[Yuanchu Technology (Beijing) Co., Ltd.]

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

Yuanchu Technology (Beijing) Co., Ltd.

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

Beijing, China

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

Wei Wei

Brief company or organization description <20 words

Yuanchu Technology utilizes industrial alkaline solid waste and propitiate reactor to enhance weathering with 100X speed of carbon removal.

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

Technology Description:
We have developed an innovative Direct Air Mineralization (DAM) technology which merge direct air capture and carbon mineralization into one step. We could use existing calcium/magnesium

[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.

contained industrial waste, or natural rocks as our feedstock. We have designed a patented YAM reactor. The industrial waste feedstock, such as carbide slag, will be fed into this reactor meanwhile the air is blown into it. Calcium oxide will react with CO_2 to form the solid calcium carbonate at room temperature and atmospheric pressure. With our approach, CO_2 will be removed from the air and then converted it into solid material, which is the most stable state to permanently store CO_2 for over 1000 years. Our innovative technology and patented equipment enable us to achieve direct air mineralization at over 100 times the speed compared with the other available enhanced weathering approaches. Additionally, since our reactor and the process flow are very easy to scale up, we expect the cost of our technology to be below \$100/ton CO_2 in a large scale, such as 100,000 tons CO_2/year. Thus, our technology will provide a high-efficiency and low-cost approach for CO_2 removal.
There is a wide range choice of our feedstock, including nature ores and alkaline industrial wastes, such as steel slag, waste concrete, plaster, and red mud, etc. The alkaline waste feedstock we used typically contains calcium or magnesium, after activation by our specific method, the calcium ion and magnesium ion can react with CO_2 to form the most thermodynamics stable materials calcium carbonate and magnesium carbonate.
The chemical reaction is represented as follows:

$$(Ca, Mg)^{2+} + CO_3^{2-} \longrightarrow (Ca, Mg)CO_3$$

What differentiates us:

Our innovative technology provides a unique approach to achieve CO_2 removal and permanently sequestration with high-efficiency and low cost.

1) **100x reaction speed for carbon removal**: Compared to other enhanced weathering approaches, we use an engineering approach and we have developed a specifically designed reactor which greatly increase the surface contact area of Calcium oxide. This design significantly enhances the mass transfer process from the CO_2 in the air to the surface of calcium oxide where the reaction would occur. As a results, the reaction efficiency is greatly increased and the reaction speed is over 100 times faster than the natural weathering methods.
2) **High throughput and small footprint**: Our well-designed process flow and high efficiency reactor also enable us to achieve continuous operation instead of a batch process. So our process throughput is also much higher than conventional enhanced weathering approach, and since we don't have to spread out the feedstock material in a very large area as the other enhanced weathering approach does, our system's footprint is much less. This importance of these high throughput and small footprint advantage will become more significant for the large-scale application scenario.
3) **Low CapEx and OpEx**: Compared to the current Direct Air Capture technologies, our process is completely operated at room temperature and atmospheric pressure, so our operational cost is very low. Also, we designed our process in the principle of unit operation, so our system is very compact which significantly reduce the CapEx. In addition, the output of other DAC technologies is the concentrated CO_2 gas and it still needs to do further treatment for permanent storage. However, our process is able to capture CO_2 from air and directly convert it to a solid carbonate material. So, our approach also has the competitive advantage on the total cost.
4) **Cost will be reduced to < \$100/ton CO_2 at large scale**: By leveraging our high efficiency reactor and module-based process flow, our process is very easy to scale up. Based on our previous scale-up experience in chemical engineering industry, The CapEx and OpEx will exponentially decreased when we scale up to a large volume such as 100,000

tons/year or above.

5) **Abundance of feedstock materials which enables us to store > 1Gt CO_2:** There are more than 70G tons of various resource materials available for us to be used as our feedstock, including but not limit to: existing industrial waste materials such as Carbide Slag, Red Mud, Magnesium slag, and also natural rocks such as basalt. In addition, we have also developed another innovative technology which could convert the calcium sulfate such as desulfurization gypsum and phosphate rock, into calcium oxide, which even expand the availability of feedstock resources for our approach. So, our process is able to remove > 1 Gt CO_2.

Yuanchu technology addresses the following priority innovation areas identified in the RFP

In general, Yuanchu's technology belongs to enhanced weathering, we use solid waste and natural ores as the feedstock of our innovative Direct Air Mineralization (DAM) technology,

EW Innovation-Different with other available enhanced weathering approaches, which typically adopt agricultural method. For example, using superfine basalt powder and spreading the powder on the farmland, to capture the CO_2 in atmosphere and land, adjust the pH of soil and improve the crop yields. Although this can bring some benefits to farmers, e.g. improving yields and saving cost of soil conditioner, it is difficult to monitor, report and verify. Additionally, this kind of approach relies on existing farmland and the feedstock should be carefully selected in case of any contamination on farmland. We upgrade the enhanced weathering technology from agricultural level to industrial level, with below advantages.

- Feedstocks variety, both of industrial waste and natural ores can be utilized by our technology.
- Easily MRV, the sampling process of our technology is easier than agricultural method, the captured carbon dioxide turns to carbonate products with relevant representative samples
- Easily scale up and engineering, our first pilot gross CO_2 capture capacity is 3000 tons/year, the facility can be scaled-up to 100,000 tons/year or 1Mt/year
- Combine direct air capture and carbon mineralization into one step.

Economic and environmental benefits-we currently use waste carbide slags as feedstock, which is a kind of alkaline solid waste for the production acetylene and PVC, it usually is stacked in waste dump and may cause environmental issues.

- Utilization of solid waste, prevent environmental issues and saving feedstock cost.
- Product with economic value, we turn waste to treasures. The products can be used in mine filling, building materials or even high value calcium carbonate. The product with negative carbon property, this may contribute to the carbon saving for relevant industry in scope 3.

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

[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.

Project Objective:

Our first pilot project aims to develop a new system which could achieve a gross carbon dioxide removal capacity of 3,000 tons/year by using our innovative Direct Air Mineralization (DAM) technology. This DAM technology seamlessly integrates direct air capture with carbon mineralization in a single, efficient step. This groundbreaking process utilizes our proprietary YAM reactor, which is designed to accept a diverse range of feedstocks, including alkaline solid waste and naturally occurring mafic/ultramafic ores that are rich in calcium and magnesium.

By leveraging our cutting-edge technology, carbon dioxide is actively removed from the atmosphere and transformed into the most thermodynamically stable carbonate material known to science. This process ensures the long-term sequestration of CO_2, providing a permanent storage solution that safeguards against any risk of leakage for a minimum of 1000 years.

Our DAM technology offers a sustainable and environmentally friendly approach to mitigating the impacts of excessive atmospheric carbon dioxide, making a significant contribution to global efforts aimed at curbing climate change. The development of this technology not only demonstrates our commitment to innovation but also our dedication to creating solutions that contribute to a greener, more sustainable future.

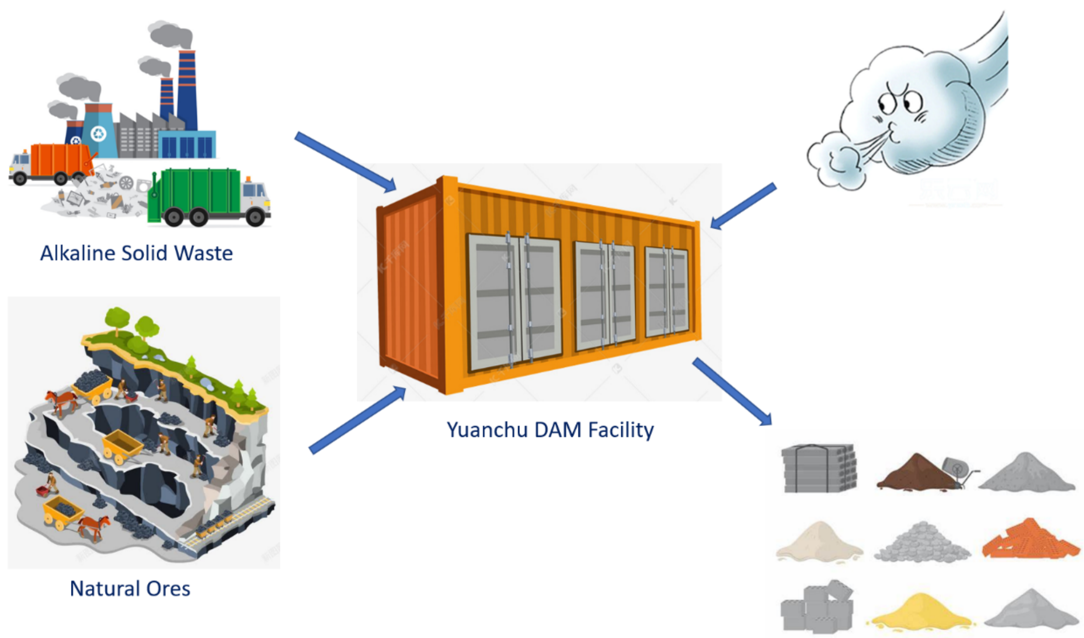

Figure 1: Project Process Schematic

The carbonate products derived from our innovative technology serve as an eco-friendly alternative to conventional building materials, thereby curtailing the carbon emissions associated with the production of traditional construction elements. Our technology exclusively utilizes mineralized feedstocks, water, and atmospheric CO_2 as inputs. The end products of this process are carbonate materials, eliminating the generation of wastewater or solid waste materials.

Furthermore, the efficiency of our technology is significantly enhanced by employing a high-performance reactor designed for continuous operation, transcending the limitations of batch processes or the traditional method of enhancing weathering through the application of superfine basalt powders on agricultural lands. This advanced operational mode enables us to achieve higher throughput with a smaller environmental footprint, facilitating the seamless transition to large-scale application scenarios in the future.

Our journey is guided by the objective to attain high efficiency while minimizing energy costs. We are steadfast in our pursuit to remove carbon dioxide with minimal energy consumption at accelerated rates. Current Carbon Dioxide Removal (CDR) technologies often demand over 5 GJ of energy for each ton of captured carbon dioxide, resulting in elevated costs. However, as we scale up to a capacity of 1 million tons, our innovative approach promises to reduce these costs to less than $100 per ton of CO_2, marking a significant stride towards economically viable and sustainable carbon sequestration.

Location and scale:

Our project is set to be established in Fujian Province, China. The strategic location of our facility near a port guarantees convenient transportation links, facilitating the smooth movement of materials and resources. For our first project, we have designed it to achieve a gross carbon dioxide removal capacity of 3,000 tons. Given the high efficiency and low land footprint of our technology, this initial scale allows us to maximize investment efficiency while generating valuable data to inform future large-scale projects.

To reach the Frontier’s criteria, we must consider the cost breakdown and various factors that influence the cost of carbon dioxide removal. The cost of carbon dioxide removal is highly dependent on several key factors, including the efficiency of the carbon removal process, the cost of feedstock, and labor expenses. By optimizing these factors through our efficient technology and strategic location, we aim to reduce the cost of carbon dioxide removal and achieve the Frontier’s criteria.

Efficiency of carbon removal. There are two types of carbon emissions during the project’s operation, 1) The direct and indirect carbon emissions from energy during the project operations. 2) The indirect carbon emissions caused by the processing and transportation of the feedstocks and construction materials. When calculating the efficiency of carbon removal, we need to consider the carbon emission as well. Currently, the net negativity rate is 60%(with thermal power). In future, with the optimization of our technology and the scaling-up of our project, this rate will be improved. Meanwhile, with the widely application of renewable electricity, the carbon emission factors of electricity will be lower and this can further reduce the carbon emission of our project.

The mass ration of feedstock and the amount of carbon dioxide absorbed is 4-5 :1. Therefore, it has highly impact on the cost of carbon removal. In future, with the expansion of our project’s scale, the price of feedstocks can be reduced. Meanwhile, with the mature of our technology, the utilization rate of feedstocks can be further improved. Additionally, there are a widely choices of our feedstocks. With the optimization of our technology and scaling-up of project, we can construct near to the source of feedstock, this can reduce the transportation cost.

Labor cost. For this 3,000 tons carbon removal project, we need 4 operators and 2 maintenance workers. With the scaling up of our project, the increase of labor demands will not be equal to the proportion of the growth of processing capacity. Additionally, the automation control will be added with the scaling-up of project, this can further reduce the number of operators. The use of robots will be taken into account in future.

Quantification Method:

We employ a rigorous scientific approach to measurement, reporting, and verification. Once carbon dioxide is absorbed from the atmosphere, the calcium and magnesium in our feedstock undergo a transformation into calcium carbonate and magnesium carbonate. These carbonate compounds represent the most thermodynamically stable forms, eliminating any risk of leakage. The quantification of the increase in carbonate materials in our products allows us to accurately calculate the volume of sequestered carbon dioxide.

The chemical reaction is represented as follows:

$$(Ca, Mg)^{2+} + CO_3^{2-} \longrightarrow (Ca, Mg)CO_3$$

To guarantee the precision of our measurements, we utilize titration to determine the carbonate content in our products. Titration is a well-established method in quantitative analysis. We employ the grid sampling method for collecting samples from both the feedstocks and the final products. This method, commonly used in soil and geochemical rock surveys, provides a comprehensive understanding of material distribution and yields representative data. By integrating titration with grid sampling, we can reliably ascertain the amount of carbon dioxide that has been absorbed.

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

Technical Risk:

There could be some technical improvement needed when we scale up the process from the lab-scale to the industrial scale. We will conduct ongoing extensive research to check the process corners of our technology and its successful implementation in similar contexts. Additionally, before full-scale implementation, we will conduct pilot tests in a controlled environment to identify potential issues and validate the effectiveness of the technology, making necessary adjustments before final deployment and gathering plenty of data for future optimization. Throughout the development cycle, we will implement verification and validation processes to ensure that the technology meets specified requirements and operates as intended. We also plan to obtain independent reviews by third-party experts to validate the technology and provide an unbiased assessment.

Project Execution Risk:

Projects may face delays due to unforeseen challenges or resource constraints, and the cost during operation may exceed the budgeted amount, affecting the financial viability of the project. To mitigate this risk, we will set aside an emergency fund and establish a detailed budget while closely monitoring expenses.

MRV Risk:

Poor data collection methods can lead to inaccurate data, which can result in incorrect conclusions or outcomes. To address this risk, we will develop standard operating procedures (SOPs) for data collection, handling, and analysis to ensure consistency and reliability. We will also implement training programs for personnel involved in data collection and analysis to improve accuracy and reduce errors. Furthermore, we will implement quality control checks at each stage of data collection and processing. Finally, we will use statistical methods to validate data and ensure its integrity before drawing conclusions or making decisions. We will use the grid sampling method to improve the accuracy of sampling. We will set an internal inspector position to ensure that all procedures are carried out in accordance with the regulations.

Ecosystem Risk:

We will maintain open lines of communication with all stakeholders, including community members, regulators, and partners, and establish feedback mechanisms to collect input from stakeholders and incorporate their feedback into project planning and execution. Based on the project's specifics, we plan to conduct environmental impact assessments to evaluate the project's effects on the local ecosystem and take corrective measures where necessary. We will adopt sustainable practices to minimize the project's environmental footprint and promote eco-friendliness.

Financial Risk:

The project may run out of budget. To mitigate this risk, we will consider project financing and loans to secure funding from multiple sources. We will also conduct cost analyses periodically to evaluate the economic efficiency of the project and make adjustments if necessary.

Other Risk: Changes in laws or regulations may also affect the project. We will keep abreast of legal and regulatory developments and be ready to adjust the project plan accordingly. Unforeseen events such as natural disasters or force majeure may also disrupt operations. When selecting a site, we will thoroughly investigate the natural climate and geological conditions to reduce the probability of such situations occurring. We will also ensure compliance by regularly reviewing and updating procedures to meet relevant standards, avoiding legal or reputational risks due to non-compliance with industry or regulatory standards.

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)*	>1715ton
Delivery window *(at what point should Frontier consider your contract complete? Should match 2f)*	Q1,2025
Levelized cost (\$/ton CO_2) *(This is the cost per ton for the project tonnage described above, and should match 6d)*	\$406/ton
Levelized price (\$/ton CO_2)[3] *(This is the price per ton of your offer to us for the tonnage described above)*	\$605/ton

[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).