Running Tide White Paper - Sustainably Amplifying the Natural Carbon Cycle

May 2022

Introduction

The ocean's biological carbon pump plays a significant role in the global carbon cycle. The biological pump is a natural process through which carbon is transported from the fast carbon cycle, involving the atmosphere, biosphere, and upper ocean, to the slow carbon cycle, involving the deep ocean and geosphere. The biological pump's primary mechanism is the biological transformation of CO_2 and nutrients into organic carbon in the upper ocean via photosynthesis, which then sinks through the water column, and ultimately decomposes or is buried at depth. Running Tide is developing a nature-based carbon dioxide removal (CDR) system that sustainably amplifies the biological pump's transfer of carbon from the fast to the slow carbon cycle.

This white paper provides an overview of the Earth's carbon cycle, the ocean's natural processes for capturing and storing carbon, and how Running Tide's system is designed to sustainably enhance these processes. Running Tide's CDR system combines distributed open ocean aquaculture, the sinking of biomass, and ocean alkalinity enhancement to make a significant contribution to the fight against the global climate crisis, while delivering co-benefits for biodiversity, sustainable development, inclusive economic growth, and food security.

The Earth's Carbon Cycle

The global carbon cycle operates through a variety of response and feedback mechanisms between the Earth's primary carbon reservoirs, namely the marine and terrestrial biospheres, the atmosphere, the ocean, and sediments/rocks. The carbon cycle can be broken down into two distinct, but overlapping, components: the fast carbon cycle and the slow carbon cycle.

Fast Carbon Cycle

Fast carbon encompasses the movement of carbon via photosynthesis and respiration, as well as the continuous exchange of CO_2 amongst the biosphere, atmosphere, and surface ocean. The fast carbon cycle is dynamic and volatile, and it can be best understood as the flow of carbon through living ecosystems.

Slow Carbon Cycle

Slow carbon consists of the movement of carbon via gravity, pressure, chemical weathering, and ocean currents. These processes move carbon from living ecosystems into geological and deep ocean reservoirs such as sediments, mineral deposits (oil, gas, coal), and deep waters. Slow cycle reservoirs evolve very slowly over thousands to millions of years.

One pathway carbon takes from the fast to the slow cycle is through organic matter buried in marine sediments and rocks. Phytoplankton and other marine organisms in the surface ocean fix carbon, die, sink to the ocean floor, and are buried. The biomass is slowly converted into mineral resources such as fossil fuels: oil and natural gas. Coal is formed when a similar process occurs in freshwater environments on land. Globally, this process moves a net ~2 gigatons of carbon into the slow cycle annually[1].

Without human interference, carbon moves from the slow to the fast cycle over millions of years through volcanic activity, driven by the subduction and melting of limestones and oil and gas-bearing rocks, and over intermediate timescales through ocean upwelling. By extracting and burning carbon-rich resources, humans are effectively moving ~8 gigatons of carbon from the slow to the fast cycle every year.[2]

Prior to human intervention, carbon cycling between the atmosphere, ocean, biosphere, and geologic reservoirs, in both the fast and slow carbon cycles, was generally balanced in a manner that promoted stable climates, ocean chemistry, and ecosystems over human timescales.

---

[1] Ciais, P. C., Sabine, G., Bala, L., Bopp, V., Brovkin, J. Canadell, A., et al. (2013). Carbon and Other Biogeochemical Cycles, in *Climate Change 2013: the physical science basis," in Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*.

[2] NASA. (n.d.). The Carbon Cycle. NASA. Retrieved March 2022.

Since the Industrial Revolution, widespread extraction of fossil fuels, deforestation, changes in land-use, marine habitat loss, and ocean acidification have accelerated the movement of carbon from the slow to the fast carbon cycle, while also decreasing the storage capacity of fast carbon sinks. These shifts have fundamentally destabilized the Earth's systems, causing dangerous and widespread disruption in natural ecosystems and suffering for billions of people around the world. Without significant and immediate action, this devastation is projected to increase dramatically over the coming decades.[3]

Restoration projects such as reforestation, afforestation, and coastal rehabilitation aim to rebuild natural carbon sinks within the fast carbon cycle, which are critically important to reestablishing system equilibrium, promoting a stable climate, and reducing disruption to natural ecosystems and human communities.

However, because most restoration projects address only fast cycle carbon sinks, restoration projects alone cannot rebalance the greater carbon cycle at a scale that effectively combats climate change. For this, we must engage in carbon removal by transferring carbon from fast cycle sinks (i.e., biosphere, atmosphere, and upper ocean) to slow carbon sinks (i.e., deep ocean and marine sediments).

Carbon removal should be additive, durable, and quantifiable through direct measurements of mass transfer and/or reservoir size. When combined with activities that rebuild fast cycle carbon sinks, carbon removal can both enhance the productivity of the fast carbon cycle, while also moving carbon from the fast to the slow carbon cycle.

As documented by the Intergovernmental Panel on Climate Change (IPCC), all reasonable scenarios that limit global warming to 1.5°C — the globally accepted limit beyond which the planet is likely to face dire and unpredictable effects — require the immediate reduction of CO_2 emissions across all economic sectors combined with large-scale carbon removal. The longer we wait to reduce emissions, the faster we must scale carbon removal. As seen in Figure 1, to reach net-zero targets consistent with 1.5°C warming scenarios, more than 10 gigatons of CO_2 must be removed every year. To accomplish this, humanity must use its resources to tackle one of the largest mass transfer efforts ever attempted.

---

[3] IPCC - Climate Change 2022: Impacts, Adaptation and Vulnerability

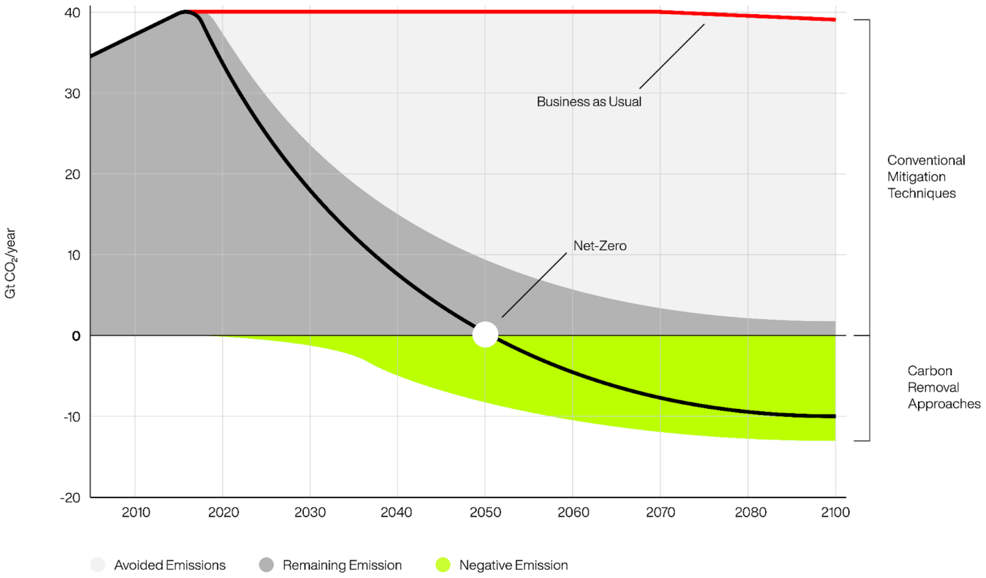

Figure 1 - All pathways to stay below 1.5 degrees of warming require negative emissions technologies (Source: Modified from the IPCC Special Report on Global Warming 1.5C)

The Ocean’s Carbon Cycle

The Biological Pump

The surface ocean and the atmosphere are coupled systems, and CO_2 levels in both rise and fall in parallel. As human emissions primarily increase concentration of CO_2 in the atmosphere, more and more CO_2 flows from the atmosphere to the surface ocean each year.[4]

By some estimates, the ocean has absorbed 30% of the CO_2 emitted since the beginning of the industrial era, mostly through photosynthetic activity.[5] The food web releases 85-90% of carbon absorbed in this way back into the atmosphere as CO_2, however, a small percentage of plankton sinks into the deep ocean after it dies, transporting the carbon acquired at the surface along with it. This process is accelerated when smaller plankton are aggregated into larger

---

[4] Ocean-Atmosphere CO2 Exchange. *Science On a Sphere,* National Oceanic and Atmospheric Administration. Retrieved May 10, 2022.

[5] Carroll, D., et al. (2022). Attribution of Space-Time Variability in Global-Ocean Dissolved Inorganic Carbon. *Global Biogeochemical Cycles* 36(3).

particles, such as the fecal pellets of larger plankton or fish, or when entrained in downwelling currents.

Once in the deep ocean, this biomass is either remineralized as dissolved inorganic carbon, or buried in marine sediments and ultimately converted to oil and gas, all of which are part of the slow carbon cycle.[6] The deep ocean is a massive reservoir that, by current estimates, stores 37,000 gigatons of carbon.

As noted in the introduction, this process of photosynthetic marine organisms moving carbon from the fast carbon cycle in the surface ocean to the slow carbon cycle in the deep ocean is known as the biological pump. Worldwide, the biological pump transfers about 2 gigatons of CO_2 from the atmosphere to the deep ocean each year,[7] where it is projected to remain, on average, for longer than 1,000 years.[8,9]

Ocean Acidification

Greater total volumes of CO_2 within the fast carbon cycle manifests as higher concentrations of CO_2 in the atmosphere and the surface ocean. The Greenhouse Effect and its associated global warming are a result of this fundamental shift in atmospheric chemistry, and acidification is the result of increased concentrations of CO_2 reducing pH of the surface ocean.

This warming and acidification of the oceans is having a disastrous impact on the marine biosphere and on human communities that depend on the ocean for their economies, food, ways of life, and culture. All life on Earth depends on the ocean, and its continued decline will have dire consequences.

Photosynthetic marine plants transform dissolved CO_2, which is a form of inorganic carbon, into organic carbon in the same way that trees and other land-based plants transform atmospheric CO_2 into terrestrial biomass. This process helps mitigate CO_2-induced ocean

---

[6] Fox, J., et al. (2022). Phytoplankton Growth and Productivity in the Western North Atlantic: Observations of Regional Variability from the NAAMES Field Campaigns. *Front. Mar. Sci*. 7.

[7] NASA. (n.d.). The Carbon Cycle. NASA. Retrieved March 2022.

[8] Krause-Jensen, D., Lavery, P., Serrano, O., Marba, N., Masque, P. & Duarte, C.M. (2018). Sequestration of macroalgal carbon: the elephant in the Blue Carbon room. *Biology Letters* 14 (6).

[9] Orr, J. C., and Sarmiento, J. L. (1992). Potential of marine macroalgae as a sink for CO_2: Constraints from a 3-D general circulation model of the global ocean. *Water, Air, and Soil Pollution* 64:405-421.

acidification by decreasing CO_2 concentration in the surface layer of the ocean. However, ocean acidification, warming, and pollution are all decreasing photosynthetic activity in the ocean, which risks triggering a dangerous feedback loop between reduced photosynthesis and increased atmospheric CO_2, further reducing the ocean's capacity to fix inorganic carbon through photosynthesis.[10] Without positive interventions, the capacity of the ocean to sequester and store atmospheric CO_2 through photosynthesis will likely continue to diminish, accelerating the increase in atmospheric CO_2, and the resulting acidification of surface seawater.

Given its scale, the ocean is a critical part of the global carbon cycle that must be enlisted, through sustainable and positive interventions, in the fight against climate change.

Amplifying the Biological Carbon Pump

Running Tide has developed a global CDR system that integrates and amplifies three natural carbon pathways. First: Running Tide processes sustainably sourced, carbon-rich terrestrial biomass into buoys on which to grow macroalgae. Second: Macroalgae growing in the surface of the open ocean fix carbon through photosynthetic growth, then sink, transporting the embodied fast cycle carbon to the deep ocean, a slow carbon reservoir. Third: buoys are coated with crushed limestone that partially dissolves, thereby sequestering CO_2 through a recognized carbon removal process known as ocean alkalinity enhancement.

Running Tide's terrestrial biomass is composed of forestry and agricultural byproducts, such as sawmill cutoffs, wildfire management burnpiles, and forestry residues, which the company processes into a porous matrix with calcium carbonate (limestone) and nutrients. The substrate is then seeded with select species of macroalgae (kelp and seaweeds) and the resultant buoys are placed in regions of the ocean that support rapid macroalgal growth and the eventual burial and preservation in deep ocean environments.

The seeded algae grow on the surface of the carbon buoys, fixing carbon through photosynthesis. At the same time, ocean alkalinity enhancement, driven by the slow dissolution

---

[10] Monroe, R. (2013). How Much CO2 Can The Oceans Take Up? *The Keeling Curve*, UC San Diego Scripps Institution of Oceanography. Retrieved May 2022.

of calcium carbonate from the buoys, sequesters additional atmospheric CO_2. The deployment of buoys into surface waters that have a relatively low saturation state with respect to calcium carbonate minerals, as well as the proprietary structure of the calcium carbonate used by Running Tide, allows for the dissolution of these alkalinity enhancing carbonate minerals.

The dissolution of the buoy also releases critical nutrients to support the growth of the macroalgae and to replenish nutrients the macroalgae have removed from the surface ocean. This introduction of nutrients helps prevent the farmed macroalgae from displacing wild microalgae (phytoplankton).

Dissolution of the calcium carbonate allows seawater to gradually infiltrate the carbon buoy, eventually causing its density to exceed that of seawater. The loss of buoyancy is timed to optimize the macroalgae's growth (approximately 3 months). Once the carbon buoy transforms from a source of buoyancy (density less than seawater) to a source of ballast (density greater than seawater), the buoy, including the embedded terrestrial biomass and attached macroalgae, sink to the seabed over a short period of time. Here they are either buried and preserved in marine sediments or remineralized as dissolved inorganic carbon in the deep ocean.

This process effectively transports carbon, stored in both the macroalgae and terrestrial biomass within the buoy, from the fast carbon cycle to the slow carbon cycle, thereby removing it from the upper ocean-atmosphere system. Buoys are designed to retain a portion of their calcium carbonate after sinking to better preserve biomass for burial in sediments on the ocean floor, increasing the amount of carbon that is removed for geological timescales.

Running Tide's approach includes continuous feedback loops to optimize the system, including those related to the size and composition of buoys, the lifecycle of the macroalgae, and the timing and location of deployments. Ultimately, Running Tide's carbon removal system will be a carbon-negative supply chain that restores and amplifies the transfer of carbon between the primary reservoirs in the carbon cycle – the atmosphere, the ocean, the biosphere (marine and terrestrial), and the geosphere – to sequester carbon from the fast cycle and store it in slow cycle reservoirs.

System Design

CO_2 Removal by Macroalgae

Running Tide seeds carbon buoys with macroalgae that grow rapidly, converting nutrients to biomass in the surface ocean and absorbing dissolved CO_2 in the process. Macroalgae are up to three times more efficient than phytoplankton at fixing carbon, due to macroalgae's higher carbon-to-nutrient (nitrogen, phosphorus) ratios. These ratios cause macroalgae to sequester more carbon for the same nutritional input. As macroalgae are comparatively large and negatively buoyant, they sink through the water column more rapidly than phytoplankton, reliably moving carbon into slow cycle reservoirs in the deep ocean.

CO_2 Removal by Sinking of Terrestrial Biomass

Running Tide produces carbon-rich buoys for macroalgal growth using biomass feedstocks that are sustainably sourced from forestry residues, forest fire fuel reduction efforts, and agricultural byproducts. This biomass, if not utilized in Running Tide's CDR system, will either decay or be burned, reintroducing fixed carbon directly back to the atmosphere as CO_2. Running Tide's process sinks terrestrial biomass along with marine biomass into the deep ocean, effectively moving the carbon contained within that biomass from the fast carbon cycle to the slow carbon cycle.

CO_2 Removal by Calcium Carbonate

Running Tide sources lime and limestone from sustainable suppliers for use as a binding agent in the manufacture of carbon buoys. Limestone contributes to carbon removal in three distinct phases of the CDR system:

- **Direct air capture** - CO_2 is captured directly from the atmosphere through the initial mineralization of the input material $Ca(OH)_2$ into the binding agent $CaCO_3$ during Running Tide's manufacture of carbon buoys. This process can sequester 1 mole of CO_2 from the atmosphere per mole of $Ca(OH)_2$ mineralized as $CaCO_3$. Contrary to the natural formation of calcium carbonate in seashells that releases CO_2, Running Tide's land-based mineralization of $CaCO_3$ relies on atmospheric CO_2 as the sole source of carbon involved in the formation of $CaCO_3$, thereby removing CO_2 from the atmosphere.

This process offsets CO_2 released by the initial calcination of the input $Ca(OH)_2$ in Running Tide's carbon accounting process.

- **Carbon removal in the ocean** - The gradual dissolution of limestone ($CaCO_3$) from floating carbon buoys sequesters atmospheric CO_2 via seawater alkalinization. At surface pH conditions (pH ~ 8.1), approximately 0.6 mole of CO_2 is transferred from the atmosphere to surface seawater per mole of $CaCO_3$ dissolved in the surface ocean.
- **Increased durability** - As buoys reach the ocean floor, the limestone coating increases the likelihood that they will be buried in sediments, thereby extending the duration of time that the carbon is removed from the fast carbon cycle.

Running Tide leverages the expertise of leading third-party ocean and climate scientists with in-house engineers to design a CDR system that minimizes negative environmental impacts while maximizing carbon removal, and environmental and societal co-benefits.

This includes deployment of the system into ocean currents that are nutritionally dense and that will ultimately transport the biomass to suitable sinking locations following a period of growth. 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. These environments exist throughout the world's ocean basins; initial Running Tide deployments are targeting the North Atlantic, North Pacific, and Antarctic circumpolar regions.

Running Tide has developed measurement, reporting, and verification (MRV) technologies that provide in-situ monitoring of the location, timing, and progress of carbon removal deployments. These technologies include hardware and software engineered to operate within the open ocean, machine vision capabilities for documenting the growth and chemical evolution of the buoys, and data processing systems that rigorously quantify total carbon removed and ensure both the issuance of robust CO_2 credits and the optimization of our methodologies.

Additional system design elements that optimize the performance of Running Tide's carbon removal systems include:

- **Small unit size**: Carbon buoys are approximately the size of a basketball, making for efficient and flexible manufacturing while limiting localized impacts in the ocean.

- **Location:** Deployment locations are selected to maximize yield (kelp growth) and durability (burial at depth), and to limit competition with existing biological and commercial activities.
- **Distribution**: After they are placed in the ocean, currents naturally disperse free-floating buoys across vast areas, reducing localized impacts on marine ecosystems.
- **Native materials**: Running Tide uses materials that are non-exogenous to the ocean, including non-proliferating variants of kelp, minerals that are distributed throughout the world's oceans (e.g. $CaCO_3$), and terrestrial biomass that already enters the oceans through rivers and other natural pathways in vast quantities.
- **Limited duration**: Each deployment has a finite and knowable lifespan that minimizes the risk of uncontrolled feedback loops and interactions with land mass or commercial fishing areas.
- **Pacing**: Calcium carbonate coatings are designed to dissolve slowly, resulting in subtle changes in ocean alkalinity that gradually rebalance surface ocean chemistry in support of CO_2 sequestration from the atmosphere.
- **Existing carbon pathways**: All three of Running Tide's carbon pathways exist today as the primary pathways by which the ocean moves CO_2 from the fast to the slow carbon cycle. Running Tide's methodology simply amplifies these natural pathways.

Conclusion

The energy provided by fossil fuels has immensely benefited humanity. However, the coincident transfer of slow carbon to fast carbon has created an imbalance in Earth's carbon cycle that we have no choice but to restore. If natural systems are not rebalanced, they are poised to reverse humanity's gains by causing widespread human suffering, ecosystem collapse, and economic loss.

The February 2022 IPCC report makes it clear: we have a small window of time to begin reversing our impact on the Earth's carbon cycle. This window gets smaller every year. It is essential that we respond not in 2050, not in 2030, but today, by leveraging technology, capital, and resources to turn the tide on climate change. To do that we need a broad set of safe and scalable carbon removal solutions.

Running Tide has developed a restorative carbon removal solution to sustainably amplify the rate at which the ocean's biological carbon pump transports carbon from the fast to the slow carbon cycle. The company's methodology minimizes human inputs by using the Earth's most efficient process of fixing carbon (photosynthesis), transferring mass (ocean currents and gravity), and alkalinizing the surface ocean ($CaCO_3$ dissolution).

The distributed nature of Running Tide's solution minimizes potential negative impacts, and open-ocean operations reduce conflicts with existing land use and coastal activities. The Running Tide system also delivers important co-benefits by promoting biodiversity, by supporting the sustainability of the forestry and fishery industries, and by revitalizing coastal communities that are disproportionately impacted by climate change.

Climate change is Godzilla. No walls will keep him out. If humanity is to give him more than a paper cut, we must enlist nature in the fight.