RUNNING TIDE

2023 Alkalinity Summary

Running Tide Technologies[1]

Overview

In 2023, Running Tide developed a [methodology (v1.6.0) for terrestrial biomass sinking](#) for the purposes of removing carbon and restoring ocean health. During the summer season between June and September, we successfully executed fifteen deployments of alkaline mineral-coated wood in the North Atlantic near Iceland.

As motivated by our [Framework Protocol](#), we operationalized the Ocean Alkalinity Enhancement (OAE) pathway for each of these deployments, applying Calcium Carbonate ($CaCO_3$) or Lime Kiln Dust (LKD) coating on the wood to ensure a net alkalinity addition to the ocean. In this document, we quantify alkalinity enhancement to estimate the net chemical effect on the surface waters. This work not only characterizes the extent to which we neutralized any acid generated by the wood, it establishes empirical support for including an equation describing carbon removal by OAE in Section 8.1 of Running Tide's Methodology v1.6.0, and future quantification of OAE-based carbon credits.

This brief precedes a full quantification report and methodology guidance document detailing the physical science basis upon which we will design future interventions and develop OAE methodologies. The final numbers reported here for carbon removals via OAE are our current best representation of the chemical perturbation on the ocean's carbonate system resulting from our 2023 deployments. Emissions liabilities have not been applied against these removals; the numbers reported here are not functionally equivalent to carbon removal credits derived from terrestrial biomass sinking.

Several modifications and additions to the 2023 system design should be employed in ocean alkalinity enhancement interventions in 2024 and beyond. Examples include:

- An improved, comprehensive monitoring scheme that addresses testing for carbonate system parameters inside of the plume of deployed material
- *In situ* measurement of environmental parameters, including salinity and pH, by passively drifting sensor buoys
- Optimization of the coated wood recipe and design of deployed material to maximize dissolution and, thus, alkalinity addition to the surface ocean
- Establishment of dissolution rate dependence on temperature, pH, and salinity via batch reactor experiments, integrating more sophisticated models for mineral dissolution as applicable
- Studying dissolution rates in the field

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Results

Laboratory Results

Batch dissolution reactor results (Figure 1) indicated that organic acid leached from terrestrial biomass was, at a minimum, balanced once the coating on the biomass recipe was changed from primarily $CaCO_3$ in early deployments to Lime Kiln Dust (LKD), which is a combination of $CaCO_3$ and $Ca(OH)_2$. In contrast with the net negative alkalinity addition for the $CaCO_3$-coated deployments, we observed a net positive alkalinity addition in the later deployments with an LKD coating of at least 2.5% by mass[2].

It is worth noting that part of Running Tide's strategy for the 2023 season was to incrementally increase coating amount and reactivity throughout the season to ensure a net positive alkalinity addition to the surface water. This facilitated experimentation with different alkaline materials and processing techniques to optimize positive impacts on the coupled ocean-atmospheric system. Over the course of the 2023 season, Running Tide invested heavily in material handling and processing improvements to accomplish this goal. Initial processes were rough and inefficient, a necessary sacrifice to quickly gain knowledge about the overall system design. As knowledge increased, improvements were made to the overall processing efficiency, material selection, and the precision with which input materials were measured and combined. These design improvements allowed us to more accurately tune shore-based processing operations to match desired impacts in the ocean.
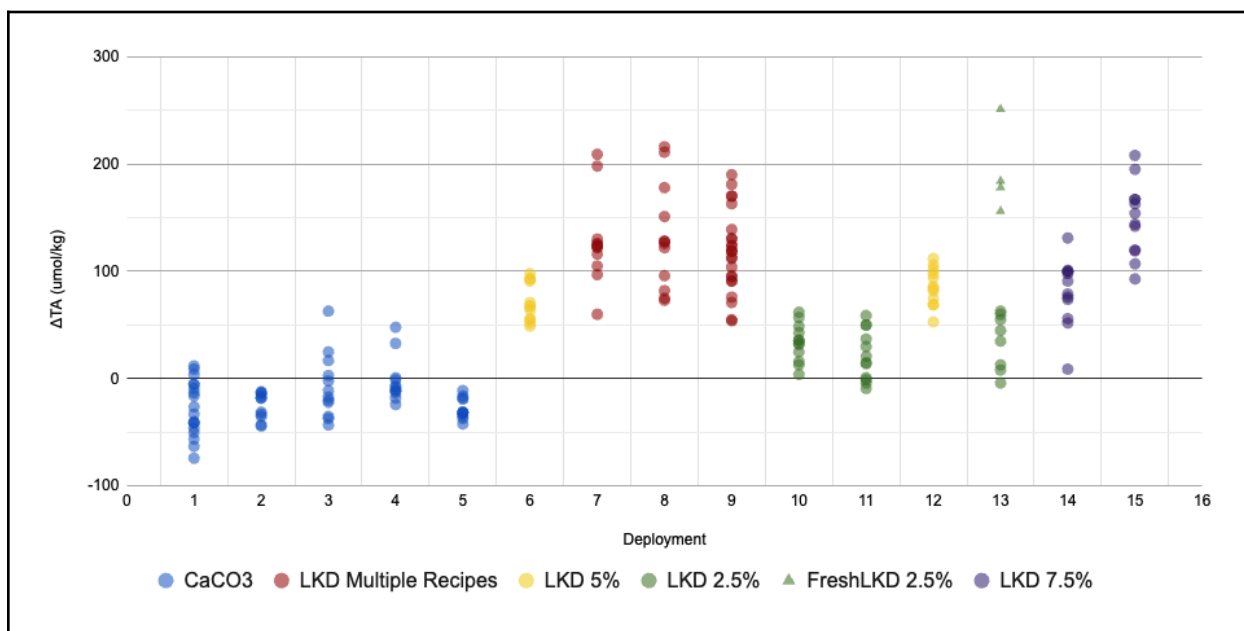
Figure 1: Approximately 10 g samples of coated wood were placed in dissolution reactors with 2 kg of seawater and stirred with a magnetic stir bar. Dissolution was allowed to proceed for 7 days, after which water samples were titrated to determine total alkalinity. Final results were corrected for

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[2] Assuming dry LKD composed of 10% $Ca(OH)_2$ by weight. Lime kiln dust has main components calcite and portlandite, the latter of which dissolves readily in seawater, yielding an increase in seawater alkalinity. The composition of LKD is highly variable and samples for quantification were tested as-processed and as-loaded (i.e., obtained directly from the deployment vessel).

evaporation and subtracted from initial known alkalinities to determine change in total alkalinity per kilogram of seawater. These net changes in alkalinity are used to inform the dissolution model as detailed in methodology (v1.6.0), Appendix II.

Final deployment reports followed Methodology v1.6.0, §8.2.3 to calculate net alkalinity added to the surface waters based on these laboratory results. Total numbers reported for added alkalinity in the far right column of Table 1 (and in Figure 2) are net of any acid released, which, by definition, offset alkalinity on a 1-1 basis. The amount of time wood chips, and therefore the coating, float in the surface ocean is represented by a float time distribution. The amount of alkalinity added is a function of this float time and the values for alkalinity added (Figure 2) for each deployment are the 50th percentile of the distribution (for further detail please see Methodology v1.6.0 Appendix II) .

deployment	f_DOC_50percentile	f_acid_50percentile	terr_added	terr_loss	DOC	Net alk change in tonnes CO2e
IS-CD-1	0.000500	-0.0000471	720.15	97.47	0.3113	-0.0293
IS-CD-2	0.000017	-0.0000001	1356.83	0	0.0225	-0.0002
IS-CD-3	0.000634	-0.0000261	1675.77	0	1.0629	-0.0438
IS-CD-4	0.000499	-0.0000016	1608.42	0	0.8027	-0.0027
IS-CD-5	0.000004	0.0000000	1919.56	0	0.0069	-0.0001
IS-CD-6	0.001200	0.0003979	2266.24	0	2.7195	0.9017
IS-CD-7	0.001690	0.0011476	2499.28	0.3	4.2233	2.8679
IS-CD-8	0.001730	0.0010875	2512.55	0	4.3467	2.7323
IS-CD-9	0.001220	0.0008816	2568.39	0	3.1342	2.2644
IS-CD-10	0.001243	0.0002013	2485.17	0	3.0901	0.5002
IS-CD-11	0.001500	0.0001760	2766.42	0	4.1496	0.4869
IS-CD-12	0.001000	0.0005838	2832.67	0	2.8327	1.6537
IS-CD-13	0.000732	0.0002834	2711.37	0	1.9846	0.7685
IS-CD-14	0.000235	0.0000050	3000.87	0	0.7057	0.0149
IS-CD-15	0.000726	0.0004709	3001.03	0	2.1781	1.4131
					TOTAL:	13.5275

Table 1: Acid leaching calculations and resulting tonnages from each deployment, demonstrating the extrapolation of carbon removals from dissolution lab tests. The total removal shown at bottom is the sum of the relevant highlighted deployments in tonnes of CO_2e. Section headers match methodology variable names; see Methodology 1.6.0 for a discussion of each term.
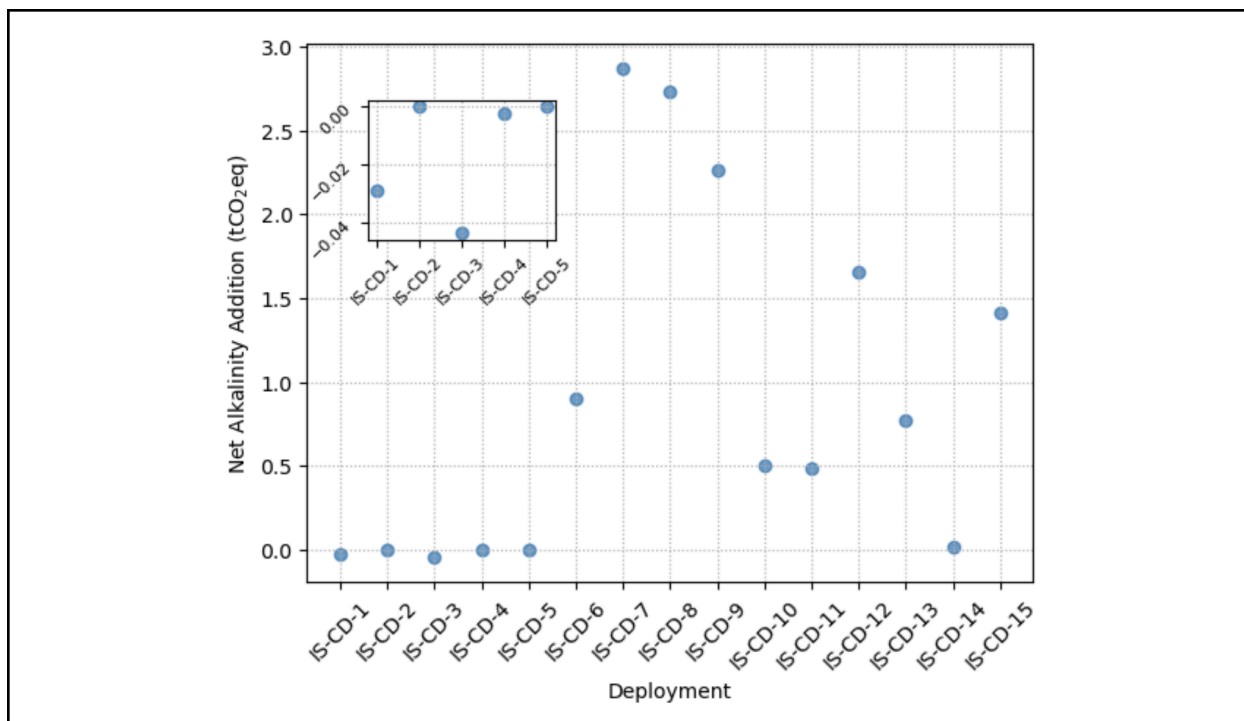
Figure 2: A plot of the Table 1 results, showing significant net alkalinity addition for later deployments.

Quantifying Gross Removal

Below, we estimate the amount of carbon moved from the fast to the slow carbon cycle via Ocean Alkalinity Enhancement by Running Tide interventions in 2023. The [Framework Protocol](#) outlines an equation to calculate gross CO_2e removal via the Ocean Alkalinity Enhancement pathway.

$$CO_2eOAE \ = \ Alk_{add} \ - \ Sec_{precip} \ - \ Carb \ - \ Acid_{add} \ - \ PMF \ + \ POC \qquad \text{(Eq. 1)}$$

Given the slow rate of $Ca(OH)_2$ dissolution and the rapid dilution of insignificantly elevated concentrations of dissolved calcium $[Ca^{2+}]$ and $[CO_3^{2-}]$ ions in the surface ocean, we expect the risk of secondary precipitation of $CaCO_3$ to be low[3]. Thus, we tentatively set $Sec_{precip} = 0$.

Mineral dissolution rate as a function of sea surface temperature, dilution rates in various sea states, and the resulting changes in saturation state changes requires further modeling and empirical investigation to determine secondary precipitation risk with a quantitative confidence interval.

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[3] *He and Tyka (2023)* addresses secondary precipitation risk of offshore OAE deployments and cites relevant literature for further reading.

Additionally, we can set $POC = 0$, and leave increases in carbon-fixing biological activity resulting from increased DIC as a topic for future study. This is conservative in the sense that it gives a lower bound for CO_2eOAE.

Thus, we are left with:

$$CO_2eOAE = Alk_{add} - Acid_{add} - Carb - PMF,$$

which simplifies to:

$$CO_2eOAE = \Delta alk \, \eta_{rxn} \, \eta_{eq}, \qquad \text{(Eq. 2)}$$

where η_{rxn} is the maximum efficiency of the conversion of CO_2 to HCO_3^- and CO_3^{2-} after the introduction of alkalinity (assuming complete equilibration) and η_{eq} is equilibration efficiency, the equilibration of disequilibrated water in the mixing layer of the ocean, prior to subduction. That is, disequilibrated water that subducts before equilibration does not count towards our total.

The forthcoming *Methodology Guidance* explains Equation 2 in more detail, and a future version of this calculation will be included in Running Tide's OAE methodologies.

For the purpose of estimating gross carbon removals, we will assume that the addition of alkalinity increases seawater DIC at a molar efficiency of 0.8, the approximate global average (Renforth & Henderson, 2017). Computational experiments show that the cold waters of the North Atlantic likely improve reaction efficiency closer to the upper end of the theoretical range at ~0.85 (He & Tyka, 2023). We assume that estimating gross removals with an efficiency of 0.8 is thus quite conservative.

$$\eta_{rxn} = \frac{\Delta DIC}{\Delta Alk} \approx 0.8 \qquad \text{(Eq. 3)}$$

Future quantification would calculate reaction efficiency at each timestep along a deployment trajectory using a combination of temperature, salinity, pH, and pressure from reanalysis datasets and as measured *in situ*.

Modeling using ECCO-Darwin, an established global ocean biogeochemistry model, indicates that equilibration efficiency (i.e., residence time of mixed layer/CO_2-equilibration timescale of alkalinized water mass; Jones et al., 2014) may be more complicated. Pulse experiments of Ocean Alkalinity Enhancement activity over the course of a month indicate that summertime deployments in the North Atlantic could plateau at an efficiency well above 0.75 and reach that plateau relatively rapidly. Wintertime deployments are significantly less efficient, plateauing around 0.5 in 5-10 years. For the sake of this calculation, which reflects deployments which occurred mostly in the summer, we will assume that $\eta_{eq} = 0.75$ represents a reasonable lower bound.

We plan to further refine equilibration efficiency by running ECCO-Darwin or a 1D vertical column model with closely correlated results to determine equilibration efficiency at each deployment location and time.

Uncertainty could be further reduced by testing the sensitivity of air-sea gas flux models. This work would include validating 1D gas exchange models against additional global general circulation models and testing the models' responses to small changes in input forcings. These latter tests would also provide insight into the precision needed for environmental forcing inputs, such as surface pH, temperature, salinity, and/or mixed layer depth.

Gross CO_2 Removal Estimate

As per the specification of Methodology v1.6.0, net alkalinity totals from deployments are already represented in terms of tonnes of CO_2e, assuming an idealized one-to-one conversion from moles of alkalinity to moles of CO_2. Thus, we can apply the efficiencies described in the previous section directly to determine more realistic CO_2e removal estimates. As shown in the table in Figure 3, we estimate a total gross removal of 7.87 tonnes of CO_2e from deployments 6-10 and 12-15. Deployment 11 is not included in these calculations as it was used to balance the net negative alkalinity delivered to the ocean from deployments IS-CD-1 to 5 as a result of the ineffective $CaCO_3$ coating.

Deployment	Delta Alk (tonnes CO2e)	Reaction Efficiency	Equilibration Efficiency	CO2e Removed (tonnes CO2e)
IS-CD-6	0.901674311	0.80	0.75	0.54
IS-CD-7	2.867936551	0.80	0.75	1.72
IS-CD-8	2.732343897	0.80	0.75	1.64
IS-CD-9	2.264380989	0.80	0.75	1.36
IS-CD-10	0.5001588415	0.80	0.75	0.30
IS-CD-12	1.653676262	0.80	0.75	0.99
IS-CD-13	0.7685336493	0.80	0.75	0.46
IS-CD-14	0.01492001948	0.80	0.75	0.01
IS-CD-15	1.413085512	0.80	0.75	0.85
			TOTAL:	7.9

Figure 3: The net carbon (in tonnes) moved to the slow cycle due to the addition of alkalinity from the 2023 deployments after accounting for the estimated impact of reaction efficiency ($\frac{\Delta DIC}{\Delta Alk}$) and equilibration efficiency (residence time of mixed layer/CO_2-equilibration timescale of alkalinized water mass; Jones et al, 2014).

It is worth noting that CO_2 removals by OAE occur over time, generally following an inverse exponential function, where rapid CO_2 uptake occurs earlier but then slows as pCO_2 equilibrium is approached. We believe it is appropriate to account for any removals that occur on timescales short enough and with long enough durability to be considered climatically relevant.

Conclusions

Based on these results and the positive relationship between net alkalinity change and %-coating of the wood substrate, we expect to have made a net fast to slow carbon transfer of 7.9 tons CO_2e via the Ocean Alkalinity Pathway in Running Tide's 2023 deployments.

As we continue to develop our alkalinity methodology and multi-pathway carbon accounting framework, we will:
- Reduce uncertainty of intervention impacts on the Earth's carbon system
- Improve CO_2 removal efficiency by collecting marginal gains from every aspect of our interventions
- Scale alkalinity-based ocean interventions, expanding our portfolio of solutions for offsetting environmental liabilities

Integrating an alkalinity methodology into our current modeling and quantification platform will allow us to produce model-driven and uncertainty-bounded quantification results, fulfilling the mandate of our Framework Protocol and unlocking our ability to commercialize OAE carbon credits, in addition to quantifying the positive externalities of our intervention activities.

References

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