PRONŒ

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

PRONœ

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

Paris, France

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

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Brief company or organization description <20 words

PRONœ restores the ocean's natural capacity to permanently remove CO_2 from the air, in a sustainable, scalable and asset-light manner.

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.

Time scales of oceanic CO_2 capture and storage

Atmospheric CO_2 levels are naturally regulated by the dissolution of CO_2 in the ocean. As CO_2 dissolves, the surface layer of the ocean becomes more acidic [1]; this acidity is slowly transported (1,000 years) to the deeper ocean layers until it reacts with the $CaCO_3$ deposits on the ocean floor [2]. In this way, the $CaCO_3$ is dissolved and restores the pH of the ocean. Additionally, silicate rocks release alkalinity into the oceans over a longer time scale (100,000 years), which eventually leads to the re-deposition of $CaCO_3$ [3]. Currently, CO_2 emissions due to human activity are not counterbalanced by natural ocean regulation, leading to an increase in atmospheric CO_2 concentration and ocean acidification.

The time required to reach CO_2 equilibrium between the ocean and the atmosphere is less than one year in the vast majority of the planet [4]; thus, CO_2 could be captured from the atmosphere within this time frame by alkalizing the ocean surfaces ("Ocean Alkalinity Enhancement", OAE).

Once the CO_2 is captured, it remains in the ocean as bicarbonates (HCO_3^-). The carbon is then stored in the ocean for 100 to 1,000 ka [5].

Chemical species involved in ocean alkalinity

The alkalinity of seawater – commonly referred to as Total Alkalinity (TA) – is the "capacity to resist changes in pH that would make the water more acidic" [6]. TA is calculated according to the following equation [7]:

$$TA = \left[HCO_3^-\right] + 2\left[CO_3^{2-}\right] + \left[B(OH)_4^-\right] + \left[OH^-\right] - \left[H^+\right] + \ldots \qquad \text{Equation 1}$$

where each term of the equation represents the molar concentration of the ion between brackets, and the three dots represent the contribution of minor components. As expressed in Equation 1, increasing the concentration of any anions (or decreasing the concentration of the cation) increases TA, contributing to OAE.

Chemistry behind oceanic CO2 capture

The dissolution of CO_2 in seawater involves 3 carbonated chemical species (i.e. CO_2, HCO_3^-, and CO_3^{2-}), related according to the following chemical equilibria [7]:

$$CO_2\,(aq) + H_2O \leftrightarrow HCO_3^- + H^+ \leftrightarrow 2CO_3^{2-} + 2H^+ \qquad \text{Equation 2}$$

[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.

The addition of carbonates (CO_3^{2-}) to seawater would modify these equilibria and consume dissolved CO_2 according to the following reaction [8], [9]:

$$CO_3^{2-} + 0.8\,CO_2\,(dissolved) + 0.8\,H_2O + \ldots \rightarrow 1.6\,HCO_3^{-} + 0.2\,CO_3^{2-} + \ldots \qquad \text{Equation 3}$$

The addition of hydroxyls (OH^-) to leads to the following reaction:

$$OH^{-} + HCO_3^{-} + \ldots \rightarrow H_2O + CO_3^{2-} + \ldots \qquad \text{Equation 4}$$

Ultimately, the CO_3^{2-} obtained in Equation 4 entail the same CO_2 removal as Equation 3.

References and a process diagram are included in question 2.a.

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.

PRONœ develops industrial systems that turn the effluents of coastal industries into a safe alkaline effluent, which is monitored and dispersed in coastal areas. This safe alkaline effluent contains locally reverses the acidification of surface waters, which has potential environmental co-benefits associated with. Furthermore, as previously mentioned in Equation 3 and Equation 4 (section 1.a), the alkalinity then serves to capture CO_2 from the air in less than a year [4] and store it as HCO_3^- for thousands of years [5].

PRONœ's automated systems seamlessly integrate with existing coastal industries and operate under current regulations, thus leveraging legacy infrastructures and available water flows and making our approach asset-light compared to other CO_2 removal approaches. By monitoring the alkaline flow and the surrounding environment, PRONœ issues high-quality CO_2 removal certificates.

This project aims at kick-starting the financing and implementation of a field-tested demonstration system of PRONœ's process. The envisioned system is a 10ktCO2/y removal capacity unit integrated with and installed on the grounds of desalination plants, wastewater treatment plants and power plants. Retrofitted plants keep on operating under current regulations. The number of suitable locations for installation is higher than 20,000 globally, considering coastal desalination plants and coastal European wastewater treatment plants only. Coastal power plants worldwide withdraw for cooling purposes about 40 times more seawater than the desalination industry. Our modular and automated unit systems can work as a single unit or in series to match site-specific capacity. Although not contemplated in this proposal, these units could also work stand-alone, with the deployment of seawater inlet/outlet and filtration infrastructure.

Reaching Frontier's removal capacity target (0.5Gt) requires scaling the manufacturing capacity of currently available industrial equipment.

Reaching Frontier's removal price target (<$100) requires economies of scale through learning, specialization, and efficient capital deployment, this is because our systems involve initial capital expenditure, and low operating costs.

A detailed description and flow diagram of the process is given in section 2.a.

The potential to scale the project is further discussed in point 3 of "Application Supplement: Surface Mineralization and/or Enhanced Weathering" – note that our approach is not surface mineralization or enhanced weathering.

Furthermore, the cost breakdown is described in section 6.a.

References and a process diagram are included in question 2.a.

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. Aim for 500-1000 words.

Technical Risks

There are always risks associated with the scaling of any technology from a laboratory bench, particularly for the performance of the neutralization and capture reactors (e.g., low-mixing points, heterogeneous zones in the reactors, inefficiencies).

To mitigate these risks, we are considering unit operations that are well-known in many other industries, and we are working with experienced providers of such technologies. Building on proven, industrial and modular technological bricks with are integrated and optimized, we drastically reduce the risks to integration risks, since each technological brick exists today as the scale required, we do not need to scale individual bricks.

Project Execution – Supply Chain Risks

The PRONœ process is a combination of existing technological bricks manufactured by different providers, PRONœ acting as an OEM. Scaling our technology requires process optimisation, unit specification and project coordination in order to assemble, integrate and test the different equipment.

Based on our previous experience, we actively engaged industrial equipment and feedstock providers to reach specifications and technical compromises swiftly.

Project Execution – Operating Partner Engagement Risk

Our first approach for deployment involves co-locating our systems with existing coastal industries. Understanding the needs of the coastal industries is key to co-locating our activities and engaging them from the earliest stage.

We contacted different water treatment groups who displayed interest in our technology. We have been invited to present at different conferences. Thanks to these presentations and on-site visits, we got in direct contact with plant directors and representatives, and were able to validate the ease of integration of our systems and validate operational synergies and key KPIs for them.

Monitoring Reporting and Verification Risks

On one hand, our process locally increases the alkalinity of seawater enough to increase its CO_2 capture capacity. On the other hand, this alkalinity variation is not great enough to be measurable with most remote-operated equipment (e.g., pH meters) and is hard to measure remotely in the environment (e.g., total alkalinity). Thus, our MRV approach consists of a mix of direct measuring and mathematical modelling.

At PRONœ, we believe that it is important to build robust MRV methods within the community of OAE start-ups, research centres and scientists. In this way, we obtain a non-biased method, third-party validated and transparent.

Failure to reach a consensus on MRV methods may lead to (i) the application of high discount factors and/or (ii) the exclusion of OAE from high-integrity methodologies, registries and customers.

Environmental Risks

Ecosystem risks are of paramount importance and at the core of PRONœ's vision.

We are constantly updating with the information published by referents like OceanNets and Ocean Visions on the environmental impact of OAE, and we are also part of a research proposal with a renowned centre on this matter. Furthermore, we will operate in strict compliance with the existing environmental regulations to ensure the safety of pH levels at the dispersion points – while actively working on reducing knowledge gaps. We will leverage established ocean outfalls that have undergone thorough validation for their plume's mixing rates, thereby minimizing the affected area. We are in contact with experts in the field, who have previous experience in the environmental impact assessments of the dispersal of coastal industries. Environmental risks will likely (and rightfully) trigger social licence risks.

Market Risks

The dynamics of the voluntary carbon credits market are uncertain, in total volumes, prices and quality expectations from purchasers. This is a risk, accounting for the relatively high price of our CDR certificates at the initial stages.

Variations in costs are minimized by having direct contact with equipment and feedstock providers. While our current proposal considers using electricity from the grid, we are also considering other electricity sources that have proven to be extremely efficient in the first potential locations.

Financial Risks

Currently high interest rates mean (i) higher cost of debt and high project profitability required to enable project finance schemes, and (ii) more difficult and/or longer fundraising cycles fundraising with VCs.

Scalability Risks

Scalability entails both time and capacity aspects.

Capacity-wise, OAE is one of the CDR methods with highest potential, and PRONœ's process is not limited by feedstock availability and accessibility, nor by the market size for co-products , nor waste disposal.

More importantly, non-reliance on partners for (geological) storage, means PRONœ is both vertically integrated (capture + storage) and geography agnostic.

Time-wise, our scalability will depend on the scaling of the Electrodialysis (EDBM) stack manufacturing capacity [not unit sizes], together with that of the necessary membranes (namely bipolar membranes). Anticipated and careful coordination with said providers needs to be achieved in order to avoid bottlenecks and delays.

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)*	212 tCO_2
Delivery window *(at what point should Frontier consider your contract complete? Should match 2f)*	September 2024 to March 2026
Levelized Price (\$/ton CO_2)* *(This is the price per ton of your offer to us for the tonnage described above)*	2210 \$/ton CO_2

** 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).*