Frontier

[Skyrenu Technologies]
Carbon dioxide removal prepurchase 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

Skyrenu Technologies Inc.

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

Sherbrooke (QC), Canada

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

Martin Brouillette (CTO of Skyrenu; martin.brouillette@skyrenu.com)

Brief company or organization description <20 words

Skyrenu proposes a direct air capture technology combined with a mine tailings carbonation process.

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

Skyrenu combines a highly efficient solid sorbent direct-air capture (DAC) system with ex-situ CO2 mineralization of mine tailings or industrial residues to produce carbonate compounds, known for long-term stability when exposed to wind and rain, ensuring durable sequestration. We use proprietary (patent pending) solid sorbent DAC and CO2 mineralization processes. Our system can

[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.

be directly installed at industrial or mine sites, thereby eliminating the need to transport CO2 or mineral feedstock over long distances.

Technology:

Specifically, our technology combines a high-efficiency solid-sorbent DAC system whose high-concentration gaseous CO2 output is reacted with existing alkaline mine tailings or industrial residues in a fast, low-temperature mineralization process.

Our DAC system leverages a proprietary architecture where structured solid sorbent elements are arranged in moving cells with separate and segmented sorption and desorption reactors. By using multiple structured sorbent cells in series, we optimize the breakthrough curve for adsorption and regeneration reactors separately, eliminating both saturated and unused zones that would increase system losses; this also maximizes system duty cycle while reducing cycle time and minimizes the quantity of required sorbent. In addition, integrated heat exchangers and heat pumps ensure optimal thermal management and minimize energy usage. Our cell-based DAC system is sorbent-agnostic and can therefore exploit a variety of sorbent materials, such as amines, zeolites and MOFs, for example, and its cell geometry is also adaptable to an array of sorbent physical configurations, such as filters and monoliths. This allows tailoring system configuration for the requirements of each particular site and climate, and is able to exploit sorbent innovations as they become mature. System parameters are then easily reconfigured via software updates for each specific cell configuration and application. Our DAC systems will be factory-manufactured in 1000 tCO2/yr modular units that will reduce manufacturing cost and facilitate deployment and scale-up. Furthermore, we have identified a clear technical pathway to an energy consumption of 1000 kWh/tCO2 at scale. The relevant intellectual property for the DAC system is protected by U.S. and international patent applications (U.S. Patent Application No. US 63/044,371 June 26, 2020; International Patent Application No. PCT/CA2021/050879 June 25, 2021].

For the CO2 mineralization process, existing alkaline mine tailings or industrial residues are crushed and powdered using conventional mining and processing equipment. The high-concentration CO2 feedstock obtained from the DAC is subsequently dissolved in pressurized water where it reacts with alkaline compounds to form solid carbonate minerals. The carbonate material is continuously removed from the reactor, along with the other solid inert residues from the reaction, and stored nearby. Owing to the high CO2 concentration and mechanical pre-treatment of the mineral feedstock, the entire mineralization reaction takes place in a few hours. Solid carbonate minerals are known for long-term stability when exposed to wind and rain, ensuring durable sequestration of the captured CO2. The carbonation reaction may also unlock other valuable minerals initially present in the source material, offering an additional source of revenue contributing to the reduction of the cost of CDR. The relevant intellectual property for the mineralization system is currently an industrial secret but will be the subject of patent applications in the future.

Proposed project:

To fulfill the Frontier CDR prepurchase of the current RFP, this proposal concerns the deployment of a 1000 tCO2/yr technology showcase for EOY 2025, starting selling CDRs in early 2026. Our system will be installed at a decommissioned asbestos mine site in the town of Thetford Mines (Québec, Canada), using chrysotile serpentine (magnesium silicate) mine tailings for the CO2 mineralization process, producing magnesium carbonate that will be returned to the bottom of the open-air mine pit. The project will be powered by the 100% renewable low-cost Hydro-Quebec grid. Notably, this project is developed with the full support of local populations, organizations and governments and uses existing permitting.

Priority innovation areas:

Our approach addresses many priority innovation areas identified in the current RFP, across different pathways:

1- We leverage existing industrial assets, by using mine tailings and industrial waste to scale carbon removal quickly and at lower costs. For example, there are 800 megatons of asbestos mine tailings in the province of Québec, offering a CDR potential exceeding 100 megatons. Furthermore, our CO2 mineralization process is generalizable to use a variety of alkaline material feedstock types.

2- Our approach can offer lower price CDR through additional revenue sources, generated by selling the non-carbonate residues from our mineralization process to operators who may want to extract valuable strategic minerals from them, such as nickel and silicon in the case of asbestos mine tailings.

3- Our approach has a clear feedstock strategy that could sum to an annual scale potential of >1Gt through the carbonation of alkaline mineral by-products actually being generated globally [see Renforth (2019) The negative emission potential of alkaline materials, Nature Communications 10:1401, https://doi.org/10.1038/s41467-019-09475-5].

4- By accelerating the mineralization reaction in a matter of hours, we eliminate uncertainties related to MRV, as the mass and composition of the products of the mineralization reaction can be measured in real time.

5- Our approach provides local environmental and economic co-benefits that build community and policy support. In general, consuming mining or industrial feedstock currently sitting in gigantic and often geomechanically unstable piles will prevent hazardous materials to be released in the air and water, for the great benefit of local populations and ecosystems. In addition, for the case of asbestos mine tailings, the mineralization reaction consumes asbestos fibers, thereby also remediating the hazardous nature of the waste material. Installing our DAC+mineralization systems at scale on abandoned mine sites also has the potential to economically revitalize historically depressed areas.

6- Especially for decommissioned mine sites, the deployment of our approach ultimately aims to restore each site to its pre-exploitation conditions, by backfilling open-air mine pits with solid carbonate mineral and other inert products of the mineralization reaction. This deployment model will therefore generate environmental benefits at the site.

7- Our DAC technology uses advanced heat pump technology and integrates with hydroelectric and wind power management. Our approach also offers an alternative to geological storage of DAC-captured CO2 by offering integration with the mineralization process.

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

The project presented in this proposal concerns the deployment of a 1000 tCO2/yr DAC+mineralization technology showcase for EOY 2025, starting selling CDRs in early 2026. This will combine a commercial-scale 1000 tCO2/yr DAC module with a small-scale ex-situ mineralization plant. The DAC module will be installed at a decommissioned asbestos mine site, specifically at the BC-2 pile in the town of Thetford Mines (Québec, Canada), where we will leverage existing permitting and repurpose mining and hydrometallurgy equipment already present in a facility owned by 3R Mineral, the mine owner, and managed by Kemitek and COALIA, two local government laboratories. At this site, we will use chrysotile serpentine (magnesium silicate) mine tailings for the CO2 mineralization process, producing magnesium carbonate that will be returned to the bottom of the open-air mine pit. The project will be powered 24/7 by the 100% renewable low-cost Hydro-Quebec grid.

After the successful demonstration of our approach at 1000 tCO2/yr with the proposed project, we will develop, for operation in 2028, our First-of-a-kind (FOAK) commercial facility nearby at the Normandie decommissioned asbestos mine, where we already have the rights to 27 megatons of asbestos mine tailings. This FOAK commercial facility will be based on a larger mineralization plant at

[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.

a scale of 50 ktCO2/yr. Following that, gradual scale-up will proceed on the same site, until reaching 1 megaton/yr Nth-of-a-kind (NOAK) scale in 2035.

Current cost breakdown:

At the 1000 tCO2/yr proposed project scale, the cost breakdown is as follows:

- CapEx $918 /tCO2
- Fixed OpEx $375 /tCO2
- Energy $88 /tCO2
- Other variable OpEx $107 /tCO2
- **Total** **$1'488 /tCO2**

Pathway to approach Frontier's targets:

The pathway to achieve Frontier's cost (100$/t) and scale (0.5 Gt/yr) criteria with our approach is clear and is based on three principal elements: 1- Improvements in DAC and mineralization technologies; 2- On-site deployment of wind and solar energy; 3- Global deployment at appropriate sites. The first two elements will allow a reduction in cost and the third will allow to reach the desired scale.

For the first element, improvements in DAC technology aim at increasing sorbent capacity and durability, decrease thermal inertia as well as improving heat pump performance. Improvements in the mineralization process essentially involve reducing the mass of mineral waste material required to mineralize CO2. Reasonable improvements point the way towards a total electrical energy input of 1200 kWh/tCO2 by 2030 for the combined DAC+mineralization process.

For the second element, on-site deployment of wind and solar, along with energy storage, will allow for a low-cost, low carbon electrical supply at most targeted sites with avail the necessary mine tailings or industrial by-products. Note that our projects in the province of Québec (Canada) will be supplied from the 100% renewable low-cost Hydro-Quebec grid.

Approach to quantifying the carbon removed:

Our DAC+mineralization process allows for accurate quantification of the carbon removed. First, the quantity and concentration of CO2 captured by the DAC system can be quantified in real time using conventional CO2 sampling industrial equipment. More importantly, the quantity of CO2 actually sequestered can be assessed by analyzing and weighing the products of the mineralization reaction. At our current laboratory scale, we use scanning electron microscope (SEM) elemental analysis and x-ray diffraction (XRD) to identify the molecular composition of the products, leading to an accurate quantification of the CO2 within.

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

For the proposed 1000 tCO2/yr system as well as subsequent commercial scale-ups, we anticipate that the main challenge will be with the supply chain for the rapid scale-up of the technology. For example, producing the required large quantities of structured solid sorbent in a timely and cost-efficient manner is requiring a lot of coordination with our manufacturing partners, since we are creating a totally new industry from scratch. Furthermore, fabricating modular units at scale does not involve complex engineering, but nonetheless will require a large manufacturing infrastructure. Fortunately, we have identified local integration partners that have the required scale and competence to tackle our scale-up plans for the proposed FOAK and NOAK projects.

We have been operating a 10 tCO2/yr DAC system based on our proprietary architecture for a year, which serves as a test bench for new sorbent media and elements, allows for the optimization of the process parameters under different weather conditions and serves to validate our performance

models. We are using this experimental facility to minimize the technical risk for the proposed 1000 tCO2/yr project. In parallel, we are developing the process parameters for the mineralization of CO2 with tailings from the same site as where the proposed project will be installed, in order to eliminate considerations regarding variations in tailings composition and granulometry. We currently have assembled most of the engineering team necessary for the design and operation of the proposed facility, and all team members have been working on the project for a few years. In parallel, we are developing the project with local partners 3R Mineral, the mine owner, and Kemitek and COALIA, two local government laboratories with expertise in applications of asbestos mine tailings, to leverage all existing knowledge in that field. We believe that these unique skills and expertise should minimize execution risk. We estimate that, for our proposed approach, the measurement, reporting and verification (MRV) risk is minimal considering the timeliness, speed and accuracy with which the DAC and mineralization operations can be quantitatively monitored, and the long-term stability of magnesium carbonate under a variety of weather and storage conditions. As for the risk to local ecosystems, our project will be established right on the mine site, so that no material will leave this location and no additional water egress will take place. Procedures for safely handling asbestos mine tailings and preventing atmospheric dispersion with heavy equipment have already been established and benefit from government approval. The fact that our process consumes asbestos fibers will actually contribute to improve local ecosystems and reduce potential health hazards. Risks pertaining to permitting are also minimal as we will be using the same protocols as a concurrently running project that produces magnesium sulfate fertilizer on a similar site with the same mine owner (please see https://ksmfertilizers.com). Finally, the primary aim of the proposed project is to finalize the engineering of the technology and demonstrate the capability to perform CDR as planned at a minimal commercial scale. This will be financed via equity investment and government grants as the value created will reside in the technical capability of our team. Profits from the sale of carbon credits for this particular project is not a requirement to ensure its financial viability.

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)*	10’000 tCO2
Delivery window *(at what point should Frontier consider your contract complete? Should match 2f)*	April 2026 to April 2027
Levelized cost ($/ton CO_2) *(This is the cost per ton for the project tonnage described above, and should match 6d)*	1488 $/tCO2
Levelized price ($/ton CO_2)[3] *(This is the price per ton of your offer to us for the tonnage described above)*	1741 $/tCO2 (including CO2 capture and durable sequestration) (includes 7% overhead and 10% profit for future R&D)

[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).