Frontier

BluestOne

Carbon dioxide removal pre-purchase application

Summer 2024

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 2024 summer purchase cycle. Include as much detail as possible but omit sensitive and proprietary information.

Company or organization name

Myblue.World (a company of BluestOne Brasil Group)

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

Brazil (Saltinho/SP)

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

Thomas Helou (BluestOne) and Marcelo Carratu (BluestOne)

Luiz Grossmann (Optionline)

Brief company or organization description <20 words

BluestOne is a waste-free mining and a climate transition solutions provider based in Saltinho, São Paulo, Brazil. Its primary product is the green metal extraction from slag (recycling from other companies' mining processes). BluestOne is the largest recovery and management of slags, wastes and by-products company in Latin America and the only one in Brazil that transforms 100% of the mine waste into high quality and performance products. Through continuous work with customers, suppliers, and the local community, the company is committed to building a more sustainable industrial sector that prioritizes the environment. BluestOne is also actively engaged in supporting biodiversity conservation.

Optionline Institute, which assists BluestOne in this project, is a non-profit organization and is responsible for this project's MRV. Optionline Institute runs a world-class research station based in Ibiuna, São Paulo, Brazil, that investigates bio-solutions for climate change mitigation.

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. 1000-1500 words

[public answer]

The CarbonFarms project proposes a new and innovative approach to Enhanced Rock Weathering (ERW) technologies in order to accelerate and promote economic sustainability to CO_2 removal through carbon mineralization of crushed mine tailings at the waste sites where they have been disposed. ERW is both a strategy for CO_2 removal and long-term storage. It offers one of the most energy-efficient and permanent forms of carbon sequestration by the natural mechanism of carbon mineralization, without requiring any additional energy inputs (Sandalow, 2021).

The CarbonFarm Concept

A CarbonFarm is our innovative approach to optimize the ERW process. Its high-performance carbon drawdown results from the following strategies:

Favorable environment and conditions for weathering

- **Alkaline Mineral Content**: our slag feedstocks sourced from nickel mining waste contain a high proportion of alkaline minerals, such as magnesium and calcium-bearing silicates. Combined CaO and MgO represent over 30% of CarbonFarm's slag stocks, enhancing carbon removal potential.
- **Fast-weathering slag:** Mine tailings or slags are leftover materials from nickel mining. In our particular case, those wastes were generated during the smelting process, which uses melting temperatures to separate the metal from impurities done by primary mining companies prior to being acquired and reprocessed by BluestOne. The material consists of an amorphous slag, which results in much faster mineral dissolution rates.
- **Optimal particle sizes**: BluestOne's recycling process involves comminuting the rock to extremely fine grain sizes (up to 325 mesh), using only physical processes and energy as inputs. The resulting slag bears much larger surface areas, speeding up the weathering rates.

[1] We use "project" throughout this template, but the 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.

Enhancing carbon removal with biology

- **Crop Integration:** The project selects a combination of plants adapted to growing (and surviving) in the slag, which is essential to pump CO_2 continuously into the root zones. Without those plants, the normal CO_2 diffusion from the air into the slag is very impaired, negatively impacting the CO_2 sequestration rates.
- **Microbial enhancements:** CarbonFarms use highly efficient microbial strains that produce organic acids that decompose silicates and increase weathering rates. Moreover, other microbial strains are used to provide Biological Nitrogen Fixation, helping the plants to survive in the harsh environment and improving the nutrient condition of the slag.

Robust measurement and monitoring

- The Field Monitoring Station (FMS) effectively measures alkalinity levels and weathering rates and evaluates uncertainty by applying innovative measurement methods associated with high-tech sensors that can measure and store data in near real time. The FMS is designed for robust statistical analysis, reducing uncertainties in the CDR measurement.

Other advantages and co-benefits of CarbonFarm:

- **No Land-Use conflicts:** CarbonFarms do not compete with other land uses and are located inside or nearby existing or retired mining waste facilities, avoiding long-range transportation of those materials.
- **Ecosystem restoration:** CarbonFarms stabilize organic matter and improve water retention, favoring ecosystem restoration in the long term. Because we propose to add slag and biologicals in large quantities to degraded lands, such as mining waste facilities or inactive quarries, we are potentially reclaiming those lands. Deadlands that are presently considered useless can actually support life again and provide long-term carbon sequestration at the same time.
- **Low carbon footprint:** CarbonFarms by design are environmentally friendly and minimize the carbon footprint

- **Scalable, circular solution for mining waste:** BluestOne's operations already recycle the slag by extracting the remaining metal from the slags for commercialization. Therefore, the slag applied in the CarbonFarm is the residue of these recycled mining tailings, which instead of sitting idle in the soil are used to rapidly remove carbon. The readily available materials make CarbonFarms easy to scale and quickly deploy, offering an efficient solution for carbon removal.

Contribution to Research and Development of ERW technique and measurement

- **Integration of crops**: We plan to evaluate the contribution of crops to the weathering process. Plants are needed to pump CO_2 into the slag's layers and, with the combination of microorganisms and water, accelerate the weathering process. Crops partnered with

specialized bacteria that fix nitrogen and capture nitrous oxide (N_2O) can significantly reduce greenhouse gas emissions. Besides N_2O sequestration, at the end of their short cycle, there will be the added benefit of nitrogen applied to the soil, favoring the growth of the next wave of plants and microbes.

- **Measurement technique:** Measuring ERW in field scales is not easy. The CarbonFarms project introduces two affordable methods for directly measuring the alkalinity resulting from carbon sequestration, which, if proven effective, can be easily replicated in other projects.

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 cost and scale criteria?[2] What is your approach to quantifying the carbon removed? Please include figures and system schematics and be specific, but concise. 1000-1500 words

[public answer]

The CarbonFarms project is a new concept that aims to provide long-term carbon sequestration and storage through ERW using existing highly alkaline mine tailings as feedstocks for Carbon Dioxide Removal (CDR). CarbonFarms' innovative approach maximizes the CDR potential from highly alkaline mine tailings by comminuting them and employing bio-enhancers – plants and microorganisms to speed up the weathering rates.

The first CarbonFarms facility will be located in the city of Saltinho, São Paulo, Brazil. That particular site is located in an environmentally degraded area, a retired mining facility, that currently provides no benefit to the climate or the environment. Therefore, CarbonFarms projects do not compete with other land uses and also provide other ecosystem services beyond CDR, such as land reclamation, nitrogen fixation, nitrous oxide sequestration, additional water retention, and organic matter build-up, allowing for life to resurge in those devastated lands.

The Saltinho CarbonFarm field has a total land area of 10 ha, allowing it to process up to 80,000 tons of slag per cycle. This pre-purchase offer involves a pilot test for processing 8,140 tons in 1 ha up to one year, precisely 1/10 of that location's potential current yearly capacity. Saltinho plant's waste facility currently stores 200,000 tons and its 10,000 tons monthly output will be able to keep the CarbonFarm field running continuously in the future, at full potential. Therefore, this single CarbonFarm project can scale up ten times per year, and 250 times if we consider the whole project life cycle.

Our techno-economic analysis revealed a cost per CDR ton operating at full capacity of $87, which complies with the path to an affordable price per ton smaller than $100/ton, at a hundred kiloton scale.

We designed two innovative methods for measuring alkalinity in open systems. A Field Monitoring Station (FMS) will provide the core measurements by collecting and analyzing the system's leachate

[2] We're looking for approaches that can reach climate-relevant scale (about 0.5 Gt CDR/year at $100/ton). We will consider approaches that don't quite meet this bar if they perform well against our other criteria, can enable the removal of hundreds of millions of tons, are otherwise compelling enough to be part of the global portfolio of climate solutions.

continuously and with robust statistics. In addition, a set of measurement devices to be placed in the CarboFarm fields will act as a backup system to sample cumulative alkalinity.

Please see the following video that summarizes our CarbonFarms project:

https://youtu.be/LoVg8c064ww

FIG. 1: Aerial view of the project area

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 any other risks. 500-1000 words

Risk	**Mitigation strategy**
Water is the most critical resource that we cannot control and will ultimately define the weathering rate. We count on the existing surface water (40,000 m^3) and expected rainfall (13,000 m^3) to support the project	Present capacity exceeds our water demand by about one order of magnitude. Nevertheless, we plan to optimize water use through keyline design (a technique developed by P.A. Yeoman in Australia in the 1950s) to control (slow down) water run-off, collect, and repump it, and therefore maximize water use efficiency.

Real-world weathering might occur slower than predicted by models or earlier experiments.	Several factors influence the kinetics of weathering rates. Once the factors are correctly identified, mitigation could be addressed individually, for instance, by supplementing additional water or adding microbial reinforcements.
Sensors miscalibrate over time	We need to find out how long sensor calibrations will endure under field conditions. Periodic sensor validations may be necessary to assess the sensors' performance.
The field environment can be harsh on sensors, increasing the need for replacements	Our near real-time sensors need to be monitored permanently. We will also need to prepare backup sensors to replace malfunctioning devices. If for any reason the sensors are considered ineffective, we may simply switch to measuring bicarbonate levels using standard analytical methods.
The weathering process might release contaminants above the threshold levels allowed by local regulations.	We intend to place CarbonFarms on water-impermeable lands and where slag has already been disposed of over the years (inside mining waste sites). If the land is permeable, we will spread the slag over plastic canvas used as ground covers similar to the ones used for biogas/composting, which prevents the slag from contacting the soil or causing water leakage underground. We will also establish a monitoring program for contaminants to ensure that their levels stay within regulatory thresholds, both concerning soil contamination (less likely due to physical barrier) and groundwater (not likely due to pH conditions). In the unlikely case of soil or groundwater contamination, our early detection monitoring system will allow us to work fast to stop the process, fix it, and remediate the damage if it occurs.

[public answer]

d. Proposed offer to Frontier: Please list proposed CDR volume, delivery timeline and price below. If you are selected for a Frontier prepurchase, 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)*	1121
Delivery window *(at what point should Frontier consider your contract complete? Should match 2f)*	Up to 1 year (7-8 months is more likely)
Levelized cost ($/ton CO_2) *(This is the cost per ton for the project tonnage described above, and should match 6d)*	$383
Levelized price ($/ton CO_2)[3] *(This is the price per ton of your offer to us for the tonnage described above)*	$446

[3] 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).