Running Tide Iceland Final Research Program Report

September 2024

This report outlines Running Tide's research program in Iceland since operations began in 2022. It is submitted to the Foreign Ministry of Iceland, the Marine and Freshwater Research Institute and the Environment Agency of Iceland as a part of the requirements set out in the research permit issued by the government of Iceland on July 8, 2022.

This report includes a high level overview of the research programs executed in relation to the permit, focused on two key broad questions: efficacy of Running Tide's proposed approach and potential environmental impact at large scales.

1. Efficacy of Carbon Removal Approach

Running Tide conducted multiple experiments across a wide swath of experiment designs and approaches to test the efficacy of the proposed carbon removal approach. The proposed approach is set out in the white paper "Carbon removal is mass transfer from fast to slow carbon cycles" and described in more detail in Framework protocol for multi pathway biological and chemical carbon removal In the ocean.

As presented in the research roadmap that was previously shared, Running Tide executed several types of deployments and ran different types of analyses on those deployments related to understanding the efficacy of the system:

Sensor only deployments: Starting in December 2022, Running Tide executed three open ocean deployments of the company's proprietary verification sensor suite to mimic workflows required for the open ocean experiments, test the sensor systems, sea-truth models with collected data, and identify and resolve bugs and errors in computational automation and infrastructure. The verification sensor suites provide critical in-situ data for analytical comparison with model output. The process of gathering data and modeling the results helped us understand and ensure the efficacy of carbon removal deployments using Running Tide's system. Read more on this in the sensor deployment report.

Macroalgae Deployments: Understanding the viability of whether land-grown seedstock can be seeded on substrate, deployed in the ocean, and lead to verifiable growth of macroalgae in the open ocean, was a critical part of our research program. Running Tide was able to visibly verify open ocean growth of both *Ulva* and *Saccharina* species. Between June and September of 2023, RT executed a total of 5 open ocean macroalgae growth experiments, both in the North Atlantic and the Pacific, and in May of 2024 a single experiment was conducted. Additionally, Open Ocean Growth Experimental deployments serve as a baseline assessment of the macroalgae product in a given oceanic location over

time, setting an important starting point and uncovering opportunities for improvement in our system design. Key results from the open ocean growth experiments performed in Iceland demonstrate a baseline of visual growth as seen in the Macroalgae Deployment Report.

Carbon Removal Deployments: A series of 15 replicated pilot scale carbon removal system experimental deployments in the open ocean were executed at conservative rates of 400 - 1,700 tons of substrate (dry mass) per deployment. The previously planned cadence of one every 2-5 weeks had to be increased to once per week on average due to weather conditions and vessel constraints.

- In total, Running Tide deployed 19,338 tonnes of material. Given the permit allows for deployment of up to 50,000 tons during the 4 year timeframe, Running Tide exhausted 39% of the permit, on schedule.

As part of the deployments, our team of scientists and engineers researched and developed a methodology and framework protocol for the quantification of carbon removed.

- Quantification data from these deployments showing the efficacy of the approach is available through a link in the email, which shows the operationalized scientific and engineering underpinnings of the method.
- A deep dive into the quantification method is available here.

Results:

- This work resulted in the understanding that **terrestrial biomass sinking is a scientifically, technically, and operationally feasible approach to durable carbon removal.** It also showed that **the intentional offshore growth of coastal macroalgae species on environmentally safe substrate** is technically feasible. The work also indicated the potential for offshore alkalinity enhancement.

Multiple research questions remain open, especially related to: reducing uncertainty around durability of terrestrial and marine biomass sinking to the deep ocean, quantification and additionality of offshore macroalgae growth for carbon removal, reducing uncertainty of terminal location of deployed material, quantifying additionality of biomass sinking in the context of forest management, most of which were on the roadmap and became important with the potential for larger, commercial deployments in the future.

2. Potential Environmental Impact of Proposed Approach

It is clear that carbon removal is needed to be able to meet our climate goals. Business as usual has a catastrophic environmental impact. Carbon removal is an *intentional* environmental impact, the transport of carbon from fast carbon cycles to slow. All carbon removal approaches will have impacts – at minimum the intended positive carbon cycle impact targeted with the carbon removal approach.

Depositing biomass in the deep ocean, and ocean alkalinity enhancement, have various potential impacts at massive scales. Running Tide worked on various projects to effectively, safely, and pragmatically assess those impacts, integrate learnings into the system design, and develop research programs that safely test the effects.

Initially, Running Tide developed a Catalog of Potential Environmental Exposures that listed and categorized the exposures or impacts to marine ecosystems. This document was shared with various people including Icelandic government agencies for feedback as it was developed, and it was reviewed by both Running Tide's independent Science Advisory Board and Deloitte in 2023. This comprehensive analysis supported the prioritization of research and analysis of potential environmental impact and was published publicly. In addition, Running Tide monitored and reported on the key environmental impact variables related to our 2023 research program as detailed in Environmental summaries 2023.

Benthic Impact Research Program

Understanding the impact of adding material to the benthic region is crucial. To address this, RT established a long-term benthic research program. This program focused on quantifying the degradation rates and other impacts of introduced biomass on benthic ecosystems, which is essential for verifying carbon removal and understanding the broader ecological effects of our interventions. The progress of these experiments has been shared in our previous data packages.

- **Iceland Coastal Benthic Experiment:** Started in June 2023, this experiment monitored the impact of deposited biomass on the benthic environment at Hvalfjörður. Water and sediment samples were collected routinely to analyze the effects on ocean and sediment chemistry, microbial communities, and local fauna. The purpose of doing an experiment in shallow waters was not only to understand the impacts on the benthic environment, but also to better develop experiment designs and protocols. Preliminary results showed no significant impacts on pH, total alkalinity, calcium, or organic carbon levels. In addition, a University of Iceland student published their BSc thesis evaluating the impact of our deposited material on Ostracods.
    - Ostracods from Hvalfjörður, western Iceland: diversity and biomonitoring experiment - Hafrún Birta Hafliðadóttir
    - ***Note:*** *The material and research equipment has been safely removed from Hvalfjörður.*
- **AWI Collaboration**: Initiated in June 2023, this experiment tested the degradation rate of carbon buoy materials at approximately 4000 meters depth in the Arctic. In collaboration with the Alfred Wegener Institute, this study was intended to assess the environmental impact after one year, with potential for further studies based on initial findings. AWI has paused this experiment.
- **Clayoquot Slope Experiment:** Since September 2023, this experiment actively monitored the degradation and ecological impact of carbon buoy materials at

approximately 1300 meters depth. Using real-time data transmission from Ocean Networks Canada, RT planned to analyze macrofauna, microbial community composition, and carbon and nutrient content in the sediment.

- **Modeling of terminal density of deployed materials:** As part of our Ocean Modeling work, we used a lagrangian simulator called Ocean Parcels to determine the terminal distribution of deployed material on the seafloor. Final modeled densities from our first deployment season provided a starting point for future research.
    - More details: A novel, modular, and scalable approach to modeling and data integration in ocean sciences for carbon removal MRV
- **Modeling of benthic biogeochemistry:** Running Tide engaged NIVA (The Norwegian Research Institute for Water and the Environment) to assess the biogeochemical impact of our planned deployments. The institute wrote a model- and literature-based assessment for Running Tide, which was then presented at the European Geosciences Union General Assembly in 2024. The goal of this work was to assess the environmental impact of woodchip and calcium carbonate deployments in the Norwegian Sea as a marine carbon dioxide removal (mCDR) approach. The results show a predicted maximum benthic density of 3600 gC/m2 and 5 mm deep would produce a pore water impact within the range considered to be good water quality. For reference, the density of wood chips on the seafloor during the 2023 deployments from Iceland was modeled to be, at a maximum, 30 gC/m2 and ~0.06 mm deep.

Monitoring and assessing environmental impact of experiments.

To understand the impact of our small scale experiments outside Iceland, RT went through a process of identifying the potential environmental impacts as a result of the carbon removal project design. Many of the potential impacts are mitigated through the project and technology design, however, some require more detailed analysis at the close of the carbon removal deployment and those are highlighted in this report.

- **Internal procedures for evaluating potential impact of substrate:** To ensure the effectiveness and environmental safety of our carbon buoys, RT conducted thorough characterization studies. Our carbon buoys were synthesized from natural materials, including forestry residues, and were designed to facilitate multiple carbon removal pathways. Key factors evaluated in our substrate studies include:
    - **Origin and Carbon Footprint:** Selecting biomass that would otherwise release carbon into the atmosphere, such as timber mill residue and damaged wood from forest
    - **Acid Leaching and Alkalinity:** Monitoring and adjusting the alkaline substances in the biomass to offset acid leaching and enhance ocean alkalinity.

- **Heavy Metals:** Carbon buoy materials underwent a layered testing process that includes laboratory-based screening and field experiments (see more: Environmental Summaries for 2023 deployments).
- **Floating Time and Sinking Dynamics:** Studying the floating duration and sinking behavior of the substrates in lab and field settings to optimize carbon sequestration.

- **Other experiments and work related to environmental impact**
  - *Assessing macroalgal and terrestrial biomass organic carbon release and biodegradability* (Aron Stubbins. Professor in the depts. of Marine & Environmental Science, Chemistry & Chemical Biology, and Civil & Environmental Engineering, Northeastern University): This report summarizes the release and bioavailability of organic carbon (OC) from four types of Running Tide macroalgae and RT woodchip biomass. The study involved month-long algal growth experiments to measure OC release and microbial incubation experiments to determine how bioavailable this OC is. The goal was to better understand what happens to the OC from RT macroalgae and woodchips in the ocean. (Link to full whitepaper here)
  - Ecotoxicology: TOXEMlab tested ecotoxicological effects on marine algae, copepods, oysters, sea urchins and fish cell lines. This project is in collaboration with Carbon to Sea and is ongoing.
  - *Akvaplan- NIVA report;* On behalf of Running Tide, Akvaplan-NIVA assessed the possible effects on the marine environment of the discharge of wood chips in the Norwegian Sea. Link to report here.