RUNNING TIDE

Quantification Methodology

v1.6.0

Abstract

The following report describes the methods used to quantify the impact on the earth's carbon cycle through the placement of passively drifting carbon buoys in the ocean.

This report includes technical details required for evaluating outcomes – models used and applied, sampling protocols followed, correlation between in-situ measurements and modeled outcomes, specific discounts, and more.

1. Introduction

This document provides the underlying methodology for the quantification of a Running Tide intervention involving the placement of carbon buoys consisting of alkaline mineral-coated wood into the open ocean. This methodology includes the underlying formulas, factors, and discounts to describe the details of how to measure, quantify, and verify results. Running Tide's published Carbon Removal Framework Protocol serves as the basis for this methodology.

2. Sources

This methodology refers to the following Running Tide protocols and project documents:

- Carbon Removal Protocol (Version 2.0 published April 2023) i.e. "Framework Protocol"
- Responsible Sourcing Strategy (Version 1.0 published July 2023)
- Running Tide's Governance Principles for Responsible Climate Intervention (Version 1.0 published July 2023)

This methodology refers to the following tools/regulation/modules/standards:

- ISO 14064-2:2019; Greenhouse gases — Part 2: Specification with guidance at the project level for quantification, monitoring and reporting of greenhouse gas emission reductions or removal enhancements.
- ISO Guide 98-3:2008 – Uncertainty of measurement — Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)

3. Summary Description of the Methodology

This methodology establishes applicability conditions and procedures to quantify project emissions and gross movement of CO_2*e* from the fast cycle to the slow cycle for projects conducting terrestrial biomass sinking in the open ocean. The basic principles are that:

- Passively drifting carbon buoys composed of terrestrial biomass and alkaline minerals are placed in the open ocean, where they float for a tuned period of time before sinking to the ocean floor below 1,000m, durably removing carbon from the fast cycle.
- CO_2e removed is quantified through a combination of in-situ measurements, oceanographic modeling, and laboratory testing. This occurs after the terrestrial biomass floating period when the carbon buoys have begun to sink to the ocean floor.
- Project emissions are subtracted from the quantity of CO_2e removed.

The methodology is developed in accordance with the requirements of ISO 14064-2:2019

4. Definitions

Refer to the Terminology section in the Framework Protocol. In addition, the following definitions apply:

- **Carbon Dioxide Equivalent (CO_2e):** The amount of carbon dioxide by weight that would produce the same global warming impact as a given weight of another greenhouse gas, based on the best available science.
- **Carbon Dioxide Removal (CDR):** The intentional movement of carbon from the fast carbon cycle to the slow carbon cycle, where the total fast carbon removed exceeds the total slow carbon emitted within a given project boundary.
- **Deployment**: The project action of placing carbon buoys and verification hardware in the ocean over the period of hours to days from a single vessel fleet.
- **Verification Hardware** (or **sensors**)**:** The tools deployed that enable accurate monitoring, measurement, and quantification of interventions. This encompasses verification hardware (camera buoys, trajectory buoys, etc.) that collects offshore data.

5. Applicability Conditions

This methodology applies to project activities that involve the sourcing, manufacturing, transportation, and ultimately, the placement of coated wood carbon buoys in the open ocean for the purpose of carbon removal.

This methodology is further applicable under the following conditions:

- Terrestrial biomass sourcing must adhere to a responsible sourcing strategy, e.g. Running Tide’s Responsible Sourcing Strategy, that has a net neutral impact on the wood basket with the goal of creating a net positive ecological impact on the area affected.
- Supplier attestations are required for raw material sources and records of material source locations and transportation details.
- Carbon removal activities conform with a governance framework, e.g. Running Tide’s Governance Principles for Responsible Climate Intervention, that ensures the work has its intended positive impact on the ocean and the communities in which the activity is conducted.
- Proactive environmental and risk assessments must be conducted to evaluate and assess potential ecological (both benthic and pelagic), economic, and social impacts before planned deployments.
- Measurement and monitoring instruments and models used in conducting research and/or evaluating results must be described as they relate to their role in quantification and independently validated where appropriate. Technology systems must be tested and verified with sample data prior to being used in planned research projects.

This methodology is not applicable under the following conditions:

- Terrestrial biomass sinking occurs in coastal waters.
- Carbon removal activities do not comply with local, regional, national, or intergovernmental/international permitting and regulatory requirements.

See Appendix II for the full list of our Governance Principles.

6. Boundary

A broad definition of the system boundaries used for the carbon accounting associated with this project is reviewed in the Framework Protocol. The specific project boundary for this system design is outlined below. Production and processing of raw materials are included within the project boundary when that activity was conducted or caused by the project activity.

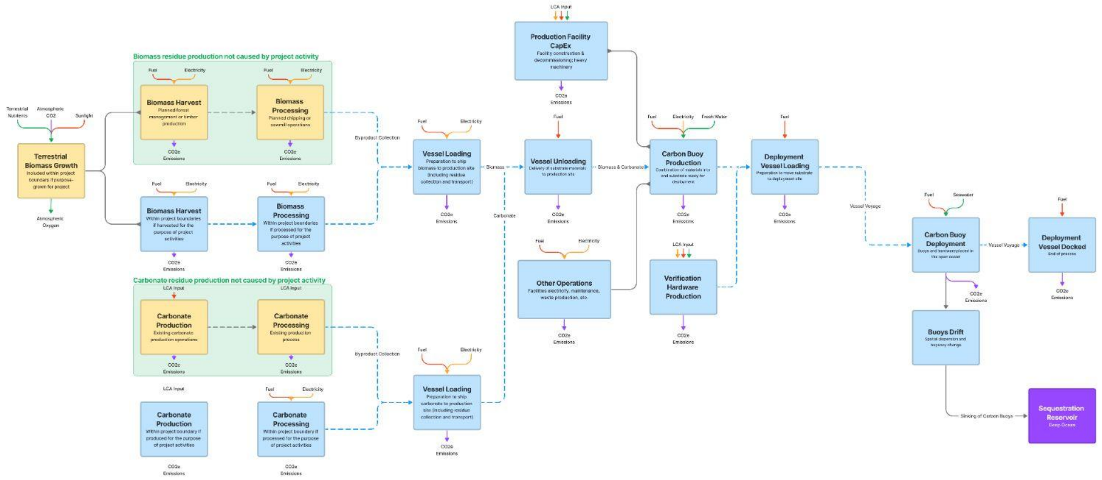


Figure 1: The project boundaries (click to enlarge).

The GHG emissions sources, sinks and reservoirs that are considered relevant for this deployment are shown in the table below.

Sources, Sinks, & Reservoirs		Category	Included / Excluded	Justification / Explanation
Baseline	Deep Ocean Site	Reservoir	Included	End state carbon reservoir for terrestrial biomass.
	Bicarbonate Pool	Reservoir	Included	End state carbon reservoir for dissolved alkaline materials.
	Deep Soil Site	Reservoir	Included	Fixed carbon from biomass growth and other sustainable land management practices are held in the deep soil reservoir.

	Growth of Terrestrial Biomass	Sink	Included	Existing forestry operations contribute to carbon fixing in deep soil reservoirs through the growth of biomass. Project activities associated with biomass sourcing that affect this sink should be included.
	Ocean Mixing	Sink	Included	Existing ocean mixing naturally carries inorganic carbon dissolved in surface water to the slow carbon cycle of the deep ocean and should be accounted for when quantifying intentional project impacts on this process.
	Processing of Terrestrial Biomass (harvest and chipping operations)	Source	Excluded	Activity is not a direct result of project operations and would have been completed regardless of project existence.
	Production of Carbonate Materials	Source	Excluded	Activity is not a direct result of project operations and would have been completed regardless of project existence.
Project	Processing of Terrestrial Biomass (harvest and chipping operations)	Source	Included	Project uses the primary product of harvest or chipping operations and they are prepared to project specifications.
	Production of Carbonate Materials	Source	Included	Project uses the primary product of these operations and they are prepared to project specifications.
	Production of Raw Materials for Verification Hardware	Source	Included	Project uses the primary product of these operations.
	Upstream Transportation & Distribution of Project Materials and Equipment	Source	Included	Activity is a direct result of project operations.
	Production of Verification Hardware	Source	Included*	Activity is a direct result of project operations.
	Production of Carbon Buoys	Source	Included	Activity is a direct result of project operations.
	Loading of Buoys onto Deployment Vessel	Source	Included	Activity is a direct result of project operations.
	Transportation of Buoys to Deployment Site	Source	Included	Activity is a direct result of project operations.
	Contractor Activities at Production Site (maintenance, equipment setup etc.)	Source	Included	Activity is a direct result of project operations.
	Production of Heavy Machinery used at Production Site	Source	Included	Activity is a direct result of project operations.

	Construction & Decommissioning of Production Site	Source	Included	Activity is a direct result of project operations.
	Sinking of Terrestrial and Marine biomass	Sink	Included	Activity is a direct result of project operations.

*Included via gap coefficient since primary activity data isn't currently available

7. Baseline Scenario

Refer to the “Baseline Scenario Considerations” in Section III of the Framework Protocol.

8. Quantification of Net Fast to Slow Carbon

Overall, net removals achieved through the considered activities are quantified as the difference between the amount of CO_2e removed and the emissions generated by the project activities, i.e., emissions related to the carbon removal operations and those associated with capital equipment.

8.1. Framework Protocol Equation

This methodology adheres to the process outlined in Running Tide’s Framework Protocol. At its simplest level, the net CO_2e removed from the deployment of carbon buoys can be calculated as:

Equation 1:

$$CO2eRemoved = \left(CO2eTerrestrial - u_{CO2e_{Terrestrial}}\right) + CO2eOAE + CO2eMacroalgae - CO2eEmissions$$

Variable	Description	Units
$CO_2eRemoved$ =	Net amount of CO_2e moved from the fast carbon cycle to the slow carbon cycle.	tonnes CO_2e
$CO_2eTerrestrial$ =	Gross CO_2e moved from the fast cycle to the slow cycle as a result of terrestrial biomass sinking.	tonnes CO_2e
$u_{CO2e\_Terrestrial}$	The combined uncertainty associated with quantification of $CO_2eTerrestrial$. See Appendix I for more details.	tonnes CO_2e

CO$_2$*e*OAE =	Gross CO$_2$e moved from the fast cycle to the slow cycle as a result of alkaline mineral dissolution.	tonnes CO$_2$*e*
CO$_2$*e*Macroalgae =	Gross CO$_2$e moved from the fast cycle to the slow cycle as a result of marine biomass sinking.	tonnes CO$_2$*e*
CO$_2$*e*Emissions =	Gross amount of CO$_2$e generated by project activities additional to the baseline scenario.	tonnes CO$_2$*e*

The gross amount of CO$_2$e moved from the fast carbon cycle to the slow carbon cycle as a result of terrestrial biomass sinking activities is calculated during vessel loading, while the vessel travels to the deployment site, and after deployment, while verification hardware provides in-situ monitoring.

In this version of the methodology, ocean alkalinity enhancement (OAE) is not quantified for the purpose of credit generation. While it is expected that there will be carbon removal via OAE during Running Tide's carbon buoy deployments, that part of this quantification methodology is still being developed, and research from early deployment observations and data collection will provide an opportunity to quantify OAE in the future. Alkalinity addition also helps to counteract any organic acid leaching from the terrestrial biomass, which we quantify in section 8.2.3.

Equation 2:

$$CO2e\ Terrestrial = Terr_{added} - Terr_{loss} - Terr_{shed} - Terr_{shal} - Terr_{stor} - LUC_{indirect}$$

Variable	Description	Units
Terr$_{added}$ =	The gross amount of CO$_2$e contained in terrestrial biomass loaded on the deployment vessel.	tonnes CO$_2$*e*
Terr$_{loss}$ =	The amount of CO$_2$e contained in terrestrial biomass that is lost between the time of measuring the loaded mass and the time of deployment.	tonnes CO$_2$*e*
Terr$_{shed}$ =	The amount of CO$_2$e in terrestrial biomass separated from the carbon buoys prior to or during the sinking process.	tonnes CO$_2$*e*
Terr$_{shal}$ =	The amount of CO$_2$e in terrestrial biomass that does not end up durably sequestered below 1000 m depth. This can happen because	tonnes CO$_2$*e*

	biomass ends up in shallower water or due to float past the duration of the tracked deployment.	
$Terr_{stor}$ =	The amount of CO_2e in terrestrial biomass that is unlikely to transition to the slow carbon cycle in the absence of sinking.	tonnes CO_2e
$LUC_{indirect}$	Emissions resulting from land use change associated with changes in the production of feedstock or management of terrestrial ecosystems due to terrestrial biomass sinking.	tonnes CO_2e

The gross amount of CO_2e emitted from project activities is calculated through a combination of activity data, spend-based data, and supplier attestations.

Equation 3:

$$CO2e\ Emissions\ = Energy_{CO2e} + OpMat_{CO2e} + CapMat_{CO2e} + Gap_{CO2e}$$

Variable	Description	Units
$Energy_{CO_2e}$ =	The emissions associated with energy use in the process of carbon sequestration.	tonnes CO_2e
$OpMat_{CO_2e}$ =	The emissions associated with project operations, including raw materials, freight, and buoy production.	tonnes CO_2e
$CapMat_{CO_2e}$ =	The emissions associated with capital goods.	tonnes CO_2e
Gap_{CO_2e} =	The emissions potentially within the project boundary that are not currently quantified according to a gap analysis.	tonnes CO_2e

8.2. Terrestrial Biomass Sinking Methodology

8.2.1. $Terr_{added}$ Calculation

Equation 4:

$$Terr_{added} = m_{load} \times f_{weight} \times (1 - f_{moisture}) \times f_{TOC} \times MR_{CO2}$$

Variable	Description	Units
m_{load} =	The mass of the carbon buoys loaded onto the deployment vessel, typically determined from a draft survey.	tonnes
f_{weight} =	The fraction of the specified carbon buoy recipe on the barge, determined on a dry basis from onsite scales and inventory tracking.	unitless
$f_{moisture}$ =	The fractional moisture content of carbon buoys at the time of loading, determined via third-party lab analysis.	unitless
f_{TOC} =	The fractional organic carbon content of the carbon buoys, determined via third-party lab analysis.	unitless
MR_{CO2} =	Fixed molar ratio of CO_2:C, i.e. 44.009/12.011	unitless

8.2.2. $Terr_{loss}$ Calculation

Equation 5:

$$Terr_{loss} = m_{DML} + m_{loss}$$

Variable	Description	Units
m_{DML} =	Mass of any dry matter loss that occurs on the loaded deployment vessel.	tonnes CO_2e
m_{loss} =	Mass of any carbon buoy loss that occurs during the vessel's journey to the deployment site, calculated from a combination of operator reports and camera monitoring.	tonnes CO_2e

This equation is used when there is an estimated amount of mass lost from the carbon buoy pile. To be extremely conservative, we assume 5 tonnes of material is lost per deployment to cover any small amount of loss that we are unable to observe. These 5 tonnes are included in our uncertainty quantification as shown in equation 10.

8.2.3. $Terr_{shed}$ Calculation

Equation 6:

$$Terr_{shed} = f_{DOC} \times (Terr_{added} - Terr_{loss}) + f_{acid} \times (Terr_{added} - Terr_{loss})$$

Variable	Description	Units
f_{DOC} =	The fraction of dissolved organic carbon (DOC) that is leached from the carbon buoys over time, expressed per tonne CO_2. This is a rate-based process that is a function of the floating time of the coated wood.	unitless
f_{acid} =	The fraction of acidity (H+) that is leached from the carbon buoys over time, expressed per tonne CO_2e of Terr_added that is not Terr_loss (i.e., negative alkalinity generated from lab experiments on coated biomass), assuming one mole of acid generation consumes one mole of alkalinity and releases one mole of CO_2. This is a rate-based process that is a function of the floating time of the coated wood.	unitless
$Terr_{added}$	Equation 4	tonnes CO_2e
$Terr_{loss}$	Equation 5	tonnes CO_2e

Image analysis from verification hardware is used to ground truth float times tested in the lab. The fraction of carbon buoys floating at each time step is collated into an array that can be used to calculate the fraction of carbon leached from the wood before sinking. Eventually, ocean state information from the verification hardware may be used to further refine the quantification of f_{DOC} and f_{acid}. Additional context for $Terr_{shed}$ can be found in Appendix II.

8.2.4. $Terr_{shal}$ Calculation

Equation 7:

$$Terr_{shal} = (Terr_{added} - Terr_{loss} - Terr_{shed}) \times f_{shal}$$

Variable	Description	Units
$Terr_{added}$ =	Equation 4	tonnes CO_2e

Variable		Description	Units
$Terr_{loss}$	=	Equation 5	tonnes CO_2e
$Terr_{shed}$	=	Equation 6	tonnes CO_2e
f_{shal}	=	The fraction of coated wood that is not durably sequestered below 1,000 meters in depth.	unitless

In order to determine the amount of carbon sequestered, a trajectory simulation is run using the Ocean Parcels Lagrangian simulator library (Kehl et al., 2023) with fieldsets from the European Centre for Medium-Range Weather Forecasts Reanalysis datasets (ERA5) for Stokes drift and windage (Hersbach et al., 2023) and the HYbrid Coordinate Ocean Model (HYCOM) for ocean surface currents (Cummings and Smedstad, 2013).

The simulation is initialized using the starting GPS coordinates of the deployment, which are taken from the in-situ trajectory buoys.

The model is tuned using the series of GPS locations reported by the trajectory buoys over the course of their ocean transport. The modeled parcels are advected by the superposition of three velocity vector fields, representing ocean currents, Stokes drift, and wind. These vector fields are then appropriately weighted so that the modeled trajectories closely match observation.

Next, the Ocean Parcels simulation is run using the diagnosed weighting coefficients. A Monte Carlo simulation considers four sensitivity parameters: (1) sensitivity to carbon buoy float time, (2) sensitivity to the strength of the horizontal velocities from surface waves, (3) sensitivity to the strength of the horizontal velocities of (primarily geostrophic) ocean surface currents, and (4) sensitivity to the strength of the horizontal velocities of the wind force on the material.

Float time (percent of carbon buoys floating each day after initial deployment) is calculated using data from test labs and observations from camera buoys deployed in-situ with actual carbon buoy samples. These float times are applied to the modeled trajectories, building a histogram of sinking depths based on the bathymetry of the sink locations. Anything sunk below 1,000 meters is considered durably sequestered.

Across the simulations, the median value is used for f_{shal}. Uncertainties presented are the fifth percentile of the results, bounding above such that an effective f_{shal} cannot exceed 100%.

For more information, please see Running Tide's
Ocean Surface Transport Methodology.pdf .

8.2.5. $\text{Terr}_{\text{stor}}$ Calculation

Equation 8:

$$Terr_{stor} = \left(Terr_{added} - Terr_{loss} - Terr_{shed} - Terr_{shal}\right) \times f_{stor}$$

Variable	Description	Units
$\text{Terr}_{\text{added}}$ =	Equation 4	tonnes CO_2e
$\text{Terr}_{\text{loss}}$ =	Equation 5	tonnes CO_2e
$\text{Terr}_{\text{shed}}$ =	Equation 6	tonnes CO_2e
$\text{Terr}_{\text{shal}}$ =	Equation 7	tonnes CO_2e
f_{stor} =	The percentage of the biomass mass that would have otherwise been moved into the slow cycle or negatively impacts the net carbon stock of the biomass source.	Unitless

While $\text{Terr}_{\text{stor}}$ is an important consideration of additionality in a mature carbon removal market, this variable will likely be “0” in the first years operationalizing this work due to the limited alternative uses for residual woody biomass that result in the movement of its carbon to the slow cycle. In the event Running Tide moves away from sourcing primarily residual biomass feedstock for our carbon removal operations, the quantification approach for this variable will be refined and updated to incorporate potential land use changes related to material sourcing that would impact the stability of natural slow carbon sinks. For more information, please see Running Tide's Responsible Sourcing Strategy.

8.2.6. $\text{LUC}_{\text{indirect}}$ Calculation

Equation 9: N/A

For this methodology, land use change and land conversion are not material risks given that the primary biomass sourced is a residue material that is Forest Stewardship Council (FSC) certified, sourced from an FSC Certified supplier and has been traced to origin from a single supplier via FSC’s Chain of Custody Certification. Low-grade biomass resources are currently in abundant supply, and existing residue materials, including forest fire reduction residues, are prioritized for biomass sourcing. Supplier attestations for this residue material are provided to detail the production practices that led to the creation of the residue material, the alternative baseline end state of sourced residue biomass in the absence of Running Tide's purchase, and the origin and storage state of the residue material when procured.

Following the project boundary diagram in Figure 1, any emissions associated with biomass harvest and processing that occur directly as a result of project activities are considered within project boundaries and included within this methodology. Different categories of residues may come with different processing requirements.

Suppliers are subject to diligence and auditing on an individual basis and must provide effective traceability into the materials they provide, such as with an FSC Chain of Custody Certification. While suppliers are expected to self-monitor and demonstrate their compliance with Running Tide sourcing requirements, Running Tide and their partners have the right to audit or inspect supplier operations and facilities to ensure compliance.

In the event that residue materials are not utilized in future versions of this methodology, a range of criteria must be met to ensure biomass eligibility and that the net carbon stock of the forest system is not negatively impacted as biomass is removed from the ecosystem. These criteria include sourcing biomass from a robust certification scheme (such as FSC), avoiding sourcing from (or converting) primary forests, and taking into account soil carbon stock changes via land use modeling following GHG Protocol best practices and industry standards. Any emissions that directly result from increased demand for biomass sourced from managed systems will be monitored and included in the calculation of net carbon removed. These criteria are further detailed in the Running Tide Responsible Sourcing Strategy and Supplier Code of Conduct (available upon request). We expect Running Tide's sourcing approach and the related impact on land use considerations to expand and mature over time in future iterations of this methodology.

8.3. $u_{CO2e\_Terrestrial}$ Calculation

Combined uncertainty for CO_2eTerrestrial, $u_{CO2e_{Terrestrial}}$, is determined according to the Uncertainty Methodology in Appendix I. It is calculated using Equation 10:

Equation 10:

$$u_{CO2_eTerrestrial} = \sqrt{\frac{u^2_{Terr_{added}} + u^2_{Terr_{loss}}}{\left(Terr_{added} - Terr_{loss}\right)^2} + ur^2_{f_{stor}} + ur^2_{f_{shal}} + ur^2_{f_{shed}}} \times CO2_eTerrestrial$$

Variable	Uncertainty Functional Equation	Description	Units
$ur_{f_{stor}}$ =	$\frac{u_{f_{stor}}}{1-f_{stor}}$	Relative uncertainty associated with f_{stor} variable.	unitless
f_{stor}	Equation 8	See equation	unitless
$ur_{f_{shal}}$ =	$\frac{u_{f_{shal}}}{1-f_{shal}}$	Relative uncertainty associated with f_{shal} variable.	unitless
f_{shal}	Equation 7	See equation	unitless
$ur_{f_{shed}}$ =	$\frac{\sqrt{u_{f_{doc}}^2 + u_{f_{acid}}^2}}{1-f_{doc}-f_{acid}}$	Relative uncertainty associated with f_{doc} and f_{acid} in $Terr_{shed}$.	unitless
f_{doc}	Equation 6	See equation	unitless
f_{acid}	Equation 6	See equation	unitless
$u_{Terr_{added}}$ =	Equation 11	See equation	tonnes CO_2e
$u_{Terr_{loss}}$ =	$\sqrt{\Delta m_{DML}^2 + \Delta m_{loss}^2}$	The absolute uncertainty associated with quantification of Terr_Loss.	tonnes CO_2e
$CO2e\ Terrestrial$ =	Equation 2	See equation	tonnes CO_2e

The variables within the uncertainty equation are listed above. The uncertainty for $LUC_{indirect}$ is not included, as the parent variable was determined to be immaterial for this quantification season.

8.3.1. $u_{Terr_{added}}$ Calculation

This is the aggregated combined uncertainty, expressed as Equation 11 using Section 2.4 of Appendix 1.

Equation 11:

$$u_{Terr_{added}} = \sqrt{\left(ur_{m_{load}}\right)^2 + \left(\frac{u_{f_{weight}}}{f_{weight}}\right)^2 + \left(\frac{u_{f_{moisture}}}{1-f_{moisture}}\right)^2 + \left(\frac{u_{f_{TOC}}}{f_{TOC}}\right)^2} \times Terr_{added}$$

Variable	Description	Units
$ur_{m_{load}}$ =	Relative uncertainty associated with m_{load} variable due to accuracy of draft survey; a precision of 0.5% (Dibble, 2009).	unitless
$u_{f_{weight}}$ =	Uncertainty associated with the f_{weight} variable due to resolution of onsite scales.	unitless
$u_{f_{moisture}}$ =	Uncertainty associated with the $f_{moisture}$ variable due to variation in lab results.	unitless
$u_{f_{TOC}}$ =	Uncertainty associated with the f_{TOC} variable due to variation in lab results.	unitless
$Terr_{added}$ =	Equation 4	tonnes CO_2e

8.4. Project Emissions Methodology

As detailed in the Framework Protocol, project emissions are the portion of total company emissions that relate directly to intervention operations. Project emissions sources are identified according to ISO 14064-2 guidance and shown in the Sources, Sinks, and Reservoirs (SSR) table in Section 6. Once identified, the relevant activity data, emissions factors, and calculation methods for each emissions source are chosen in accordance with GHG Protocol Guidance.

Quantified project emissions are allocated to individual deployments through the following equations:

8.4.1. $OpMat_{CO2e}$ Calculation

As materials move through the supply chain, production, and deployment process, emissions associated with raw material supply, transportation, and processing are attributed to their embodied carbon liability on a dry weight basis as shown in the table below.

Process Stage	Raw Material Supply	Biomass Transportation and Distribution	Carbonate Transportation and Distribution	Carbon Buoy Production	Deployment Transportation and Distribution
Measurement	Regionally Specific LCA	Fuel Invoices	Bill of Ladings	Fuel/Energy Invoices	Fuel Invoices
Frequency	Per region, per	Per Shipment	Per Shipment	Continuous	Per Deployment

	material				

To calculate the emissions associated with deployment materials and intervention operations:

Equation 12:

$$OpMat_{CO2e} = CO2e_{Mat} + CO2e_{Prod} + CO2e_{Deploy}$$

Variable	Description	Units
$CO2e_{Mat}$ =	The embodied emissions of carbon buoy materials loaded onto the deployment vessel. Includes emissions from material supply, material freight, and material offload.	tonnes CO_2e
$CO2e_{Prod}$ =	The emissions associated with production of carbon buoys and site operations. Includes emissions from carbon buoy handling.	tonnes CO_2e
$CO2e_{Deploy}$ =	The emissions associated with deployment vessel loading and transport, as well as the associated emissions of verification hardware.	tonnes CO_2e

Due to the nature of site operations and carbon buoy production, a first-in-first-out (FIFO) principle will be applied to inventory tracking and associated embodied emissions. A close-out analysis of delivered, processed, and deployed materials will be completed periodically to determine a production loss factor representing material lost during site operations and deployment vessel loading. Where appropriate, this loss factor will be applied to the material weights used for quantifying project-level emissions.

High-level assessments of cradle-to-gate emissions of verification hardware will be performed for each generation deployed. Currently, only the emissions associated with hardware material production and freight of completed hardware to the intervention site are included in this assessment. Other contributors to embodied emissions, such as production energy use and waste treatment, should be included in a future assessment when the hardware production process is more consistent and separate from R&D.

8.4.2. $CapMat_{CO2e}$ Calculation

To calculate the emissions associated with machinery & equipment purchases/rentals, facility construction, and other capital expenditures related to project operations:

Equation 13:

$$CapMat_{CO2e} = CO2e_{Cons} + CO2e_{Equip}$$

Variable	Description	Units
$CO2e_{Cons}$ =	The emissions associated with construction operations.	tonnes CO_2e
$CO2e_{Equip}$ =	The supply chain emissions associated with equipment & machinery purchases, rentals, and repair.	tonnes CO_2e

Emissions associated with capital expenditure activities will be recognized in deployments within 12 months of the site's full operation date or in-service date of the specified asset. Therefore, the recognition period for activities associated with the original site construction and commissioning will begin on the date of the first intervention for any site. Similarly, any emissions generated in this category outside of the deployment season will be accrued and applied beginning with renewed operations.

Capital goods emissions will be normalized to the dry weight of biomass scheduled for deployment over the 12-month recognition period for equitable allocation across deployments. If deployment schedules are delayed or accelerated, allocated emissions will be adjusted in order to remove carbon liability no later than the stated 12-month period.

8.4.3. $Energy_{CO2e}$ Calculation

The “EnergyCO$_2$e” variable, i.e. the emissions associated with energy use in the process of CO_2 sequestration, is not applicable for this project since all mass transfer following the placement of the carbon buoys occurs through the natural processes of sinking/downwelling/ocean energy. Energy use associated with vessel transport to the deployment site is captured in the “OpMatCO2e” variable.

8.4.4. Gap_{CO2e} Calculation

A gap analysis of project-level emissions will be conducted to determine the potential contribution of sources within the project boundary that are not currently included in the quantification. The categories identified are expected to contribute less than 1% each to the overall project footprint and would be considered immaterial in a traditional materiality assessment. However, we intend to continue improving the coverage and accuracy of our emissions accounting by including as many of these categories as possible in future quantifications.

Including the gap coefficient in the quantification of interventions ensures conservatism and incentivizes increasing the coverage of directly quantified emissions categories. The highest expected percentage contribution to the overall project footprint was used to determine the gap coefficient, and it is believed that an accurate accounting of these sources would result in an overall lower contribution to emissions in the future.

The following sources, which are not directly measured via activity data in current emissions quantification, are included in the gap coefficient:

- Verification hardware production & waste
- Cradle-to-gate raw material packaging (plastic wrap, wood pallets, etc.)
- Operations site waste
- Fuel use associated with the loading of raw materials to transport vessels and shipping container distribution

8.5. Assessment of Leakage

Leakage risks from biomass sourcing are assessed according to the Running Tide Framework Protocol. If biomass used is considered a residual or waste by-product by the supplier, the risk of additional emissions outside of project boundaries is not considered material for current project operations.

Leakage risks from nutrient resource constraints caused by the project's macroalgae growth are assessed as outlined in the Running Tide Framework Protocol. The macroalgae pathway is not currently operationalized, and as such, this risk is not material for current project operations.

No additional potential sources of leakage have been identified for current project operations.

8.6. Assessment of Durability

Durability assessments were conducted according to Running Tide Framework Protocol standards. The exact durability of carbon stored is dependent on the depth, location, and chemistry where the biomass sinks; suitable sinking locations are deep, stable, and characterized by relatively high rates of sedimentation, which will increase the proportion of biomass that is buried and preserved for millennia. In the deployment region, ocean recirculation time scales, from seafloor to surface, typically exceed several hundred years, even under the most conservative scenarios.

Given the uncertainty and the need for continued research around biomass degradation and remineralization in the benthos, we currently apply the most conservative approach possible to assessing durability and assume that 100% of biomass sunk below 1000m remineralizes immediately. Even so, established models of deep ocean recirculation demonstrate that carbon removed by Running Tide will remain in the slow cycle for an average of multiple centuries.

Appendix I: Uncertainty Methodology

1. Introduction

There are multiple sources of uncertainty in the measurements taken to quantify the impacts of Running Tide's carbon removal interventions. Common uncertainties in current quantification efforts include, but do not have to be limited to:

- Variation from a series of repeated observations
- Sensor manufacturer reported accuracy

This methodology assumes any systematic uncertainties are accounted for (e.g. calibration errors, correction factors, etc.), and only evaluates uncertainties based on their probability distributions according to the ISO Guide 98-3:2008 (shortened to *"Guide"*). As such, uncertainties of the result of a measurement should only reflect the lack of exact knowledge of the value of the measurand, even after correction for recognized systematic effects, due to random effects and imperfect correction of systematic effects.

2. Evaluating Uncertainties

This methodology follows the notation of the *Guide*, where measurand Y is often measured using N number of input quantities $X_1, X_2, \dots, X_N$. These input quantities are characterized as quantities that are directly determined in the current measurement (e.g. repeated observations, corrections to instrument readings), or from external sources (e.g. calibrated measurement standards, certified reference materials, and reference data from handbooks).

The estimate of measurand Y is denoted as y, using input estimates $x_1, x_2, \dots, x_n$. As a result, the estimate y can be expressed with the following function:

$$y = f(x_1, x_2, \dots, x_n)$$

The combined uncertainty associated with the measurement result y is expressed as $u(y)$, and the uncertainty associated with each input estimate $u(x_1)$. Each input estimate x_i and its associated standard uncertainty $u(x_i)$ are obtained from a distribution of possible values of the input quantity X_i based on a probability distribution.

During quantification of carbon removal interventions, uncertainties due to sampling and instrumentation are taken into account as shown below.

Input Quantity	Description	General Uncertainty Estimate Notation
$X_{sampling}$	Quantities associated with repeated observations from sampling	$u(x_{sampling})$
$X_{instrument}$	Quantities associated with limitations of instruments	$u(x_{instrument})$

The uncertainties evaluated in this methodology assumes:

- All sources of uncertainty are independent from each other
- Sampling variability follows a Gaussian/binomial probability distribution, unless otherwise stated, where both limits are finite, resulting in a two-sided interval (see Figure 1)
- The effective degrees of freedom is of significant size

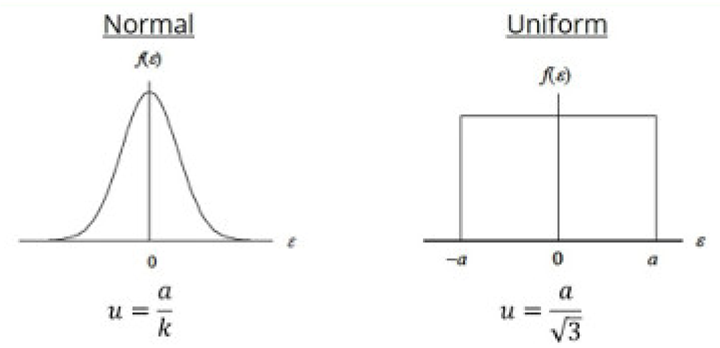


Figure 1: Normal/Gaussian/Binomial Probability Distribution (left); Uniform/Rectangular probability distribution (right)

2.1 Uncertainty from sample variations, $u(x_{sampling})$

Uncertainties associated from sample variations are due to any random effects associated with n independent repeated observations. In most cases, the best available estimate of the expected value μ_q of a quantity q is evaluated with the arithmetic mean, $\overline{q}$ represented in **Equation 1**:

$$\overline{q} = \frac{1}{n}\sum_{k=1}^{n} q_k$$

Individual observations q_k will differ in value due to random variations. The experimental variance of the observations, s^2, which estimates the variance of the population variance σ^2 of the probability distribution of q, given by **Equation 2:**

$$s^2(q_k) = \frac{1}{n-1}\sum_{j=1}^{n}\left(q_j - \overline{q}\right)^2$$

This estimate of variance and its positive square root $s(q_k)$, is the **experimental standard deviation**, which characterizes the variability of the observed values q_k, or their dispersion about their mean, $\overline{q}$.

This methodology assumes the number of observations n should be large enough to ensure that $\overline{q}$ provides a reliable estimate of μ_q, and so conversely $s^2(\overline{q})$ provides a reliable estimate of the variance $\sigma^2(\overline{q})$. The difference between $s^2(\overline{q})$ and $\sigma^2(\overline{q})$ must be considered when one constructs confidence intervals.

To increase the likelihood that the calculated mean value is as close to the true expected value, a 95% confidence interval is constructed using the experimental standard deviation in order to provide a larger range of values where the expected value $\overline{q}$ will lie based on the lab data. Assuming the distribution of q is a normal distribution, a two-sided confidence interval is constructed using **Equation 3**:

$$\overline{q} \pm t_{\alpha/2,\, n-1} \cdot \frac{s}{\sqrt{n}}$$

where

$\overline{q}$ is the sample mean
$t_{\alpha/2,\, v}$ = the t-distribution value for the associated confidence level
s = the sample biased standard deviation (assuming n is sufficiently large)
n = the number of samples

$t_{\alpha/2,\, v}$ is determined using a t-distribution table (similar to Figure 2 at the end of this appendix) for varying degrees of freedom. Running Tide uses the Python library `scipy.stats.t` to generate these values.

The upper and lower bounds of the interval will be used to calculate the relative uncertainty of the variables.

2.2 Uncertainty from instrument resolution, $u(x_{instrument})$

The sensors used for quantification have a finite instrument resolution, reported accuracy, or discrimination threshold. Although not all measuring instruments are accompanied by a calibration certificate or a calibration curve, most instruments are constructed to a written standard and verified, either by the manufacturer or by an independent authority, to conform to that standard. The compliance of the instrument with these requirements is determined by comparison with a reference instrument whose maximum allowed uncertainty is usually specified in the standard. This uncertainty is then a component of the uncertainty of the verified instrument.

In the quantification of carbon mass, the uncertainties are characterized by the manufacturer's reported accuracy of the mass sensors, or the published accuracy from reference material of draft surveys for mass loading on barges.

The *Guide* recommends that if nothing is known about the characteristic error curve of the verified instrument, it can be assumed that there is an equal probability that the error has any value within the permitted limits - that is, a rectangular probability distribution (see Figure 1). This means, given upper and lower limits for a value, it can be stated that "the probability that the value X_i lies within the interval a_- to a_+ for all practical purposes is equally probable and equal to one, and the probability outside this interval is essentially 0". Then x_i, the expectation or expected value of X_i, is the midpoint of the interval, and its variance is expressed as **Equation 4**:

$$u^2(x_i) = \frac{a^2}{3}$$

where a is the half width of the interval. Thus, the uncertainty component is calculated with the positive square root of Equation 4.

2.3 Monte Carlo Simulations

Monte Carlo simulations are utilized where complex scientific models are used to assist quantification of net fast to slow carbon. Simulations are run by perturbing the input parameters following their uncertainty distributions. For these perturbations, the standard deviation (or full covariance matrix when we have it) is the correct uncertainty to use because it describes the spread of the distribution rather than the uncertainty of the mean. Simulations are run many times to get a full understanding of the resulting probability distributions - these are explicitly not normally distributed.

Any variable of interest can be calculated in each simulation, and thus whatever summary statistics are desired across the simulations. The summary statistics are presented using the median as a representative "typical case". Confidence intervals use the fifth percentile as a conservative cut.

2.4 Combined Standard Uncertainty

The combined standard uncertainty, $u_c(y)$, of measurand Y is determined by appropriately combining the standard uncertainties of the input estimate using the Law of Propagation of Uncertainty. The combination of the uncertainties will be based on the functional equation of the input quantities $X_1, X_2, \dots, X_N$ as it relates to the calculated expected value.

In the following example, z is the calculated expected value dependent on x and y variables.

For a functional equation of $z = x + y$ or $z = x - y$, the respective equation can also be used express its uncertainty components, i.e. $\Delta z = \Delta x + \Delta y$. When adding (or subtracting) independent measurements, the absolute uncertainty of the sum (or difference) is the root sum of squares (RSS) of the individual absolute uncertainties, expressed as **Equation 7**:

$$(x \pm \Delta x) + (y \pm \Delta y) = (z \pm \Delta z)$$

where

$$\Delta z = \sqrt{(\Delta x)^2 + (\Delta y)^2 + \dots}$$

For a functional equation where variables are multiplied or divided, their uncertainties combine as relative uncertainties, as seen in **Equation 6**:

$$ur = \frac{\Delta z}{z} = \sqrt{\left(\frac{\Delta x}{x}\right)^2 + \left(\frac{\Delta y}{y}\right)^2 + \dots}$$

In this methodology, we use u to denote absolute uncertainties, and ur to denote relative uncertainties.

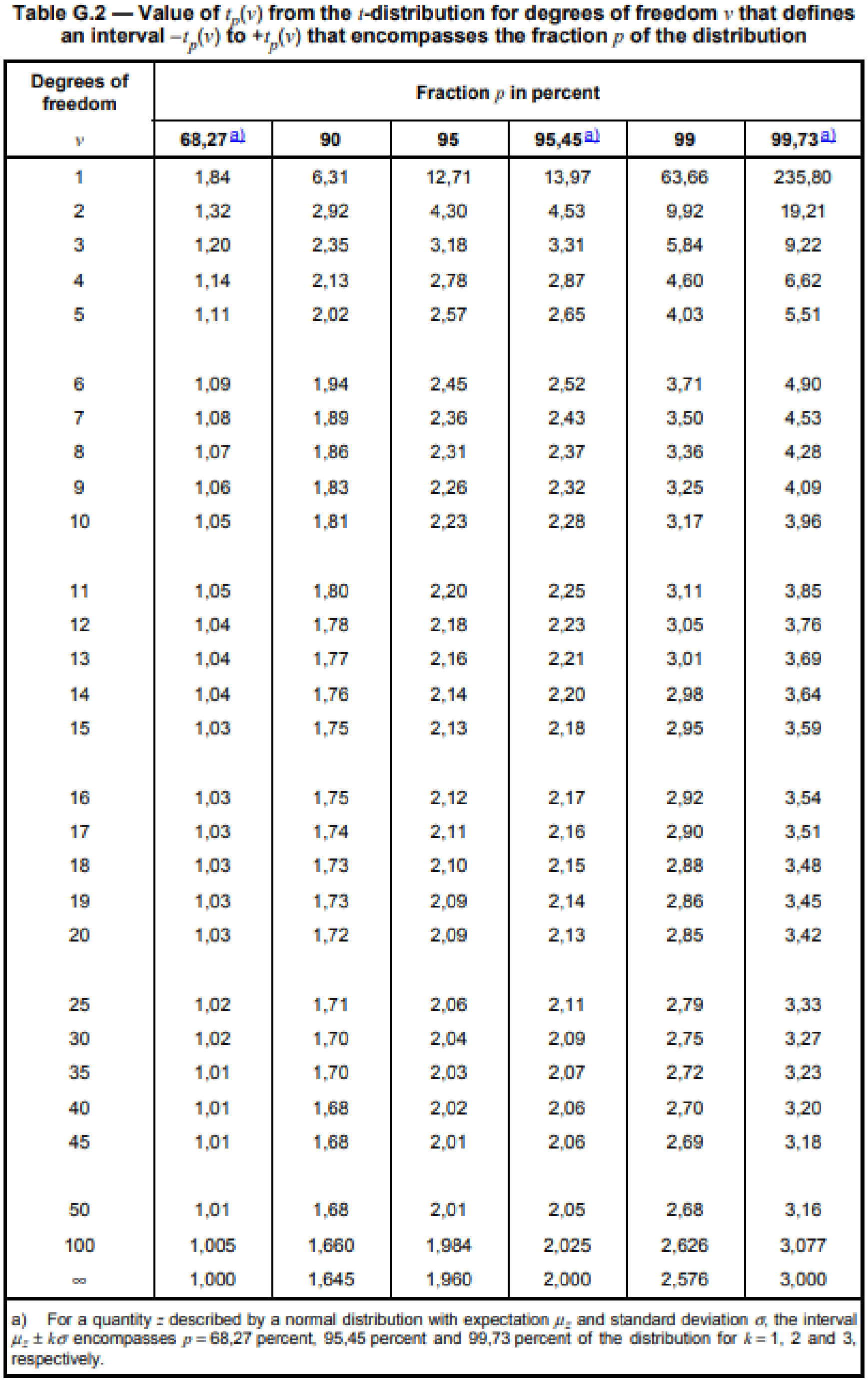


Table G.2 — Value of $t_p(\nu)$ from the t-distribution for degrees of freedom ν that defines an interval $-t_p(\nu)$ to $+t_p(\nu)$ that encompasses the fraction p of the distribution

Degrees of freedom	Fraction p in percent					
ν	68,27[a]	90	95	95,45[a]	99	99,73[a]
1	1,84	6,31	12,71	13,97	63,66	235,80
2	1,32	2,92	4,30	4,53	9,92	19,21
3	1,20	2,35	3,18	3,31	5,84	9,22
4	1,14	2,13	2,78	2,87	4,60	6,62
5	1,11	2,02	2,57	2,65	4,03	5,51
6	1,09	1,94	2,45	2,52	3,71	4,90
7	1,08	1,89	2,36	2,43	3,50	4,53
8	1,07	1,86	2,31	2,37	3,36	4,28
9	1,06	1,83	2,26	2,32	3,25	4,09
10	1,05	1,81	2,23	2,28	3,17	3,96
11	1,05	1,80	2,20	2,25	3,11	3,85
12	1,04	1,78	2,18	2,23	3,05	3,76
13	1,04	1,77	2,16	2,21	3,01	3,69
14	1,04	1,76	2,14	2,20	2,98	3,64
15	1,03	1,75	2,13	2,18	2,95	3,59
16	1,03	1,75	2,12	2,17	2,92	3,54
17	1,03	1,74	2,11	2,16	2,90	3,51
18	1,03	1,73	2,10	2,15	2,88	3,48
19	1,03	1,73	2,09	2,14	2,86	3,45
20	1,03	1,72	2,09	2,13	2,85	3,42
25	1,02	1,71	2,06	2,11	2,79	3,33
30	1,02	1,70	2,04	2,09	2,75	3,27
35	1,01	1,70	2,03	2,07	2,72	3,23
40	1,01	1,68	2,02	2,06	2,70	3,20
45	1,01	1,68	2,01	2,06	2,69	3,18
50	1,01	1,68	2,01	2,05	2,68	3,16
100	1,005	1,660	1,984	2,025	2,626	3,077
∞	1,000	1,645	1,960	2,000	2,576	3,000

a) For a quantity z described by a normal distribution with expectation μ_z and standard deviation σ, the interval $\mu_z \pm k\sigma$ encompasses $p = 68{,}27$ percent, 95,45 percent and 99,73 percent of the distribution for $k = 1$, 2 and 3, respectively.

Figure 2: Table G.2. from ISO 98-3:2008

Appendix II: f_{DOC} and f_{acid} Context and Expanded Methodology

f_{DOC}:

Context: The *Framework Protocol for multi-pathway biological and chemical carbon removal in the ocean - Version 2.0* published by Running Tide in April 2023 includes accounting for the amount of organic carbon that is separated or dissolved in the surface ocean prior to sinking. Organic carbon that is separated or dissolves once woody biomass arrives at the seafloor is considered sequestered on the same timescales as any dissolved inorganic carbon from biomass remineralization at the seafloor.

From the Framework Protocol:

> *"Shed = Portion of carbon in terrestrial biomass separated from carbon buoys prior to or during the sinking process that does not make it to the ocean floor.*
>
> - *Laboratory experiments are conducted to measure remineralization rates, sinking rates, and the amount of organic compounds leached, dissolved, or otherwise separated during the flotation time of terrestrial biomass (including particulate organic carbon and dissolved organic carbon such as organic acids).*
> - *Direct observation of biomass loss via in-situ image analysis from verification hardware further informs and refines float times.*
> - *Conservative estimates of terrestrial biomass separation during floating periods outside of eligible sinking locations are applied."*

Running Tide is supporting research at Northeastern University to proceed with initial investigations into the generation and degradation of dissolved organic carbon.

From Running Tide's Research Roadmap:

> *"Chemical studies: Running Tide has developed capabilities to assess the impact on seawater chemistry when exposed to our carbon buoys. Our dissolution reactors continuously log temperature, pH, salinity of water, and* pCO_2 *of air at the surface. Alkalinity is monitored with an auto titrator, and water samples are routinely sent away for additional elemental analysis. We ran preliminary experiments to characterize the effect of organic acid leaching from wood and the mitigation of this by alkaline mineral dissolution, namely lime kiln dust. These interactions are then incorporated into our predictive modeling of the perturbation to the ocean carbon cycle caused by our proposed interventions. Additional planned experiments include further acid leaching and alkaline material testing in the Running Tide Chemistry Laboratory in Portland, Maine (see below), as well as dissolved organic carbon degradation studies in partnership with Northeastern via Dr. Aron Stubbins' lab group."*

Scientific motivation: For the release of coated carbon buoys during this year's deployments, we are quantifying the dissolved organic carbon released from terrestrial wood. Different species and categories of wood will leach different types and amounts of organic carbon during water logging (Bantle et al., 2014, Svensson et al., 2014). Dissolved carbon leaching from wood occurs naturally on land, in freshwater ecosystems, and when terrestrial biomass is transported to the ocean via natural processes. The organic compounds released during leaching can include a variety of functional groups that impact abiotic degradation and photodegradation (e.g. Timko et al., 2015), protection from degradation (e.g., Gonsior et al., 2022, Lønborg et al., 2020), and biotic degradation (e.g., Lønborg et al., 2020), and contain varying ratios of carbon (Aminot and Kérouel, 2004, Schneider et al., 2003). Released organic matter can be consumed in the surface ocean leading to carbon dioxide generation, consumed and incorporated into biomass that contributes to marine snow, and/or transported along with other dissolved compounds (Figure $\text{Terr}_{\text{shed}}$1).

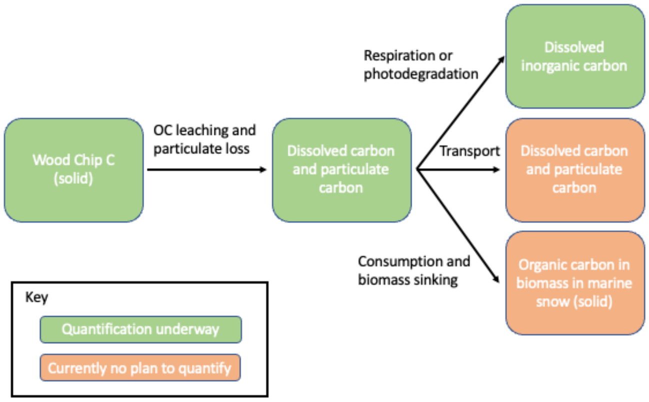


Figure $\text{Terr}_{\text{shed}}$1: *Conceptual understanding of additional organic carbon pathways in the surface ocean and quantification coverage*: Both woody biomass and macroalgae will release organic carbon into the environment as dissolved and particulate organic carbon.

Our path to quantification: At Running Tide, we are interested in quantifying the amount of organic carbon that is lost from woody biomass prior to sinking, the amount of released organic carbon that is respired in the surface ocean, and the abatement of pH changes arising from leaching of organic acids from the biomass. Abatement of pH changes arising from leaching of organic acids will be addressed via a lime kiln dust coating, a byproduct of the cement industry composed of a mixture of $CaCO_3$ and $Ca(OH)_2$) on terrestrial biomass carbon buoys and are part of the f_{acid} calculation (see below). In addition to the dissolved organic carbon that is leached from the wood chips, there is a percentage of sourced wood that is so small in diameter that it dissolves readily and is addressed elsewhere in the quantification method.

We quantify f_{DOC} using rates derived from laboratory experiments piloted by our external collaborators at Northeastern University to quantify the amount of organic carbon released from woody biomass and its degradation rate (Figure $\text{Terr}_{\text{shed}}$2). Like the dissolution of other chemical compounds, we expect organic compounds released from organic matter to follow kinetic rate laws. Batch reactors were used to measure this release of organic carbon per mass of wood over time. Released organic carbon was then incubated with a cosmopolitan oceanic microbial consortium to determine the fraction of released organic carbon that is readily respirable. We note that it is widely accepted that lab-derived dissolution rates and incubations frequently deviate from, and overestimate, *in situ* dissolution and respiration (Tune et al., 2023, White and Brantley, 2003), while also leading to a thermodynamic dissolution limit due to the small volume of the reaction vessel. Therefore, we expect our path to quantification using lab-based rates to continue to be an area of development as we apply the ratesthem to quantify chemical processes in the open ocean and work to quantify uncertainty. We also acknowledge that additional adjustments to lab experiments could be made in the future to further refine DOC leaching estimates. *In situ* water sample collection and subsequent analysis will occur during deployments and will continue to be developed based on laboratory results. However, we do not expect to be able to observe DOC (Dissolved Organic Carbon) and POC (Particulate Organic Carbon) release at the deployment site due to dilution and carbon buoy dispersion. While it is unknown if DOC leaching is dependent on surface area, this is a future avenue of inquiry for laboratory experiments.

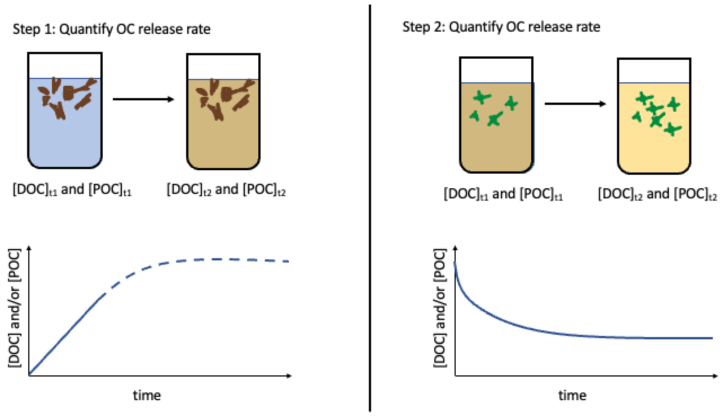


Figure Terr$_{shed}$2: *Conceptual diagram of experimental setup for leaching experiments, incubations, and expected results*. During the first experimental step, woody biomass (brown) is added to vials of solvent and leached over the course of days to weeks. During the second experimental step, woody biomass is removed, and a cosmopolitan microbial consortium (green) is added to the solvent with leached DOC to measure the amount that is readily respirable.

Methods:

Step (1): Organic carbon leaching from terrestrial biomass

Experimental set-up: A known amount of terrestrial biomass was measured for carbon and moisture content, and was added to experimental treatments of artificial seawater and ultrapure laboratory water (Milli-Q water). Treatments were kept at room temperature and completely covered with foil to prohibit photodegradation and biofilm growth. Leaching experiments were repeated so that wood chips were initially leached for 14 days, placed into a new solvent, and then allowed to leach again for an additional 14 days. DOC measurements were completed at days 0, 1, 2, 6, 9, and 14. For better kinetic modeling, leaching experiments were extended for 60 days. During these initial experiments, wood chips were not separated by size.

Rate calculation: The results of the DOC leaching experiments follow a curve described by the equation:

$$R_{DOC}(t) = k\,t^{n} \quad \text{(Eqn Terr}_{\text{shed}}\text{1)}$$

Where R_{DOC} is the rate of mass of carbon leached as DOC in the experiment [gC_{DOC}/hr], t is the time in hours, and k and n are fitting constants. The results from this fitted equation can be used to calculate the rate of DOC leached per mass of carbon in the terrestrial biomass over time normalized to the biomass used in the experiment (RN_{DOC}, [$gC_{DOC}/gC_{biomass}$/hr]). Note, when this mass fraction per hour is converted to tonne CO_2e, the conversion factors cancel out in the numerator and denominator so that the units of RN_{DOC} may also be expressed as [tonne CO_2e/tonne CO_2e/hr]:

$$RN_{DOC}(t) = \frac{R_{DOC}}{m_{biomass}} * \frac{1}{f_{carbon}} \quad \text{(Eqn Terr}_{\text{shed}}\text{2)}$$

Where f_{carbon} is the mass fraction of carbon of the biomass and $m_{biomass}$ is the amount of biomass used in the experiment. We note that we expect the kinetics of DOC leaching to decrease at colder temperatures.

Step (2): Incubation of leached organic carbon

Experimental set-up: Leached DOC was then incubated by removing wood chips from the solvent and a cosmopolitan mix of microorganisms was added to the DOC mixture. Similar to the leaching experiment, experimental treatments were kept in the dark and at room temperature. Nutrients were added to raise phosphorus and available nitrogen concentrations in proportions equivalent to the Redfield ratio in order to ensure that nutrient limitation was not inhibiting microbial use of DOC. DOC concentrations were measured at days 0, 1, 3, 7, and 14, or until a shallowing of the slope of [DOC] (DOC concentration) over time was observed, indicating a limit on the degradability of the DOC remaining in solution.

Degradability calculation: The kinetics of DOC degradation were not investigated as part of this experimental treatment. Instead, the objective of this experiment was to determine the fraction of total DOC that was readily degraded, or $f_{respirable}$. $f_{respirable}$ is calculated by fitting first order decay kinetics to the laboratory results of [DOC] over time as DOC is consumed. This is a continued area of research and development in collaboration with the Stubbins group as we seek to quantify our impact on the long residence time DOC pool in the ocean.

Step (3): Modeling f_{DOC} based on floating time of carbon buoys

Using Eqn. $\text{Terr}_{\text{shed}}2$, f_{DOC} is calculated based on the fraction of buoys that are floating each day based on laboratory and open-ocean float tests described elsewhere. This resembles the following:

$$f_{DOC} = \sum_{i=1}^{N} RN_{DOC}(t_i) * f_{FLOAT}(i) \quad \text{(Eqn Terr}_{\text{shed}}\text{3)}$$

Step (4): Calculating uncertainty and introducing conservatism into the results

Currently, uncertainty is primarily derived from the uncertainty in the float time (f_{FLOAT}). Uncertainty calculation is an area of development for the future as the chemical model continues to be developed.

Results: The initial results for DOC leaching from terrestrial biomass are shown in Figure Terr$_{shed}$3 along with the fitted curve described in Eqn. Terr$_{shed}$1. The wood chips used in the experiment are sampled from the deployed wood chips, which contain about 48 dry-weight-% carbon. The total f_{DOC} of the wood chips during their float duration is multiplied by the tonnage of CO_2e deployed into the surface ocean. It should be noted that this calculation does not yet include how photodegradation, biofouling, physical breakdown, or other degradation mechanisms may alter the solubility of the wood chips.

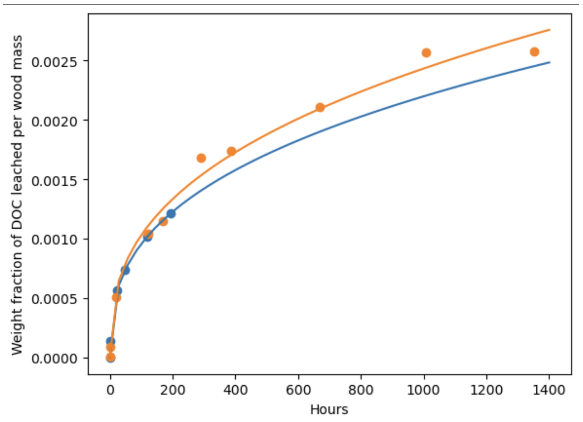


Figure Terr$_{shed}$3: *Results from DOC leaching experiments as carried out by the Stubbins Lab, led by Prof. Aron Stubbins of Northeastern University.*

f_{acid}:

Context: The *Framework Protocol for multi-pathway biological and chemical carbon removal in the ocean - Version 2.0* published by Running Tide in April 2023 includes accounting for the amount of acid and the reduction in alkalinity that occurs due to acidic compounds leaching from deployed biomass in the surface ocean prior to sinking. We strive to offset any leached acidity with the alkaline coating, we test a subsample of the deployed coated biomass in a laboratory setting to monitor acid leaching and quantify as needed.

From the Framework Protocol:

> “*Acid = Any addition of acidity to the ocean that reduces the alkalinity of surface seawater and the associated sequestration of atmospheric CO_2, expressed as the resulting change in* [seawater] *alkalinity.*
>
> - *Terrestrial biomass contains organic compounds with functional groups that, when dissolved in water, may contribute acidity to the surface ocean environment. Leaching experiments in a laboratory setting will quantify the amount of acidity that is generated from organic carbon dissolution, which can be extrapolated to the scope of the project activity.*
> - *This release of acidity would effectively* [consume] *a molar-equivalent portion of alkalinity* [in the seawater and release approximately a molar-equivalent portion of CO_2 from the DIC (Dissolved Inorganic Carbon) reservoir (slow carbon cycle) back to the atmosphere (fast carbon cycle)].”

Scientific motivation: For the release of coated wood during 2023 deployments, we test batches of coated wood after on-site processing in Iceland as representative samples of the deployed coated wood in the Running Tide chemistry laboratory and quantify the net decrease or increase in alkalinity during floatation. Please see the documentation for f_{DOC} for a brief description of organic carbon leaching from wood.

Our path to quantification: At Running Tide, we are interested in quantifying the abatement of pH changes due to the leaching of organic acids from biomass prior to sinking. We abate pH changes due to organic acids by coating the biomass with lime kiln dust, a byproduct of the cement industry composed of a mixture of $CaCO_3$ and $Ca(OH)_2$. As we work to formalize and operationalize the coating process, there may be inconsistencies in the coating that need to be quantified and addressed.

We quantify f_{acid} using rates derived from laboratory experiments that capture how the entire coated wood system affects net alkalinity of seawater in a batch reactor system. Like dissolution of other chemical compounds, we expect organic compound release from organic matter to follow kinetic rate laws. Similar to f_{DOC}, we expect our path to quantification using lab-based rates to provide an estimate for these processes. We also acknowledge that additional adjustments to lab experiments could be made in the future to further refine acid leaching estimates and net changes in alkalinity after abating the acid leaching via the dissolution of alkaline minerals. In situ water sample collection and subsequent analysis will occur during deployments and will continue to be developed based on laboratory results. However, we do not expect to be able to observe DOC release and acid leaching abatement in the field during deployments due to dilution and carbon buoy dispersion that will effectively reduce changes in measured parameters to below detection limits.

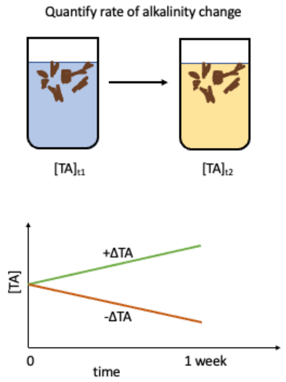


Figure $Terr_{shed}4$: *Conceptual diagram of the experimental setup for leaching and dissolution experiments and the expected results*. Coated biomass chips (brown) are added to beakers with filtered seawater. Over the course of the experiment, alkalinity is measured to establish a rate of change in net alkalinity as a result of acid leaching (contributing to negative alkalinity) and the dissolution of the mineral coating (contributing to positive alkalinity).

<u>Methods:</u>

Step (1): Acid leaching from terrestrial biomass.

Experimental set-up: Briefly, coated wood was subsampled in Iceland from the larger tonnage deployed and sent to Running Tide's chemistry laboratory in Portland, Maine. The subsampled coated wood was added to replicate batch reactors of filtered seawater collected from Casco Bay in Maine, USA, where the laboratory is located. Treatments were kept at room temperature and agitated for a duration of seven days. Temperature, conductivity, and pH were measured continuously and replicate alkalinity measurements were completed at intervals throughout the experiment. A more detailed protocol is available upon request.

Rate calculation: The net change in seawater alkalinity resulting from the dissolution of the alkaline mineral coating and leaching of organic acids from the biomass is treated as a linear function over the relatively short period of time that the coated wood floats. The rate of alkalinity change, normalized to the CO_2 content of the wood, is calculated from the laboratory results as follows:

$$RN_{alk} = \frac{\Delta TA * M_{SW} * 12.01}{t * M_{wet\ wood} * (1 - \theta_{wood}) * 1e6 * f_{carbon}} \quad \text{(Eqn Terr}_{shed}\text{4)}$$

Where RN_{alk} is the normalized rate of alkalinity change in [tonnes CO_2e/tonnes CO_2e wood/hr], ΔTA is the amount of alkalinity change over the course of the experiment after correcting for evaporation, M_{SW} is the mass of seawater used in the experiment, 12.01 is the molar mass of carbon, t is the duration over which ΔTA was measured in hours, M_{wet} wood is the mass of wet wood used in the experiment, θ_{wood} is the gravimetric moisture content of the wood as measured in the lab, and f_{carbon} is the mass fraction of carbon in the dry wood, or the organic carbon dry weight fraction of biomass. The gravimetric moisture content of the wood (θ_{wood}) is measured in the lab prior to beginning the dissolution experiment, and f_{carbon} is assumed to be equivalent to the f_{carbon} measured in the material that was deployed.

Step (2): Modeling f_{acid} based on the floating time of carbon buoys.

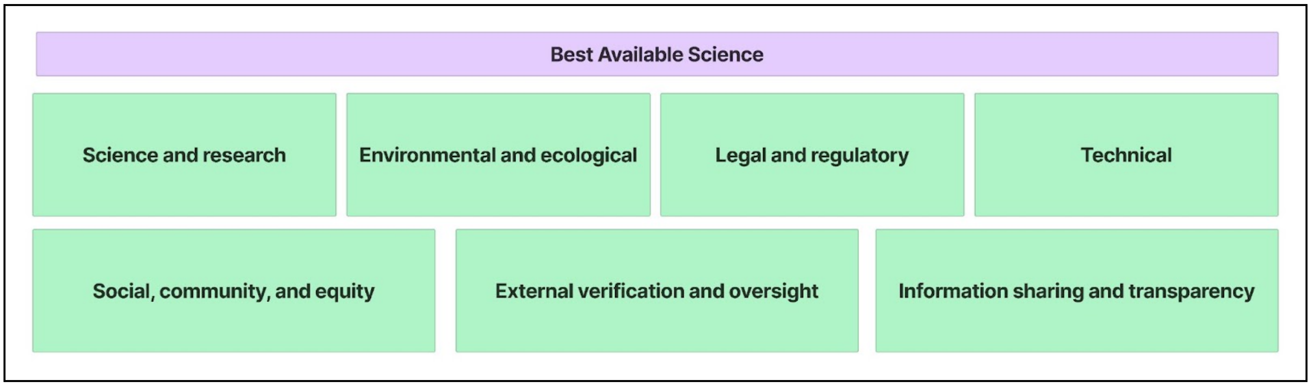
Using Eqn. $Terr_{shed}5$, f_{acid} is calculated based on the fraction of biomass that is floating each day (relative to initial biomass deployed) based on laboratory and open-ocean float tests described elsewhere. This resembles the following:

$$f_{acid} = \sum_{i=1}^{N} RN_{alk}(t_i) * f_{FLOAT}(i) \quad \text{(Eqn Terr}_{shed}\text{5)}$$

Step (3): Calculating uncertainty and introducing conservatism into the results.

Currently, uncertainty is primarily derived from the uncertainty in the float time (f_{FLOAT}). Uncertainty calculation is an area of development for the future as the chemical model continues to be developed.

Appendix III: Summary of Running Tide's Governance Principles



Category	Our principles
Best Available Science	• The foundation on which our governance approach and principles are built. An established practice in natural resource management that ensures an activity evolves to match the best current available understanding of Earth systems.
Science and research *Is the project based on foundational science? Has the project identified key research questions and developed plans to address them?*	• Our system must be built on the foundation of best available science. • Research is focused on questions that will reduce scientific uncertainty, with the end goal of identifying solutions that can effectively mitigate climate change. • Research will be conducted with scientific integrity. • Research plans are documented and publicly available to advance collective knowledge. • Research is iterative and follows a staged progression towards scale, starting with laboratory and/or small-scale controlled pilot experiments.
Environmental and ecological *Has the project effectively considered the potential environmental and ecological impacts of planned activities, both positive and negative?*	• Environmental risk is mitigated wherever possible through the design of the system deployed (i.e., "mitigation through system design"). • Proactive environmental risk assessments must be conducted prior to planned deployments. Processes must be implemented for ongoing monitoring, assessment, and data collection of potential risks identified. • Monitoring plans must be shared and reviewed by an independent Scientific Advisory Board or similar impartial expert body prior to planned deployments. • Methods for the accurate assessment of ecological impacts are informed by ongoing research and continuously refined based on best available science.
Legal and regulatory *Does the project have clear permission to operate and an understanding of the legal and regulatory frameworks that*	• Clear permitting or permission to operate must be secured from relevant jurisdictions prior to planned deployments. • Any potential conflicts with other ocean users must be evaluated and effectively managed. • Where possible, Running Tide will advocate for regulation to enable the

impact the proposed activities?	responsible implementation of positive interventions. ● The precautionary principle is considered in relation to our responsibility to act and the declining baseline state of the ocean.
Technical *Do those conducting the project activity possess the technical capacity to understand project impacts, and effectively monitor and measure results?*	● We must demonstrate a level of technical expertise required to fully characterize the potential impacts of our intervention prior to deployment. ● The quantification tools we use must enable comprehensive monitoring of risks specific to the system deployed, both during and after deployments. ● We must maintain the technical capability to fully understand the impacts of our work and refine the system based on the data collected. ● Measurement and monitoring instruments and models used in conducting research and/or evaluating results must be described as it relates to their role in quantification and independently validated where appropriate. ● Technology systems must be tested, documented, and verified with sample data prior to being used in planned research projects. ● Where possible, subject matter expertise relevant to each component of the system deployed should be developed and resourced in-house. Where this expertise does not exist, collaboration with external researchers and subject matter experts is required.
Social, community, and equity *Have those conducting the project worked with all relevant local and community stakeholders to educate, engage, and garner feedback on plans and research?*	● Where possible, we target our work to benefit communities among the most vulnerable to the impacts of climate change, and where the greatest socioeconomic, mitigation, and adaptation benefits can be realized. ● Communities impacted by our work, including coastal and indigenous communities, must be meaningfully engaged prior to conducting research, and longer-term engagement strategies must be developed. Running Tide must provide mechanisms for ongoing feedback and grievance resolution with affected communities. ● Assessments of potential community impacts must be conducted and monitored over the life of a project. Where possible, these assessments should include quantitative metrics.
External verification and oversight *Have those conducting the project ensured that independent expert parties can effectively review and validate the project work, approach, and results?*	● Creation of an independent Scientific Advisory Board or similar oversight body to evaluate project approach and research plans. ● Environmental evaluations must be reviewed by independent third parties and be made available for review. ● Quantification protocols and processes should be peer-reviewed by industry experts and open for public feedback and consultation. ● Audits must be conducted on at least an annual basis by a qualified, impartial third party to confirm work conforms to criteria dictated by our Framework Protocol and results are accurately reported. ● Where they exist and are deemed appropriate, projects should follow established industry standards, such as GHG Protocol Inventory Best Practices and ISO standards.
Information sharing and transparency: *Has the project demonstrated the level of transparency around processes, plans, and results such that reviewers and the public can effectively evaluate them?*	● Data sharing builds trust, encourages action, and furthers our collective knowledge towards the goal of mitigating climate change. ● To further collective knowledge, Running Tide commits to sharing our research results, and ensuring that data and outcomes are transparent and available for the public and decision-makers. ● Deployment-specific documentation will be public or available upon request. ● Supplier attestations are required for raw material sources, as well as records of material source locations and transportation details.

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