Rewind.earth (C-Sink Ltd)

Carbon dioxide removal prepurchase application

Summer 2023

General Application

(The General Application applies to everyone; all applicants should complete this)

Public section

The content in this section (answers to questions 1(a) - (d)) will be made public on the Frontier GitHub repository after the conclusion of the 2023 summer purchase cycle. Include as much detail as possible but omit sensitive proprietary information.

Company or organization name

Rewind (C-Sink Ltd.)

Company or organization location (we welcome applicants from anywhere in the world)

Israel

Name(s) of primary point(s) of contact for this application

Ram Amar , Kobi Kaminitz , Noa Olenik

Brief company or organization description <20 words

Rewind is developing the science, methodology, and MRV to sequester organic carbon in deep, anoxic waters e.g Black Sea.

1. Public summary of proposed project[1] to Frontier

a. **Description of the CDR approach:** Describe how the proposed technology removes CO_2 from the atmosphere, including how the carbon is stored for > 1,000 years. Tell us why your system is best-in-class, and how you're differentiated from any other organization working on a similar approach. If your project addresses any of the priority innovation areas identified in the RFP, tell us how. Please include figures and system schematics and be specific, but concise. Aim for 1000-1500 words.

[1] We use "project" throughout this template, but note that term is not intended to denote a single facility. The "project" being proposed to Frontier could include multiple facilities/locations or potentially all the CDR activities of your company.

CDR Approach

Rewind is removing CO_2 from the atmosphere by accelerating a natural process, whereby CO_2 is captured by plants via photosynthesis, then transported through rivers to the bottom of the sea, and ultimately accumulated as organic carbon in the sediments (Hage, 2022; Reschke, 1999). Rewind will mimic this process by collecting agriculture and forestry residues, analyze and package them in an environmentally safe manner, and transport them for storage on the deep anoxic seafloor of the Black Sea.

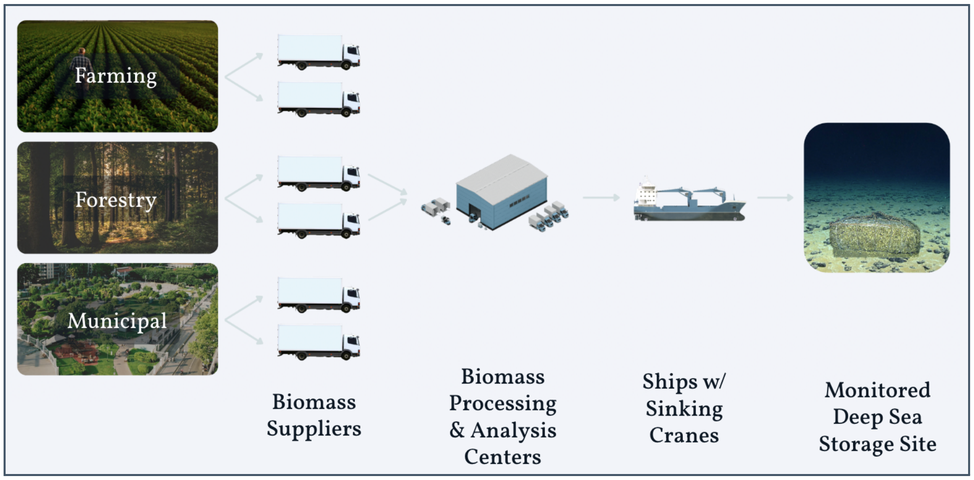

Figure 1 - The Rewind Supply Chain

The proposed project is Rewind's second phase of experimentation & prototyping, targeted at demonstrating the permanence, environmental safety, and measurability of the method. The project will include a series of experiments at two different locations, in Turkiye and in Georgia, using residual woody biomass from two types of feedstocks: agricultural tree prunings from the northeastern part of Turkiye, and residual river driftwood accumulated at the top of the Enguri dam in Georgia. Success in the experiments will include the removal of 773 tons of CO_2, the advancement of science in collaboration with global and local research partners, an initial prototype of Rewind's MRV system, and an acquired license to continue larger-scale piloting in the Black Sea.

1000 Year Permanence

Two principles ensure the long-term sequestration of organic matter in the Black Sea. The first principle is the slow rate of decomposition of organic material in euxinic environments (no oxygen, high sulfide). This can be seen in the ancient shipwrecks discovered in the deep Black Sea (Pacheco-Ruiz, 2019), it is well documented in the literature (Arndt et al., 2013; Jessen et al., 2017), and it was also demonstrated by in-situ experiments we have performed in 2022. Furthermore, based on the fact that lignin does not decompose in the absence of oxygen (Hedges and Keil, 1995; Wang et al., 2011), our project focuses on deposition of woody residues. The second principle to ensure long-term sequestration of the organic matter is very slow vertical mixing. The age of the water at the bottom of the Black Sea is estimated to be between 500 to 2,000 years (Kwiecien et al., 2008), ensuring that even the fraction of decomposed organic material (dissolved inorganic carbon, DIC, released from the decay of organic material) will not reach the surface for thousands of years.

Best in Class Solution

The Black Sea Advantage - The optimal place for sinking biomass is the Black Sea for its unique natural features: stratification at 200 m depth and below, no oxygen & high concentration of sulfate in the deep layer, and a stagnant layer of water at the bottom (2 km deep). The surface waters of the Black Sea are highly alkaline which makes this body of water a sink for atmospheric CO_2. Moreover, the sea is a natural sink of organic carbon as it is surrounded by a huge fertile watershed, and the ancient wooden ships on its bottom are living proof of sunken carbon permanence. The Black Sea also happens to be a prime location for sourcing biomass, as it is surrounded by countries with abundant agriculture and forestry.

Science led - As we are developing a novel CDR method, it is critical to provide scientific evidence for the permanence as well as environmental safety of the method. We conducted multiple scientific experiments to measure the decomposition rates of different types of biomass in various aquatic environments: in the lab, and in-situ in Israel, Germany, and the Black Sea. We share the data collected from these experiments with a scientific committee that we assembled and we plan to release it to the public in the future. We are writing together with Puro.earth the first public methodology of Aquatic Storage of Biomass, to the highest possible standard. Just recently we initiated the Black Sea Climate Roundtable, a group of marine scientists from the countries surrounding the Black Sea. Our global collaborative scientific efforts help in building rapport and support for biomass sinking while allowing us to develop the best-in-class MRV solution.

Accurate, end-to-end MRV solution - Since our CDR methodology can scale very quickly and be performed by many local biomass suppliers, our differentiation is in building the MRV system required to measure, verify, and monetize the proper implementation of the method. Our technology includes cost-efficient techniques to sample and monitor the sequestered biomass and the environment in the deep sea, which cannot be performed at scale with today's expensive technologies (ROVs, etc.). Our MRV will also ensure a sustainable and efficient supply chain, tracking and analyzing different types of biomass from the source (agriculture/forestry/municipal) to the seabed storage site. Lastly, we are designing the methodology to be accountable, via a designated and revisitable storage site, and environmentally safe, relying on sinking only organic matter without any additional ballasting mass.

Energy efficiency - The best CDR solutions should require the least amount of energy to remove CO_2 for the longest possible duration. The great advantage in sinking biomass is that the capture of CO_2 has already been accomplished by photosynthesis, and the export of the carbon to the lithosphere is assisted by gravity. Since sinking terrestrial biomass requires mostly kinetic energy, our LCA shows 93% efficiency in this process. To maximize Rewind's efficiency, we developed an innovative and proprietary sinking method, and in the future, we plan to utilize transportation powered by renewable energy.

Optimally Located - Headquartered in Israel, we are deeply connected to highly skilled engineers and scientists, and we are located close to the Black Sea, enabling us to utilize existing economic and diplomatic relationships. This allows for efficient communication and fast cycles for scientific experiments and government communication required for permitting.

Global Climate Potential - Sinking terrestrial biomass in the Black Sea on its own is sufficient to reach gigaton scale CDR. Information from the FAO regarding agriculture & forestry production around the

Black Sea indicates that there is 0.5 gigaton of biomass available for deposition every year. The volume and depth of the Black Sea (500,000 km^3) allow for gigatons of biomass to be stored at a fraction of its size (1 gigaton of CO_2 in biomass would take up roughly 1 km^3).

Environmentally Sound - Several factors support the ecological safety of biomass deposition in the Black Sea. Beneath 200 m depth, the biodiversity of the Black Sea is extremely limited due to the natural euxinia: lack of oxygen & high saturation of toxic sulfide (Sergeeva, 2014). The euxinia is caused by the permanent stratification, which prevents oxygen from mixing down below the halocline at 200 m depth. Without oxygen, there's almost no multicellular life, and the microbes that do live in the Black Sea perform anaerobic decomposition of the sunk organic matter by sulfate reduction. These sulfate reducing organisms contribute to the concentration of sulfide , and also inhibit methane formation (Treude 2004). Increased production of sulfide due to the accelerated sinking of biomass, may be balanced by the iron rich sediments, which can sequester the sulfide as FeS or pyrite. Another greenhouse gas that may be emitted during anaerobic biomass decomposition is N_2O, both via nitrification and denitrification, but conditions are not optimal for this to occur in the Black Sea (Westley et al., 2006). We are committed to continuously analyzing, mitigating, and monitoring environmental risks. This is reflected in the design of our technology. Aside from monitoring the biochemical conditions of the seabed storage sites, our MRV will test and filter out biomass containing unwanted chemicals, and our sinking technology will ensure rapid sinking and minimal impact on the biota in the top aerobic layer of the sea.

Addressing Frontier Priority Innovation Areas - Our approach is categorized as a BiCRS method as well as an Ocean CDR method. We plan to rigorously demonstrate the ability to measure storage losses, environmental impacts, and biomass source nutrient management. Measuring storage losses will be demonstrated by two sets of experiments. The first set will place different types of organic matter in mesh bags to enable exchange with the surrounding water, at 1,000 meter depth, and periodically (every few months) extract samples of the biomass for analysis (to monitor decomposition) over the course of at least 1 year. The second set of experiments will measure and monitor both vertical and horizontal currents over the course of 1 year at the 1,000m deposition site. The 2 sets of experiments will provide data supporting the 2 components of permanence: slow decomposition and lack of vertical mixing. To measure ecosystem effects, the experiments will incorporate an initial EIA (environmental impact assessment), and periodic testing for sedimentological, geochemical and biological parameters (survey of spatial and vertical distribution of the microbial community) in the storage site as well as a control site. In terms of nutrient management, our biomass sourcing will include an in depth review of the suppliers, their existing nutrient management practices, and the nutrient content within the biomass.
Being a Marine BiCRS method, we plan to advance our understanding in oceanography and biogeochemistry to enable more responsible and science-based decision making, and more accurate measurement of ocean biomass sinking.

b. **Project objectives:** What are you trying to build? Discuss location(s) and scale. What is the current cost breakdown, and what needs to happen for your CDR solution to approach Frontier's $100/t and 0.5Gt targets? What is your approach to quantifying the carbon removed? Please include figures and system schematics and be specific, but concise. Aim for 1000-1500 words.

The project objectives are:

1. Sequester net 773 tons of CO_2 in the deep Black Sea
2. Build a prototype for our deep sea biomass MRV system
3. Measure decomposition rates in the operation site
4. Measure deep water mixing patterns in the operation site
5. Measure bio-geo-chemical changes to the environment

To achieve these objectives, we will build prototypes of our deep sea MRV system and use them to run scientific experiments to test the permanence and safety of the biomass sinking methodology. The prototypes and series of scientific experiments include the following:

1. Decomposition rate measurements

Using a series of rigs, containing wood in mesh cages, which will be moored on the seafloor with acoustic release mechanisms to enable recovery of these at predetermined intervals to monitor decomposition rates.

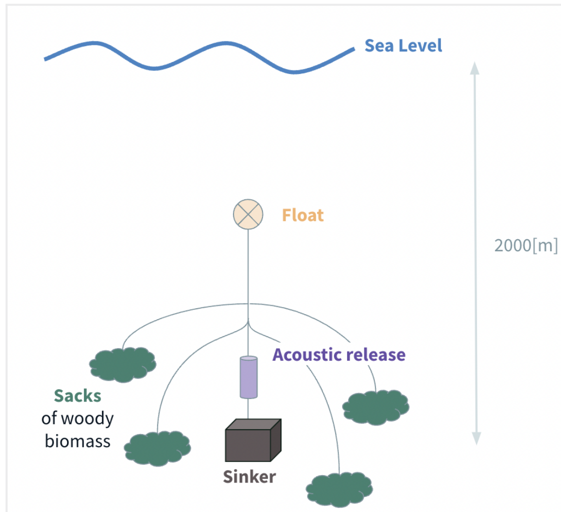

Figure 2a - Decomposition rate experiment setup

2. Currents in the deep water

Will be measured using an ADCP that will take measurements at several depths in the water column. Measurements will be recorded at all seasons to capture seasonal variation at the storage site. These data will be used to establish a physical oceanographic mixing model for the storage site.

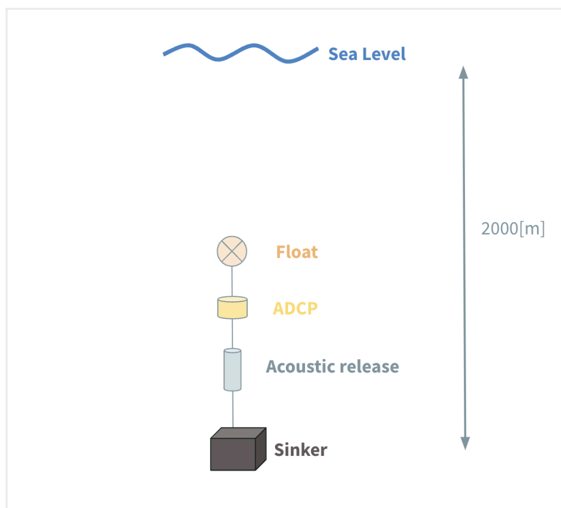

Figure 2b - Set-up for taking current measurements in the bottom of the sea

3. Biogeochemical environmental effects

Will be measured via a series of experiments depositing increasing amounts of woody biomass (1 ton, 10 ton, 100 tons, etc.). Samples of the water, the sediments, and the biomass will be taken before and during the deposition. A control site will also be monitored to compare any observed changes in the microbial community, DIC, sulfide, methane, and N_2O.

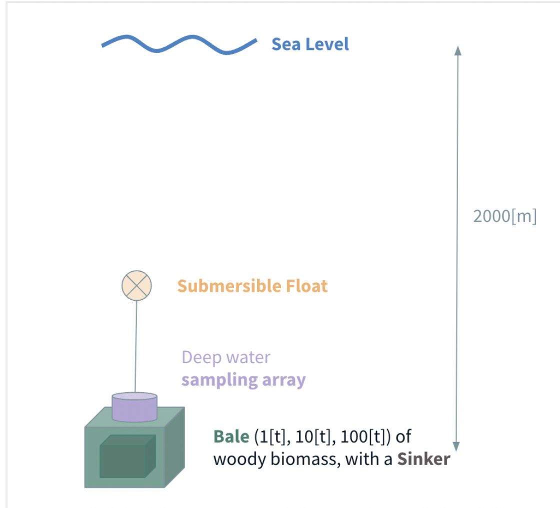

Figure 2C - setup for taking deep seawater samples next to the deposited organic material

Location and Scale

The experiments will be carried out in the southeastern region of the Black Sea, in the exclusive economic zones of Georgia and Turkiye. In both countries, we are collaborating with marine research institutions, environmental organizations, the fishing industry, and the government to coordinate and approve experimentation at scales ranging gradually from 1 ton to 10,000 tons. The availability of woody residual biomass in these regions far exceeds the necessary amount.

Current and Future Cost Projections

The following table represents our estimates for short and long term operational costs:

	Cost ($) per ton	
Stage	Up to 10,000 tons per year	Beyond 100,000 tons per year
Collection from field	25	10
Ground transportation	60	35
Shredding & Packaging	50	15
Shipping & Sinking	60	20
Total	$195 / ton CO2	$80 / ton CO2

The costs of transporting biomass have been obtained from actual price quotes, as this is a very mature industry. We don't expect technological advances which will reduce these prices (electrification will reduce carbon footprint), so the costs will quickly come down with economies of scale.

In addition to the operational costs (OPEX), there are capital expenditures (CAPEX) which include the MRV system and its maintenance, the sinking mechanism, the development of a storage site, and other components which are detailed in the TEA and amortized into the cost per tCO_2. The main cost reduction in CAPEX will come from the increase in the capacity of a storage site & MRV deployment. The MRV prototype will have a capacity of 50,000 tons per year, while the production MRV system will have a capacity of 1,000,000 tons per year.

Reaching 0.5 $GtCO_2$ per year

According to statistics and reports published by the FAO and the ICCT, woody residues from forestry and agriculture in the Black Sea region alone accumulate to a total of 245 megatons of yearly sustainable biomass, representing ⅓ of total available woody biomass. When reaching out further into Europe, via the Danube, the Dnieper, and the Mediterranean Sea, an additional 376 megatons of sustainable woody biomass become accessible. Our approach is to build the best-in-class automated MRV system and to allow any biomass supplier/transporter to quickly onboard and profit from sequestering organic carbon. In addition, as we look out of the Black Sea and to other locations worldwide, we believe that with the advancement in biogeochemical science and understanding of natural seabed carbon sinks, there will be other locations fit for becoming carbon sinks, such as anoxic basins/trenches, and low oxygen zones.

Quantification of the carbon removed

Our approach to quantifying the carbon removed relies on weighing all of the sequestered biomass, sampling the biomass for carbon content analysis, and monitoring the storage site to verify the permanence forecasts. In addition, our MRV will account for all process emissions, a dynamic and continuous LCA, at the granularity of a truckload (±20 tons).

c. **Risks:** What are the biggest risks and how will you mitigate those? Include technical, project execution, measurement, reporting and verification (MRV), ecosystem, financial, and other risks. Aim for 500-1000 words.

Permitting

Obtaining a permit and commercial license for storing organic carbon in the Black Sea is an operational challenge we are facing. The legislative and regulatory frameworks differ from country to country and are mostly unaware of marine CDR. To mitigate the risk, we lead our work with collaborative science and engagement with local scientists (e.g. the Black Sea Climate Roundtable we formed), environmentalists, and other local stakeholders. In addition, we are requesting permits for gradually increasing volumes, assisted by internationally respected law firms, and guaranteeing full transparency and accountability. Lastly, we are reaching out and communicating our work to several countries at once as well as to the Black Sea Commission and the IMO / London Protocol.

Ecosystem Risks and Mitigation

Negative effects on flora and fauna in the Black Sea - One of the main concerns with activities such as the deposition of biomass in aquatic ecosystems are the changes it may cause in local biological communities. In the upper oxic layer of the Black Sea, there is a wide variety of life forms. In order to avoid impacts in the aerobic layer we will sink the biomass rapidly through this to minimize contact between the two. As dissolved oxygen levels drop below the oxic layer, the ecosystem rapidly shifts from a diverse multi-taxon community to one that consists primarily of bacteria and archaea. In the deeper, anoxic layers our main concern will be to maintain the ecological functioning of bacteria and archaea. Since this environment is permanently anoxic, macrofauna is not expected. However, sediment samples will be taken to study prokaryotic diversity in the sediments, both before and after deposition of the biomass, as well as sulfate reduction, methanogenesis, and AOM.

Chemical changes in the aquatic environment - Rewind operations may cause the following changes to the Black Sea: $CO2$ re-emission, Sulfide, methane & nitrous oxide re-emissions, Pollutants formation, and toxicity. To mitigate the various biological and chemical risks we will first perform a comprehensive environmental impact assessment (EIA). Then we will insert biomass gradually, starting with 1 ton and gradually reaching hundreds of tons while measuring parameters as described in the table in section 5b.

Terrestrial nutrient depletion. Terrestrial biomass includes valuable nutrients for agriculture and natural ecosystems. Loss of nutrients and micronutrients in soil can lead to poor crop yields. To mitigate it Information on fertilization practices will be collected for every source of organic matter. Where applicable, some of the organic matter will be left at the field for composting and fertilizing, according to the best practices in the specific field (Fajardy & MacDowell, 2017).

Biomass Supply

Another risk we face is the procurement of sufficient and sustainable biomass to make a significant impact on climate change. To mitigate this, we have consulted with experts on forestry, agriculture, and bioenergy, we conducted online and on-the-ground research on biomass availability in the region, and we formed a partnership with Renesco, a leading biogas company in Turkiye.

R&D risks and mitigation

Building an electronic monitoring system that can withstand the harsh conditions of euxinia at 2000 m depth, involves some technical and logistical challenges. To address these challenges we have started to conduct experiments on biomass at shallower depths in the Black Sea, and will gradually proceed to deploy and monitor the biomass at deeper depths. Due to the corrosive nature of the Black Sea water (high levels of hydrogen sulfide and low pH), there are risks that gear, such as acoustic releases may “seize” and not function properly. We plan to mitigate or minimize risks related to corrosion by using stainless steel, titanium, and plastic parts where possible/affordable. In the event that experiments or gear deployed at depth needs to be recovered, we will utilize an ROV.

d. **Proposed offer to Frontier:** Please list proposed CDR volume, delivery timeline and price below. If you are selected for a Frontier pre purchase, this table will form the basis of contract discussions.

Proposed CDR over the project lifetime (tons) *(should be net volume after taking into account the uncertainty discount proposed in 5c)*	773 tons
Delivery window *(at what point should Frontier consider your contract complete? Should match 2f)*	73 tons by Q3 2024 700 tons by Q3 2025
Levelized Price (\$/ton CO_2)* *(This is the price per ton of your offer to us for the tonnage described above)*	\$647 per ton

** This does not need to exactly match the cost calculated for “This Project” in the TEA spreadsheet (e.g., it’s expected to include a margin and reflect reductions from co-product revenue if applicable).*