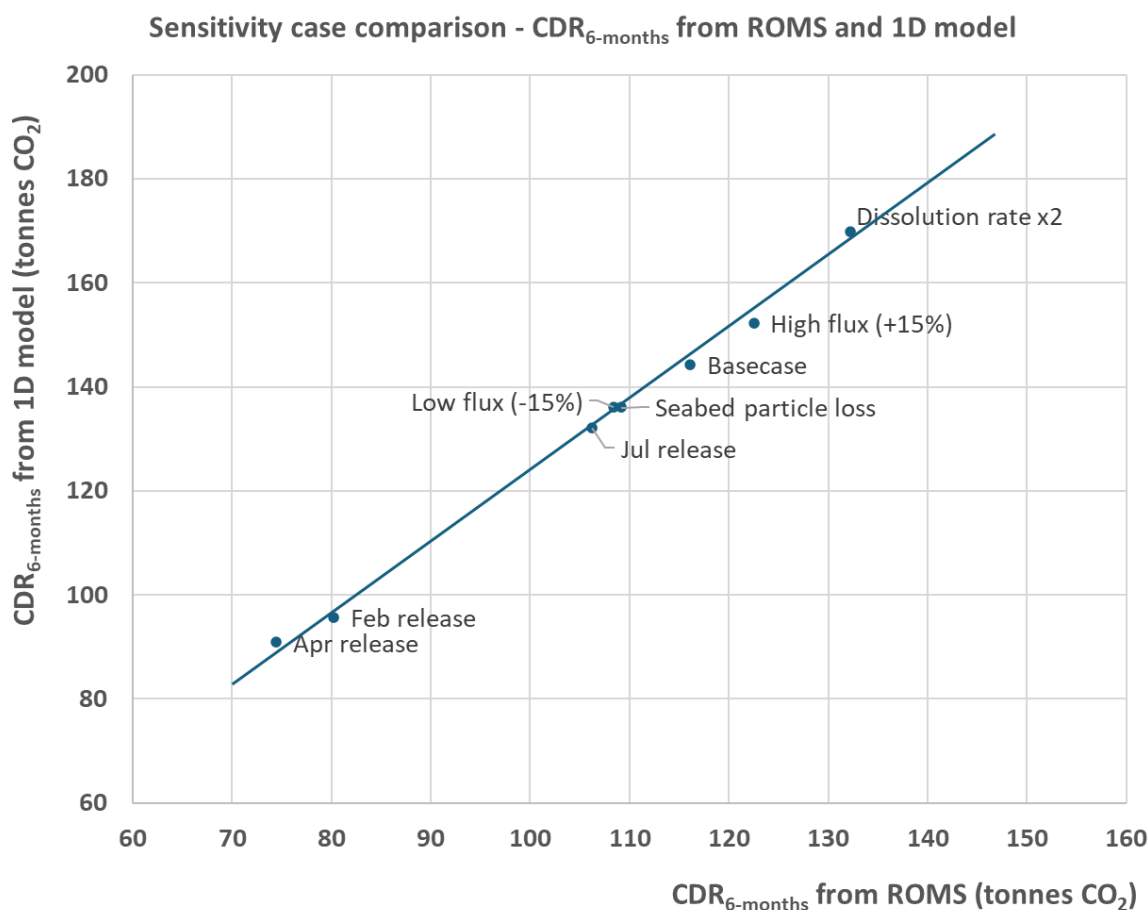
[1] Cai, C., Kwon, Y.O., Chen, Z., and Fratantoni, P., 2021. Mixed layer depth climatology over the northeast US continental shelf (1993–2018). *Continental Shelf Research*, 231, p.104611.

[2] Shadwick, E.H., Thomas, H., Azetsu-Scott, K., Greenan, B.J., Head, E. and Horne, E., 2011. Seasonal variability of dissolved inorganic carbon and surface water pCO₂ in the Scotian Shelf region of the Northwestern Atlantic. *Marine Chemistry*, 124(1-4), 23-37.

Please describe the analysis of model output and how it was used in the project.

The 1D model is used to broaden the ensemble of sensitivity cases. A suite of sensitivity cases was run using the ROMS model and the 1D model, covering different dosing seasons, wind speeds, particle dissolution rate, etc. The results for the two models are shown in the figure below, and demonstrate that the 1D model closely reproduces the

variability of the CDR estimate generated by the ROMS model for these cases. The slope of the line is 1.37 (i.e. $dCDR_{1D} = 1.37 dCDR_{ROMS}$) so that the use of 1D sensitivities as a proxy for ROMS sensitivities is conservative.



Additional sensitivity analyses will be incorporated into the final CDR calculation, with results provided in the crediting package.

Please describe how uncertainty of the model and model results is accounted for.

The 1D model is used to broaden the ensemble of sensitivity cases.

- I confirm that the model results are reproducible and all model files and code needed to reproduce the results are available (see protocol section 14.6, and Air-sea CO_2 Uptake Module Section 5.0 for examples)

[insert link to model files and code, e.g. github repository]

Code needed to reproduce results can be made available upon request.

Section 1.6 – Ancillary Research Activities

Description of ancillary research activities
<i>Please provide a summary of any concurrent ancillary research activities that are not directly carried out by the Project Proponent or included within the system boundary for GHG accounting. This can include academic research collaborations, for example.</i>
A significant amount of academic research will take place during the trial. Details of the Dalhousie efforts are described in the Monitoring section above. Dye release studies conducted by Dalhousie are also described elsewhere in this document.
<i>Please describe any additional data produced through these activities that may be used to inform or support future validation and verification of this project.</i>
Data collected by the Dalhousie team will be used to further validate the ROMS model. Additional data collected from boats, buoys, and autonomous vehicles will be used to validate the OAE process for proof-of-concept.

Appendix 2: Rock and mineral feedstock characterization PDD template

This Appendix follows the requirements of the Rock and Mineral Feedstock Characterization Module and must be completed for each feedstock type and feedstock provider used in this Project.

Section A: Key information

Redacted information in both **Section A and B** available upon request.

Feedstock Provider Organizations
<i>Please provide a complete list of organizations involved in providing the feedstock, clarifying the organization's role and providing contact information for each. (Please duplicate the below rows for each additional organization you wish to add)</i>
Organization 1
Company registration number : [REDACTED]
Organization Name: [REDACTED]
Organization Address: [REDACTED]

Spain
Contact Person: Managing Director
Contact Email Address:
Contact Phone Number:
Organization role in project: Alkalinity manufacturer
Organization 2
Company registration number
Organization Name:
Organization Address:
Contact Person:
Contact Email Address:
Contact Phone Number:
Organization role in project: Parent company to alkalinity supplier

Section B: Feedstock background

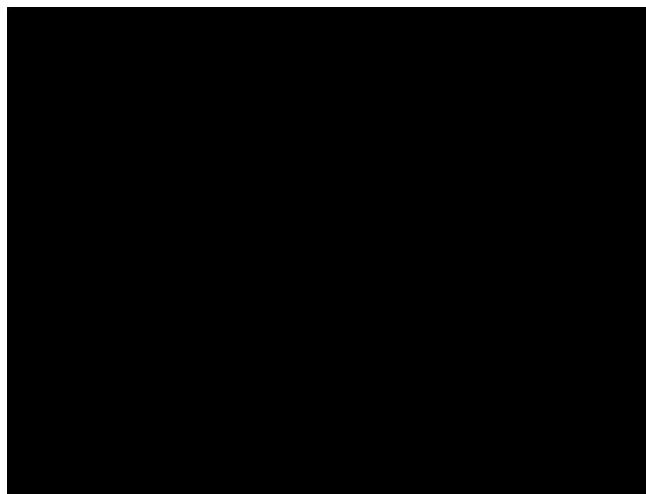
Feedstock background
<i>Please describe your Feedstocks used, following the requirements in the Rock and Mineral Feedstock Characterization Module Section 2.</i>
The feedstock selected and tested for this project is a semi-calcined magnesite produced by in Spain.
<i>Please provide information on the location that the feedstock was recovered/collected</i>

The magnesite is extracted from [REDACTED] located [REDACTED]. It is further processed at production facility located [REDACTED]

Please provide information on how the rock/mineral feedstock was recovered

An overall flow diagram for the production of the feedstock is provided below

[REDACTED]



Feedstock production flowchart from mineral extraction to packaging.

A site visit of the mine and processing facility was conducted on February 6th, 2024. The following notes and images are from direct interactions with senior foreman and operators at both sites supplemented with available literature.

[REDACTED]

[REDACTED]

[REDACTED]

[REDACTED]

[REDACTED]

Please provide a description of any pre-processing that has occurred on location, prior to characterisation

[REDACTED]

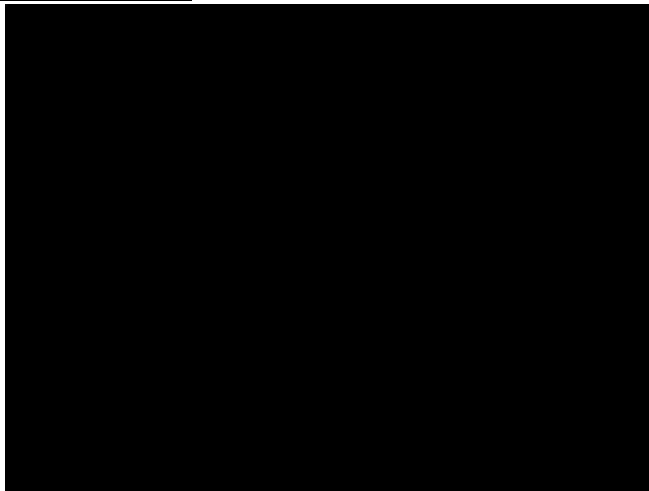
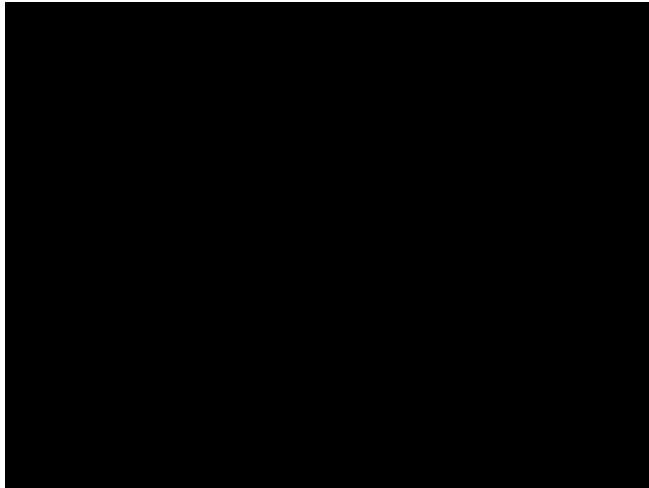
Planetary team members met with the Deputy General Director [REDACTED], as well as the Factory Director, [REDACTED] who provided an explanation and gave a tour of the production process on February 6th, 2024.

The [REDACTED] plant has been in operation since [REDACTED] and currently produces [REDACTED] of finished magnesia products, of which [REDACTED] % is [REDACTED]

[REDACTED]

The magnesite ore trucked from the [REDACTED] mines undergoes beneficiation at the [REDACTED] site [REDACTED]

[REDACTED] Beneficiation steps at the factory include screening and classification, as well as gravity separation using shaking tables and spiral concentrators.



[REDACTED]

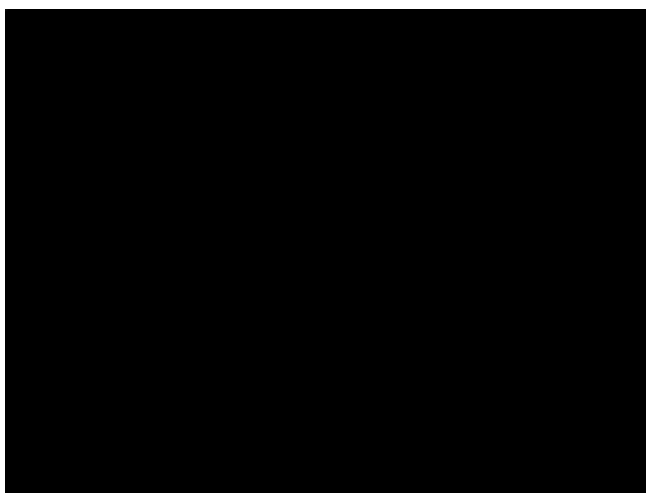
Where available, please provide geological maps and detailed descriptions of the location and deposit that the rock or mineral feedstock was recovered

[REDACTED]

[REDACTED]

[REDACTED]

[REDACTED]



Please provide an outline of any prior geochemical or physical characterization carried out on the rock or mineral feedstock utilized within this project

██████████ collects and tests samples from each batch of feedstock produced. Test results including elemental composition (%) for SiO_2 , CaO , Fe_2O_3 , Al_2O_3 , SO_3 and MgO as well as particle size distribution were provided from June 2023 to February 2024. Independent testing was conducted by SGS Canada on different samples provided directly from the factory as well as collected in-person by Planetary staff during the February site visit. These tests are described in the following sections. Finally, SGS Spain was enlisted to collect further samples from procured batches prior to shipment to Halifax for quality assurance testing ██████████

Where the project proponent is unable to provide the information requested in the previous sections supporting documentation/information may be submitted to explain why admissions have been made - Please contact the project VVB if this section is required

N/A.

Has the rock/mineral feedstock been recovered as a by-product of an extractive process, such as mining or quarrying? (Yes/No) If 'No' please continue to the next section

No.



If the proposed rock or mineral feedstock has been recovered from an extractive process please provide information and supporting documentation on the legal status of the material. This requirement applies if the material has previously, or is, classified as a waste product under national regulations, such as the Extractive Waste Directive 2006/21/EC.

N/A.

Section C: Characterization requirements

Analytical Methods and Standards

Please provide a detailed bulleted list of the relevant standards that have been utilized in the characterization of the project rock or mineral feedstock - This list does not need to contain data or results and is intended as a reference list for the methods/standards utilized by project proponents - Please refer to section 3.1 and Appendix 1 of the Rock and Mineral Feedstock characterisation module for more details.

Where National standards, or recommended standards, have not been used, or a specific Standard Operating Procedure (SOP) has been used in place of a standard please provide additional information on the methods utilized - additional documentation, such as the used SOP, may be required for validation by the project VVB

Preliminary characterisation - SGS Lakefield

- Moisture content (internal SOP)
- Bulk density (internal SOP)
- Specific gravity using gas pycnometer, based on ASTM D5550-23 and ASTM C604-18
- Particle size distribution by Malvern analyzer (internal SOP)
- Total inorganic carbon (TIC) through coulometric titration (based on ASTM D4129-05).
- Graphitic carbon through hydrochloric acid leach and combustion infrared detection (internal SOP: A weighed sample is roasted at 500°C for 1 hour to remove all organic carbon. Carbonate carbon is then leached/evolved using HCl, the sample is then dried to remove chlorides. The residue is mixed with metal accelerators and placed in the LECO IR combustion system. The residual carbon is taken as graphitic carbon).
- Carbon and sulphur % through LECO analysis (internal SOP: A weighed sample is crushed and pulverised, before being mixed with an accelerator, combusted and analysed through infrared detection on LECO instrumentation).
- Total organic carbon through calculation (based on other carbon speciation analyses)
- Major and rare earth element oxides by borate fusion and X-ray fluorescence (XRF) spectrometry (internal SOP: Samples are crushed and pulverized, and samples formed into homogeneous glass disks by fusion of sample with lithium tetraborate/lithium metaborate mixture. The prepared disks are analyzed by wavelength dispersion XRF, with the following percentages of the whole rock suite reported: SiO₂, Al₂O₃, Fe₂O₃, MgO, CaO, Na₂O, K₂O, P₂O₅, MnO, TiO₂, Cr₂O₃, V₂O₅, BaO, SrO and ZrO₂). Loss on ignition (LOI) at 1000°C is also reported.
- Elemental analysis through inductively-coupled plasma optical emission spectroscopy (ICP-OES) (internal SOP: Samples are crushed and pulverized, then an aqua regia mixture (HCl:HNO₃ at 3:1 ratio) is used to leach acid extractable analytes from sample. As aqua regia digestion is partial, the remaining precipitate is filtered and fused with sodium peroxide, with the two portions analyzed and summed to produce a final result. Elements reported are: Ag, Al, As, Ba, Be, Bi, Ca, Cd, Co, Cr, Cu, Fe, K, Li, Mg, Mn, Mo, Na, Ni, P, Pb, Sb, Se, Si, Sn, Sr, Te, Ti, Tl, V, Y, Zn.
- Mercury by cold vapour atomic absorption spectroscopy (CVAAS). Method derived from EPA 245.1, EPA 7471B and MA.200.
- X-ray diffraction analysis to identify mineral/compound phases based on crystallinity, crystal structure and orientations. Quantitative Rietveld Analysis is used to quantify composition of: quartz, magnesite, periclase, dolomite, anhydrite, calcite, brucite, lime, melanterite, diaspore, portlandite.

Preliminary characterisation - SGS Spain

- Moisture content (internal SOP)
- Total Sulphur by high temperature combustion and infrared detection with LECO instrument (internal SOP).
- Total Inorganic Carbon - modified from EN:15936:2022
- Granulometry (internal SOP)
- Major metals through alkaline fusion method followed by analysis with ICP-OES, after ISO 14869-2. The sample is fused with lithium borate flux and the obtained pellet is dissolved using microwave assisted acid digestion and analysed by ICP-OES.
- Trace metals through aqua regia digest with microwave assisted digestion, followed by analysis through ICP-MS (internal SOP).

- Mercury through cold vapour atomic absorption spectroscopy - ISO 15587-1
- Hexavalent chromium - Cr(VI) - EPA 3060A & EPA 7196A

Quantitative characterisation - ALS Dartmouth

- Moisture content by gravimetry (Method reference: CCME Canada-Wide Standards for Petroleum Hydrocarbons (CWS-PHC) in Soil - Tier 1. Moisture is measured gravimetrically by drying the sample at 105°C. Moisture content is calculated as the weight loss (due to water) divided by the wet weight of the sample, expressed as a percentage).
- Total inorganic carbon by coulometry (Internal SOP: Diluted perchloric acid is added to the sample to react with metal carbonates, yielding CO₂ which is measured by coulometry).
- Total Sulfur by high temperature combustion. Method reference: ISO 15178:2000
- Metals by Collision/Reaction Cell (CRC) Inductively Coupled Plasma Mass Spectroscopy (ICP-MS). Method reference: Modified from EPA 6020B to report bioavailable metals after aqua regia digest (Ag, Al, As, B, Ba, Be, Bi, Ca, Cd, Co, Cr, Cu, Fe, K, Li, Mg, Mn, Mo, Na, Ni, P, Pb, S, Sb, Se, Sn, Sr, Ti, Tl, U, V, W, Zn, Zr).
- Mercury by cold vapour atomic absorption spectroscopy (CV-AAS). Method reference: Modified from EPA 200.2/1631
- Hexavalent chromium (Cr(VI)) by ion chromatography. Method reference: APHA 3500-CR C
- Trivalent chromium (Cr(III)) by calculation. Method reference: BC WLAP LAB MANUAL / EPA 3060A & 7196A
- Tier 1 Risk Based Corrective Action (RBCA) hydrocarbon suite (Method reference: Atlantic RBCA Version 3.1 - Tier 1), comprising:
 - Volatile petroleum hydrocarbons by headspace gas chromatography flame ionization detection (GC-FID)
 - Extractable petroleum hydrocarbons by GC-FID
 - VPH C6-C10 (less BTEX)
 - Modified TPH - Tier 1
- BTEX by headspace GC-MS (Method reference: EPA 8260D).

Sample Preparation and Handling

Please describe the sample preparation and handling methods used in the extraction, handling and preparation of rock and mineral feedstocks, both before and during the characterisation program - Where a national or local standard has been utilized please outline with specific reference to the standard and any deviations

Preliminary feedstock characterisation was carried out by two different labs (SGS Canada and SGS Spain). This preliminary testing is completed to ensure the material is suitable for dosing, both in terms of efficacy (i.e. has sufficiently high hydroxide content) and safety (i.e. has sufficiently low enough concentration of heavy metals). Final characterization of the feedstock for CDR quantification is conducted using composite samples collected in Halifax prior to dosing.

Preliminary characterization by SGS Canada Inc. was completed on six individual samples collected in Spain and shipped to SGS Lakefield. These samples, each about 4-5 kg, were withdrawn using a hand shovel from separate supersacks each containing ~1200 kg

material. The feedstock samples did not require crushing because of obvious (or visual) fineness of the particle size. A rotary splitter (riffler) was used to homogenize and reduce the weight of each sample to ~500 g subsamples (8 to 10 subsamples from each bag). The subsamples then are submitted to the analytical or metallurgy labs for targeted analysis.

A second round of preliminary characterization as completed by SGS Spain on the entire tonnage procured for the trial. The sampling was conducted while preparing the material for the shipment.

The feedstock is stored in 1200 kg supersacks separated into 23 'batches'. Each batch contained a different quantity of material. In order to collect a representative composite sample for the each batch, we used the following sampling criteria based on the batch size: Batches with < 10 bulk bags, 1 duplicate sample per bag was taken; Lots with a cumulative total mass of up to 100 tonnes, 10 samples each from different bags; lots with cumulative total mass of > 100 tonnes, 15 samples each from different bags were taken. Each bag sampled was opened, and a shovel was used to mix it well before taking several scoops. All samples were placed into a large plastic sack which was labelled by batch number. Sampling in Halifax prior to dosing follows this same procedure.

Has an unbroken chain of custody been collected for characterized feedstocks? (Yes/No)

If 'Yes' please provide a chain of custody document to the project VVB with this completed document. If 'No' please refer to the next question

Please Note: Chain of custody documents must outline detailed information on the handling of rock and mineral feedstock materials, from their source location to the production of characterization results.

Yes a chain of custody is in place.

[REDACTED]

[REDACTED]

[REDACTED]

[REDACTED]

[REDACTED]

The confidential documents provided demonstrate a chain of custody with elements of the identity preserved and mass balance models. For 2024, each unit of alkalinity sold to Planetary is identified by a batch number (day-month-year) and matched to shipment ID traceable by license plate, ocean voyage, and warehouse location data.

This is consistent with expectation #1 outlined in ISO 22095 "1) *Item-based: the material or product received bears all the characteristics identified by associated information*"

If 'No' was answered to the last question please provide a detailed explanation for breaks in the chain of custody for an intended feedstock

Physical Characterisation

Please provide details of the geotechnical testing carried out on rock and mineral feedstocks utilized within this project - See section 3.3.1 of the Rock and mineral feedstock characterization module for more details

These methods relate to the preliminary testing carried out by SGS Lakefield.

Determination of moisture content- A small amount of sample was taken from a 500 g subsample using a grab sampling technique for moisture determination. The sample was placed in a tared sample cup, weighted and dried at a 80°C temperature until all hygroscopic water was driven off, and then weighted again. The difference in weights represents the moisture content.

Determination of bulk density- Subsamples were placed into a tared measuring cylinder and gently agitated to eliminate all significant void space caused by air. The weight and volume were measured and the ratio reported as the uncompacted density of this sample. Next, the measuring cylinder with the sample was placed on a vibrating table and allowed to compact, the volume was measured again and used to calculate the compacted density.

Determination of particle density using a gas pycnometer-The specific gravity (or specific density) of each sample was determined using a gas pycnometer. The gas pycnometer measures the volume of a known weight of powdery, granular, porous, and irregularly shaped solids. In this method Helium gas was used since its small atomic dimension assures penetration into crevices. Displacement using helium gas proceeds until the cell equilibrates at target pressure. The sample volume is then calculated and translated into the specific density, as the weight of the sample is known. Specific density, also known as relative density (alternate terms for specific gravity) is a ratio against a known density and therefore unitless.

Please provide details of the Particle Size Distribution (PSD) and surface area analysis undertaken on characterized rock and mineral feedstocks

Determination of particle size distribution by Malvern analyzer-The particle size analysis was done using a method of Malvern laser diffraction. The Malvern sizing is based on laser light passing through a dilute suspension of the particles which circulate through an optical cell. A theory of light scattering is used to calculate the particle size distribution, finer particles inducing more scatter than coarser particles. Laser diffraction instruments are fast, easy to use, and can give reproducible results. However, results can depend on the relative refractive indices of the solid particles, liquid medium, particle shape and must be understood well and to compensate for these effects or apply calibration inputs for users.

Trained SGS lab personnel performed this analysis on subsamples (~5-10g). The sample as a slurry (mixed with DI water) was added slowly to a stirred beaker of distilled water feeding to the analyzer.

Specific surface area (BET) was determined by measuring the amount of Nitrogen gas adsorbed on the sample surface under controlled conditions at ambient temperature (300K). Approximately 0.5 g sample was required for this measurement. Three surface areas were reported per sample: (1) Singlepoint BET, (2) Multipoint BET and (3) Langmuir area corresponding to the monolayer on the surface. For estimating reaction kinetics, we were advised to base our calculation on Multipoint BET value. The surface area analysis was done at McGill Chemical characterisation facility.

Where alternative methods to those outlined in section 3.3.2 of the Rock and mineral feedstock characterization module have been used to determine PSD and surface area please provide justifications and detailed descriptions of alternative methods

Geochemical Characterisation

Elemental Characterisation

Please provide details of the elemental characterisation framework designed for, and carried out on, rock and mineral feedstocks utilized within this project - See section 3.4.1 of the Rock and mineral feedstock characterization module for more details

Where an alternative elemental testing procedure/procedures to those required has been carried out, please provide detailed justifications and descriptions. This will include a description of the specific methodology used and any accompanying SOP's.

These methods relate to the quantitative characterisation carried out by ALS Dartmouth on each batch of material, as well as on each weekly composite sample.

Elemental analysis, to assess both the equivalent hydroxide content and the concentrations of trace metals, is performed using **inductively coupled plasma mass spectroscopy (ICP-OES/MS)** in a collision/reaction cell (CRC). This method is based on aqua Regia digestion, using a mixture of nitric and hydrochloric acid. The mercury content is analysed using a quicktrace cold vapour atomic absorption spectroscopy. The hexavalent chromium content is determined through ion chromatography with UV detection. The reporting limits are shown in the table below.

Elements and Reporting Limits (in mg/kg)							
Ag	0.1	Cu	0.5	Sb	0.1	Zr	1

Al	50	Fe	50	Se	0.2	Hg	0.005
As	0.1	K	100	Sn	2.0	Cr (VI)	0.1
B	5	Li	2.0	Sr	0.5	Cr (III)	0.03
Ba	0.5	Mg	20	S	1000		
Be	0.1	Mn	1.0	Ti	1.0		
Bi	0.2	Mo	0.1	Tl	0.05		
Ca	50	Na	50	V	0.2		
Cd	0.02	Ni	0.50	Zn	2.0		
Co	0.1	P	50	U	0.05		
Cr	0.5	Pb	0.5	W	0.5		

Where elemental characterisation of rock or mineral feedstocks has been carried out in excess of the minimum requirements of *section 3.4.1 of the Rock and mineral feedstock characterization module*, please provide details

Please describe the methods utilized in the analysis of Total Carbon and Sulfur contents of proposed rock and mineral feedstocks

The total Carbon and Sulfur in feedstock samples were determined using a **Leco analyzer** based on combustion and Infrared Detection. For sulfur, an air-dried sample is ignited i/n a combustion analyzer, then sulfur content in the reduced SO₂ gas is determined using a thermal conductivity detector. For total carbon, the sample is heated to 1350°C in an induction furnace with an oxygen stream. Carbon dioxide released from the sample is then measured by an IR detection system (LECO analyzer). The element detection limits are 0.05% S and 0.01 % C.

Where dry combustion has not been utilized in the determination of rock or mineral feedstock total carbon and sulfur please provide details of, and justifications for, the alternative method used in this project

N/A

Radiation Analysis

Please provide details of methods used to determine the radiation levels of rock or mineral feedstock utilized within this project

Where an alternative method to ISO 10694:1995, such as a national standard, has been used to determine radiation levels please provide detailed descriptions and justifications

Radiation analyses were completed during the preliminary characterization by SGS. The method based on ISO 18589 was used by SGS Lakefield to determine gross Alpha and Beta activities in composite samples. An aliquot of a finely ground solid sample is measured onto a pre-weighed 2-inch (50.8 mm) planchet. A small amount of deionized water is used to disperse the material evenly across the planchette. A fixative is used to adhere the sample to the planchette sample. The sample is air dried and analyzed by gas flow proportional detector.

Where pre-existing data has been used to demonstrate negligible radioactivity of a rock or mineral feedstock please provide details

Please Note: The use of pre-existing data related to a materials radioactivity requires prior consultation with Isometric and the project VVB

Mineralogical Characterization

Please provide a detailed description of the mineralogical analysis framework used to characterize rock and mineral feedstocks in this project - Please refer to section 3.4.4 of the *Rock and mineral feedstock characterization module*

During the preliminary characterization by SGS, major, moderate, minor and trace mineral identification on composites were done using X-ray diffraction (XRD) analysis (Bruker D8 ADVANCE diffractometer). This method uses ~10 g dry sample pulverized. Manual and computer assisted search/match and identification of mineral and material species done by EVA software and ICDD PDF 2/ PDF 4 Database. The interpretation of XRD patterns is facilitated by chemical analysis and background information on the sample.

Imagery of the material was also obtained using scanning electron microscopy (SEM).

Where alternative mineralogical assessment methods, to those required in section 3.4.4 of the *Rock and mineral feedstock characterization module*, have been used, please provide justifications

Please provide details on assessments carried out to assess the potential for (1) Human/health Risk, Environmental Risk and CO₂ Removal Inefficiency

Please Note: This should include assessments of specific mineral groups within a rock or mineral feedstock, including, but not limited to, carbonates, sulfides and asbestos group minerals

-The feedstock contains trace amounts of silica (2-3%) and sulphur (1-2%). Regarding safety, general guidelines including eye and skin contact is advisable. Also, avoid inhalation and generating airborne dust. Wearing appropriate protective clothing is mandatory.

-Sulfides and carbonates can lead to removal inefficiency. The equivalent hydroxide content (EQOH) method used takes into account the influence of sulfides and carbonates.

-Asbestos testing was done at LEX Scientific Inc using a polarized light microscope (PLM). None of the following four main asbestos types were detected (Chrysotile, Amosite, Crocidolite and Tremolite) in the feedstock sample. The detection limit for this PLM method is 0.1%.

Assessment of CO₂ removal potential

Please describe the carbon removal potential of the feedstock following Section 3.4.1.1 of the Rock and Mineral Feedstock Characterization Module.

Planetary quantifies the potential alkalinity released on dissolution of mineral feedstock by determining the “Equivalent Hydroxide Alkalinity” (EQOH), expressed as kilograms of hydroxide contained in one tonne of dry feed.

EQOH is calculated from the sum of magnesium and calcium oxides that form hydroxide upon hydrolysis. Sulphate and phosphate anhydrite are excluded as they do not hydrolyse to form hydroxide, and other alkali anhydrites (e.g., Na₂O, K₂O) are only included when soluble, such as in nephelite syenites. Calcium and magnesium carbonates, which are minor components of the feedstock, are included with a stoichiometric weighting of 1, compared to 2 for the hydroxides.

Composite samples of each lot of feedstock are collected onsite and submitted to ALS Dartmouth for chemical characterization. Using this data, specific chemical compositions and ratios are calculated using stoichiometry.

η is the location-specific molar ratio of the seawater DIC (dissolved inorganic carbon) increase after air-sea equilibrium for a given divalent alkalinity (total alkalinity or TA) released from the feedstock dissolution:

$$\eta = \frac{\Delta DIC}{\Delta TA}$$

ALK_{pot} is calculated for each lot of feedstock, and provides the kilomoles (kmol) of divalent alkalinity per tonnes (t) of feed:

$$ALK_{pot}(\eta)(\text{kmol}/t_{\text{dry feed}}) = \left[\frac{CaO_{\text{Total,Oxide}}}{MW_{CaO}} + \frac{MgO_{\text{Total,Oxide}}}{MW_{MgO}} + \frac{Na_2O_{\text{Total,Oxide}}}{MW_{Na_2O}} + \frac{K_2O_{\text{Total,Oxide}}}{MW_{K_2O}} - \frac{SO_4}{MW_{SO_4}} - \frac{P_2O_5_{\text{Total,Oxide}}}{MW_{P_2O_5}} - \frac{CaCO_3}{MW_{CaCO_3}} - \left(\frac{\frac{MgCO_3}{MW_{MgCO_3}}}{\eta} \right) \right] \times \left(\frac{1000}{100} \right)$$

MW denotes molecular weight.

The calcium carbonate component is subtracted as it is assumed to not dissolve in seawater, and the magnesium carbonate component undergoes a correction because 1 mole of magnesium carbonate only achieves η -1 moles of CDR (η is defined for divalent alkalinity).

In order to calculate the metal oxide and metal carbonate terms for use in the ALK_{pot} equation, some further equations are required. Total metals from the ICP-MS are expressed as total metal oxides, as per the following:

$$Metal_{\text{Total, Oxide}}(\%) = \frac{Metal_{ICP}(\text{mg/kg})}{MW_{\text{Metal}}(\text{g/mol})} \times MW_{\text{Metal oxide}}(\text{g/mol}) \times 10^{-4}$$

To calculate the metal carbonate term, the Mg, Ca, Na and K data from the ICP-MS assays are first normalised, as follows:

$$Metal_{\text{Min norm}} = \frac{Metal_{ICP}(\text{mg/kg})}{Mg_{ICP}(\text{mg/kg}) + Ca_{ICP}(\text{mg/kg}) + Cr_{ICP}(\text{mg/kg}) + Al_{ICP}(\text{mg/kg}) + Fe_{ICP}(\text{mg/kg}) + Na_{ICP}(\text{mg/kg}) + K_{ICP}(\text{mg/kg}) + Mn_{ICP}(\text{mg/kg})}$$

Then, the metal carbonate term can be calculated as:

$$Metal\ Carbonate(\%) = (Metal_{\text{Min norm}} \times CO3(\%)) \times \frac{MW_{\text{Metal}}(\text{g/mol})}{MW_{CO3}(\text{g/mol})} \times \frac{MW_{\text{Metal carbonate}}(\text{g/mol})}{MW_{\text{Metal}}(\text{g/mol})}$$

To express the ALK_{pot}, with a moisture correction, in terms of equivalent hydroxide ions with units of kilogram hydroxide per tonne of feed:

$$EQOH(\eta)_{\text{moisture corrected}}(kg_{OH^-}/t_{\text{feed}}) = ALK_{\text{pot}}(\eta) \times MW_{OH^-} \times 2\text{mol} \times \left(1 - \frac{\text{moisture}}{100}\right)$$

Note that a moisture value of 0.2 is used when the moisture is below the detection limit (< 0.25 %).

As per the sampling guidelines above, bulk bags that had less than 10 tonnes dosed within the crediting period are not required to be sent for analysis. Thus, any bulk bags fitting that requirement and were not analyzed are assigned the average EQOH of that crediting period instead of a calculated batch-specific EQOH.

The bulk bags of feedstock are weighed prior to delivery onsite and tracked by lot number. The mass of dosed material is summed by lot. Then a weighting factor is calculated:

$$\text{Weight factor} = \frac{\text{Tonnes of Material Dosed by Lot}}{\text{Total Tonnes of Material Dosed}}$$

Then the EQOH associated with the lot is multiplied by its weighting factor to get a weighted EQOH.

$$\text{Weighted Average EQOH}(\eta)_{\text{Lot}} = EQOH(\eta)_{\text{moisture corrected}}(kg_{OH^-}/t_{\text{feed}}) \times \text{Weight factor}$$

All weighted EQOHs are summed to get the Weighted-Average EQOH

$$\text{Weighted Average EQOH}(\eta) = \sum \text{Weighted Average EQOH}(\eta)_{\text{Lot}}$$

The carbon capture potential (E_{pot}) of a feedstock (defined in Isometric's ACM, Section 3.4.1.1) can be determined from EQOH via:

$$E_{\text{pot}}(kg_{CO_2}/t_{\text{feed}}) = EQOH \times \frac{MW_{CO_2}}{MW_{OH^-}} \times \frac{\eta}{2}$$

Where MW_X is the molar mass of X; η , as defined in the ACM,^[1] is the molar ratio of the resulting seawater DIC increase after air-sea equilibration to the divalent alkalinity released from feedstock dissolution. This value depends on local ocean conditions (T, S, pH) but is typically around 1.7. η is divided by 2 because EQOH expresses monovalent (OH^-) rather than divalent alkalinity.

[1] Note that η is more commonly used in OAE practice, including Planetary's MRV protocol, to denote the time-varying ocean efficiency (see next section).

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Feedstocks Sourced from Mining Operations
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<i>If rock or mineral feedstocks are sourced from mine wastes or by-products, please describe the geochemical characterization of the wastes following Section 3.4.5 of the Rock and Mineral Feedstock Characterization Module.</i>

Feedstock characterization discussed in earlier sections.

Where existing characterisation databases exist for a rock or mineral feedstocks, please provide a description of this data and its availability for interpretation

Please Note: The use of pre-existing characterisation data for the purposing of fulfilling the requirements of the <i>Rock and Mineral Feedstock Characterization Module</i> requires consultation with Isometric and the project VVB

A full characterization of the feedstock sourced for this project was conducted by independent third-party laboratories as described in previous sections.
--

Section D: Sampling procedure

Sampling Guidance, Laboratory Requirements, and Data Quality

Please describe and justify the sampling procedure and number of analyses based on the project-specific considerations, following Section 4.1 of the Rock and Mineral Feedstock Characterization Module.

The preliminary characterisation of feedstock was conducted on 6 individual samples. These samples (~ 500 g) were produced from 4-5 kg tertiary samples. The latter was sourced from secondary samples presented as 1200kg bags. Each bag was randomly selected from a large number of bags.

To demonstrate whether the weight and number of samples are adequate, the theory of fundamental sampling error (FSE) can be applied. Typically, five parameters (shape factor (f), the granulometric factor (g), the mineralogical composition factor (c), and the liberation factor, l, sample size d_N) are required to obtain a minimum sample mass by Gy's equation published elsewhere ($FSE = clfgd_N^3$) and claim sampling representativity. These factors contribute to the compositional and distribution heterogeneity.

The shape factor is related to the volume and the diameter of the particles and typically $f = 0.5$. The liberation factor is between 0 (no liberation) and 1 (complete liberation). The granulometric factor g is reasonably close to 0.25 for most applications and is estimated from the ratio of the nominal top particle size to the lower particle size. The mineralogical factor consists of two components, the density of the mineral of interest versus the density of gangue mineral and the relative proportions of the element of interest.

The MgO in the feedstock sample is about 57.5%. The specific density of 3.04 g/cm³ versus 3.58 g/cm³ for pure MgO. Taking the largest particle size 95% passing as 81 µm, the theoretical minimum sampling mass based on the FSE equation is 3.2 mg with 95% confidence level of ±0.1%. This indicates that taking several kg for the first sampling and ~ 500 g for second sampling is above the theoretical and demonstrates that the proper sampling for analysis was followed for feedstock material.

Feedstock Sampling Plan during Operations:

The sampling strategy at the site is similar to the one followed by SGS Spain except each bag will be sampled and stored in a sealed plastic container. The bags will be sampled as soon as they are opened and before dosing into seawater. The collected subsamples will be analysed following the same characterisation protocol.

Please provide a list of the analytical laboratories that have been utilized for feedstock characterization, including whether they are an accredited commercial laboratory.

ISO accredited commercial laboratory-
SGS Canada Inc.
PO Box 4300, 185 Concession Street
Lakefield ON, K0L 2H0 CANADA

Where a project has utilized a non-standardized methodology or SOP for the determination of a required parameter in the Rock and Mineral Feedstock Characterization Module, please provide details and justifications for the use of these methods/SOP within the project

Please Note: Where these alternative methods have been reported in previous sections of the PDD a project proponent does not have to repeat descriptions in this section

Section E: Data reporting

Data Reporting

Please provide details of data analysis methods utilized for data reporting in this project

The analysis done by accredited commercial labs is fully verifiable. Certain methods -Determination of particle density using a gas pycnometer, X-Ray Fluorescence Spectrometry, ICP-OES, Leco analyzer and X-ray diffraction (XRD)- include quality control materials, replicates and reference materials and instruments calibrated rigorously using certified relevant standards.

The data provided by certified labs are collected and organized in a single summary table using excel format. The table includes some statistical evaluation such as (1) Arithmetic mean or average obtained by dividing the sum of a set of data by the number of individual measurements, (2) Standard deviation which is the square root of the sum of the squares of the deviation between individual results and the mean of the series, (3) Variance or a square of the standard deviation, (4) Relative standard deviation by dividing standard deviation by the mean of the series and (5) Standard error in the mean (SEM) calculated by dividing the standard deviation by the square root of the number of the individual measurements.

Please provide information on analytical uncertainty, number of samples taken, standards used and number of standard runs, standard deviation and percentage errors reported within data reports submitted to the VVB - Please refer to section 5.1 of the *Rock and mineral feedstock characterization module*

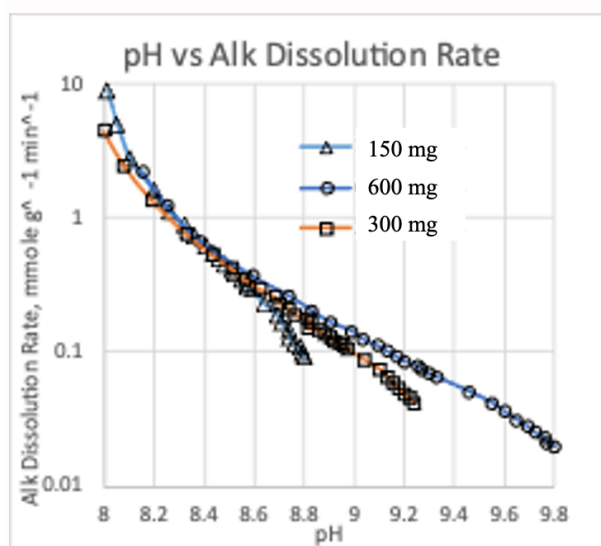
Section F: Pathway specific requirements

Pathway Specific Feedstock Characterisation Requirements - OAE Projects

Feedstock dissolution rate

Please describe how the feedstock dissolution rate is characterized, including evidence of whether or not the feedstock is fast dissolving as outlined in section 9 of the OAE in Coastal Outfalls protocol.

Multiple lab experiments have been conducted to estimate feedstock dissolution rates. The primary analysis prior to dosing, conducted in March 2024, involved tracking dissolution of varying feedstock concentrations in seawater over a 1 hour period. The change in pH over time was used to estimate the rate of alkalinity generation, which corresponds to the dissolution rate. An example of one such analysis yielded the following dissolution rates as a function of pH.



Dissolution slows dramatically as pH rises and the solution becomes more saturated within the enclosed beaker. Given the reality of rapid dilution in the field, we use the initial dissolution rate as a first-order estimate (10 mmol/g/min , or $1.67 \cdot 10^{-4} \text{ mol/g/s}$), and using BET surface area, this corresponds to $1.05 \cdot 10^{-5} \text{ mol/m}^2/\text{s}$. A temperature correction to average autumn sea temperatures in Halifax Harbour (12°C) can be made using data from Bharadwaj et al. (2013) for $\text{Mg}(\text{OH})_2$ ^[1]. Further tests are underway to understand replicability, to minimize assumptions, and to further understand effects such as temperature on this estimate.

For comparison with published results, Mejias et al. (1999)^[2] state that MgO dissolution kinetics are strongly influenced by the surface defect concentration, with a simple model predicting a dissolution rate of $10^{-6} \text{ mol/m}^2/\text{s}$ for a typical surface defect concentration of 0.1. The experiment described above measured initial dissolution rates (at 22°C) that were

10 times higher than this simple model, possibly due to the high temperatures used during production of this feedstock.

Further dissolution experiments for this feedstock have also been conducted by Dr. Kai Schulz as part of the AlkAlign project. In this experiment, conducted at $T = 7^{\circ}\text{C}$ and salinity $S = 18$ ppt, and using a refined feedstock sample that passed a $32\text{ }\mu\text{m}$ sieve, half of the expected total alkalinity was released within the first 50 minutes ($\sim 1.4\%$ per minute). The slower dissolution rate is explained by the lower temperature, and by the declining dissolution as pH increases (again a closed system). In this experiment pH had increased by ~ 0.5 after 50 minutes resulting in a ~ 15 -fold reduction in dissolution rate according to the image shown above. A temperature correction from 7°C to 22°C would increase the dissolution rate by a factor $\sim 5.3\times$. Taken together these two factors are sufficient to explain the difference in observed alkalinity release rates.

Using these dissolution rates alongside the average particle sizes (i.e. D50) and seawater densities, and Stokes' drag factor, a 1D dissolution/sinking model yields $>97\%$ dissolution at the 20m depth horizon (i.e. near the discharge point) and $>98\%$ dissolution at the 70m horizon (i.e. in the deep basin).

The rapid decline in dissolution rate in the $8.0 < \text{pH} < 8.1$ range (see Figure above) will be accentuated by the dissolution of very fine particles ($D < 1\text{ }\mu\text{m}$) with high specific area. However, extrapolation of the semi-log trend established at $\text{pH} > 8.3$ suggests that this correction will be less than a factor of 10. If the dissolution and sinking calculation is repeated with a $10\times$ lower dissolution rate (1 mmol/g/min), the model predicts 95% dissolution within 21 hrs, 99% within 39 hrs, and the largest particles fully dissolved in 4 days. Around 96% of the feed would be fully dissolved at 70m depth.

Although more testing will be completed, the rates and analyses described above suggest complete dissolution of the feedstock in the ocean within 1 day, which should classify this material as a 'fast dissolving feedstock'.

[1] Bharadwaj, H.K., Lee, J.Y., Li, X., Liu, Z. and Keener, T.C., 2013. Dissolution kinetics of magnesium hydroxide for CO_2 separation from coal-fired power plants. *Journal of hazardous materials*, 250, 292-297.

[2] Mejias, J.A., Berry, A.J., Refson, K. and Fraser, D.G., 1999. The kinetics and mechanism of MgO dissolution. *Chemical Physics Letters*, 314(5-6), 558-563.

Planetary may also conduct further in-house bench-top dissolution experiments using a multiparameter sensor that will continuously measure pH and turbidity / TSS in a beaker containing a known concentration of feedstock. A preliminary version of this experiment was conducted in March 2024.

