Cquestr8

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

Cquestr8 Ltd

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

London and Malaysia

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

Nishul Saperia, Jerry Joynson & Steve Willis

Brief company or organization description <20 words

Cquestr8 is a low-cost scalable sequestration technology that utilizes readily available alkaline materials in an industrial mineralization 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. Aim for 1000-1500 words.

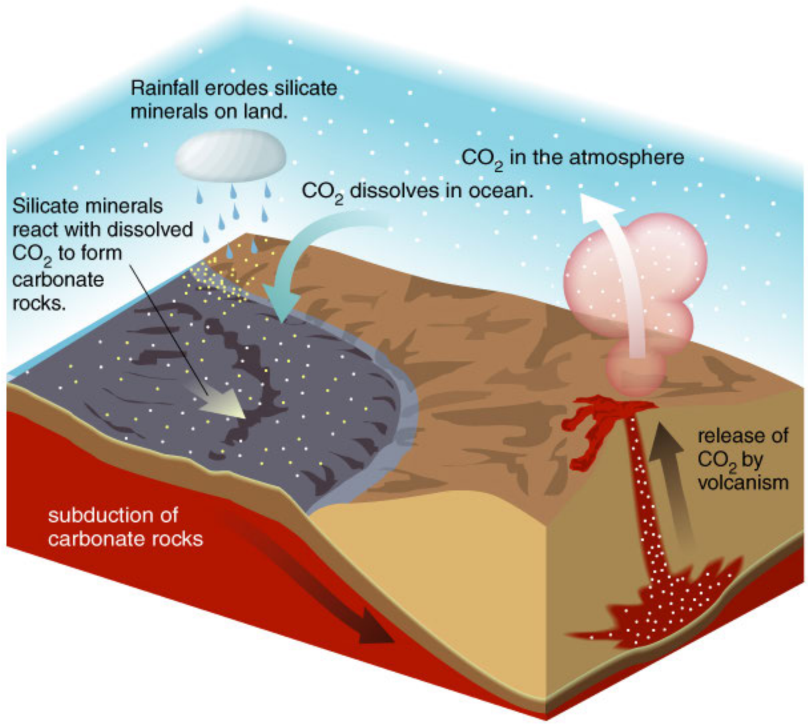
CQuestr8 is building an industrial reaction system which mineralizes CO_2, forming solid carbonates in order to store the CO_2 permanently. The process accelerates the naturally occurring yet very slow reaction that takes place with silicate rocks.

Drawing on decades of heavy industrial experience gained from upstream oil and gas production, chemicals manufacturing and catalyst development, our approach leverages existing proven technologies to optimize the reaction design of a reaction system to deliver an energy efficient and cost-effective industrial solution for the enhanced weathering of silicate rocks. There is a clear objective to build a system that can operate at 1MT+ scale on each site, so that global throughput at GT scale can be achieved.

This reaction occurs in nature as part of the long-term carbon cycle, and the chemistry of the reaction is well documented. In nature, CO_2 in the atmosphere is absorbed into rainwater forming a weak carbonic acid. Rain landing on alkaline minerals reacts with them, forming carbonates or bicarbonates. It is estimated over 1 GT of CO_2 is removed from the atmosphere via this process naturally.

The following diagram by Wesley Longman of Addison neatly illustrates the natural process:

[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.

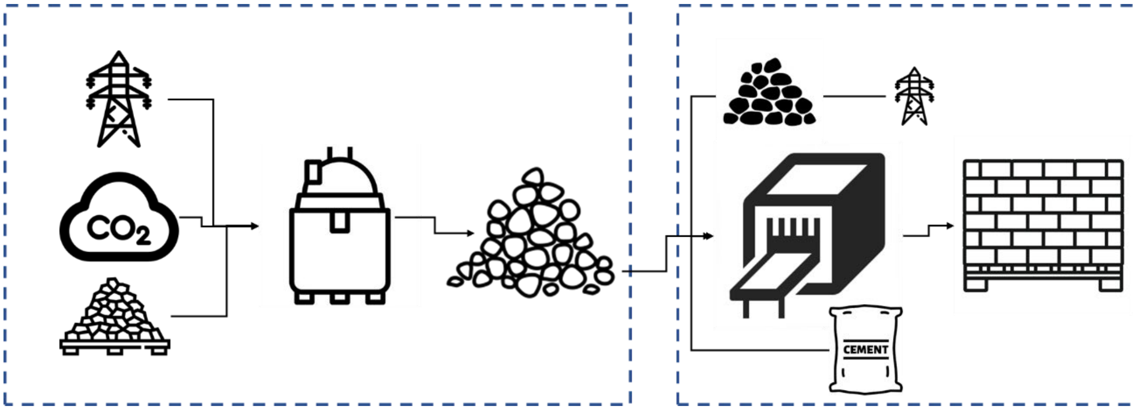


We propose to take more concentrated sources of CO_2 than found in the air, using biogenic sources and DAC partners that need sequestration for the CO_2 they have removed. Our process reacts CO_2 with selected minerals in a closed-loop batch reactor vessel. The key variables that influence the rate of reaction include temperature, pressure, surface contact area (particle size), agitation and abrasion, and accelerants including acids/bases and bio-enzymes. Our process applies a combination of factors to achieve an acceptably low specific energy consumption, making the process economically attractive.

The products of the reaction are magnesium carbonate, which is known to be a solid store of carbon that is stable for over 1000 years, and silica.

We propose to use our reaction products to make construction related materials for industry (in ways that will not compromise the stability of the stored carbon). Our initial construction product will be concrete in a variety of forms, including blocks, which will have the mineralized CO_2 stored within the aggregate as carbonate. The silica, known to be a supplementary cementitious material (SCM) will also help to reduce cement requirements, further increasing our overall CO_2 impact (cement production is a large emitter of CO_2 globally). Beyond the impact on CO_2 it has been demonstrated that silica used as an SCM has advantages in increasing concrete strength when replacing cement (see literature review by Shyam, Anwar and Ahmad 2017), potentially increasing its value. Silica is currently not commonly used as an SCM because of its high cost.

A flow schematic of how our process works:



Here are our first test blocks made in the civil engineering lab of our partner The University of Nottingham:

Our process addresses one of the key areas of the RFP, namely 'Approaches to geochemical CDR that accelerate weathering rates'.

Cquestr8 is significantly differentiated from other companies offering mineral carbonation for several reasons:

- Our reaction system has been designed to minimize the specific energy consumption. It contains innovations in energy recovery and noting that traditionally grinding to create surface area can add significantly to the energy consumption the process introduces a novel way of enhancing active surface area.

- Our founding engineering team has deep experience in developing and scaling large industrial infrastructure, and hence is well versed in the challenges, not only of designing new technology from scratch, but also scaling it. Noting that thousands of units will be required given the enormous amount of CO_2 needing to be sequestered, our process is modular, which allows for production-line delivery of much of the process system, reducing site construction costs, and accelerating the global roll out.

- We have tested a variety of silicate minerals in our facilities in Malaysia with support from Nottingham University and have built up a strong body of knowledge regarding reaction rates under varying conditions, which have been applied to our reactor design.

- Many CO_2 sources can be quite dilute (< 20% CO_2. Our goal is to be able to use less than pure CO_2 streams, to reduce the high costs of CO_2 capture technology, or avoid it completely. These opportunities are quite source specific. This will potentially allow our system to work with a wider range of biogenic and DAC suppliers at reduced overall cost.

- Our goal is to monetize the products of the mineralization reaction. One of the key challenges is post-processing of the products, to meet the needs of large industrial customers. Our overall system approach has been therefore to design end-product production processes that minimize the post-processing required.

- We recognize that the technology development cycle requires many steps to be tested and verified, not just the reaction system, but also the finished products, the equipment and consumables supply chains, logistics, regulations and so on. Consequently, our plants will be capable of consuming a variety of mineral feedstocks, including the simpler reactive materials such as Brucite and Wollastonite (which are both expensive and in limited supply), and slower reacting materials including Olivine and Serpentine, and even some demolished concretes. This development plan will accelerate the path to large scale deployment and proactively address the many other challenges that need to be resolved.

- There is a huge potential resource comprising billions of tonnes of already mined and finely crushed mine tailings, left over from the extraction of valuable metal ores. Many of these tailings contain suitably reactive minerals. Once the system is proven, we will seek out opportunities to partner with the respective mining companies to make use of their mine tailings, and our system is therefore designed with the required flexibility. We expect there will be opportunities for some mine tailings stabilization. Key challenges include the remoteness of many mines, the current lack of CO_2 sources nearby (which may be solved by co-locating DAC facilities), the costs of moving any potential products to markets, and the very high volumes that may be produced.

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.

PILOT
Cquestr8 proposes to build a reaction system with a sequestration capacity of 1,000 tCO_2/y located adjacent to an anaerobic digestor plant in the UK. We are aiming to commission the plant mid to late 2024.
We have identified several target sites where biogenic sources of CO_2 can be found, where the necessary industrial land is available, with suitable access to bring in the mineral reactants, and ideally adjacent or close enough to the biogenic CO_2 supplier that we can connect by pipe. We prefer an unused brownfield site, with an open-air yard that already has hard standing, fencing, ideally a secure building for logistics and protected working space, and both water and electrical supply available, of which there are several around the UK coast.
The core reaction system will be fabricated and packaged in Malaysia by our existing plant fabricator, near Kuala Lumpur. This will be built into standard shipping containers for transportation to the UK. Some standalone equipment will be delivered direct to the site. Almost all the equipment to be used will be standard, available industrial equipment.
The delivered equipment, all of which will be self-standing, will require system assembly, and hook-up

to the water and electrical supplies, followed by commissioning. A small control room, laboratory, instrument panels, and electrical switchgear, with be delivered as one or two pre-commissioned containers. The yard will have space for storage of both the mineral raw materials and finished construction materials.

SCALEUP

The system is intended to be modular, allowing for rapid and lowest cost manufacturing of the system. The maximum size of the reactor will be confirmed through the pilot program. A reasonable first assumption is that each reactor may be capable of processing 35,000 tCO_2/y. Assuming there was access to enough CO_2 to achieve 500 Mt/y of sequestration this would require 15,000 reactors. This would require 15 reactors/week to be built over a period of 20 years. This is small scale compared to, say, ship building, cars and commercial vehicles.

The plant can accept CO_2 from any point source. Anaerobic digestion plants that produce methane are ideal sources of CO_2, as are fermentation processes. However it is unlikely these will collectively produce 500 Mt CO_2/y. To achieve this figure CO_2 from DAC will likely be required.

Regarding feedstock, olivine is one of the most common minerals and widely distributed across the globe. There are also hundreds of millions of tonnes mine tailings to be access if DAC can be built nearby at the appropriate scale. Moving large amounts of minerals from quarry/mine sites to the operations site will vary by location, however all the technical challenges have been solved by the various mining operations over the many decades of activity globally. The key is ensuring acceptable economics at each location. The ubiquity of olivine helps to keep distance short, and costs low.

Ultimately, we envisage Cquestr8 plants will be located in almost all the highly populated and at least semi-industrialized countries.

COSTS

The capital expenditure for our 1000 t CO_2/y unit is estimated to be $420,000. This covers the fabrication, purchase and installation of the onsite equipment including reactor, CO_2 delivery system, solids and slurry handling, control and instrumentation, container control room/laboratory, concrete block making package, and ancillaries including switchgear, portable tools and equipment.

The operating expenditure will be approximately $800,000. This covers site labor, land rental, the elevated costs associated with purchasing small batches of minerals for the pilot, electricity, and consumables (cement, gravel) for making our blocks, rental of some equipment and tanks.

We estimate that sequestration of 1000 t of CO_2 will produce concrete blocks capable of generating sales revenue between $600k and $1.4m, allowing us to achieve a net sequestration cost of $100/t CO_2. It is uncertain how many blocks we will sell from the pilot however as we work to gain product acceptance in a market that requires certain performance standards.

To reduce the price per tonne of CO_2 further, we will be looking to achieve the following:

- Maximize the automation of the process to significantly reduce labor costs per tonne of CO_2 sequestered. Labor currently represents a large percentage of the sequestration costs.
- Build larger plants, as this reduces both CAPEX and operating man-hours per tonne of CO_2.
- Buy minerals in bulk will increase efficiency at the quarries, leading to lower extraction and shipping costs.

Regardless, it is challenging to assume that this model will hit the 0.5 $GtCO_2$/y scale sought by Frontier. The reason being that there is a limit to the amount of construction materials (and other materials for other markets) being used globally, and at the target 0.5 Gt/y our process would potentially exceed market demand. Whilst the global market is many times bigger than this, it is fragmented and very widely distributed geographically, hence it will be challenging to take huge market share. Also much of the demand overall is in Asia today, where demand for lower carbon products are not quite there yet.

When also considering that the total global crude oil production in 2021 was 4.2Gt*, it becomes apparent the enormity of the problem.

Whilst we will continue to scale this process, which we believe can reach 50 $MtCO_2$/y, we are also considering how to partner with the mining industry, which already produces sufficient mineral waste

to sequester 0.5 Gt.
The mining industry produces an estimated 12.7 Gt/y** of mine tailings (mine tailings refers to the waste rock that is mined and processed to access the small percentage of valuable metal ores and gems within, and is then discarded once the valuable mineral is extracted). For example, the concentration of copper is 1% to 2% in the source rock. 21 million tonnes of copper was mined in 2021 producing around 2 Gt of rock tailings waste, discarded and stored in tailings dams.
Whilst much of that will not be suitable for sequestration, a significant proportion of it will be suitable. Mines typically produce multi-millions of tonnes of tailings per year, and there are already billions of tonnes from past mining activity in tailing dams. It is estimated that approximately 1-10 tonnes of tailings will sequester 1 tonne of CO_2. Hence, if 5% of the tailings on the planet are a good fit, conservatively 60 Mt/y or more could be sequestered annually just based on annual production volumes, ignoring the tailings already stored. Increased pressure on mining companies to better manage these deposits is increasing the demand for reprocessing to allow for the potential to provide carbon sequestration.
Mining companies and mine tailings is however not a beachhead market:

- Not all mining companies know exactly what potential their tailings have to sequester CO_2.
- Mining companies need proven technology to be able to scale up to match their tailings production rates.
- Many mines are remote and do not produce CO_2 to match the sequestration potential of their tailings. There would either need to be new pipelines to deliver CO_2 to site, or new DAC facilities built adjacent to the mines. The DAC industry has a way to go to reach the required scale.

The economics of sequestration using mine tailings will vary according to the remoteness, the type of mineral in the tailings, the cost of renewable power locally, and so on.
Note we are in discussion with a number of mining companies and will continue those conversations as we develop our primary approach.
In summary to get to 0.5Gt removal, we take the following pathway:

- Partner with biogenic sources of CO_2 (typically up to 20k tonnes of CO_2 per annum) to build repeatable modular units that can prove out the technology. There are 20,000 of these in Europe alone, many of which will be suitable. Note though many of these will be smaller than 20k. This path is not cheap but will be subsidized by material sales.
- Given mining companies need proven scalable technology, once we have proven out our technology to a certain scale we will begin deployment with mining companies. With a goal of sequestering 1 Mt per annum ultimately at each site, sufficient automation and scale will kick in to drive down the cost to hit the $100/tonne price without needing material sales (although we will seek monetization opportunities). We will be likely partnering with scaled up DAC partners using purpose built renewable energy at this point.

QUANTIFYING THE CARBON REMOVED
The system is closed-loop and all inputs and outputs are fully measurable using well established and standardized instrumentation and meters.

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https://www statista com/statistics/265229/global-oil-production-in-million-metric-tons/#:~:text=In%202021%2C%20global%20crude%20oil approximately%204 2%20billion%20metric%20tons
**
https://theintelligentminer com/2022/03/30/mine-tailings-waste-not-want-not/#:~:text=Making%20rehabilitation%20economic&text=To%20put%20the%20opportunity%20into,tailings%20are%20produced%20every%20year

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.

The biggest risks are:

Technical

Risk	Mitigation Strategy
At large volumes, ensuring sufficient completion of reaction which would impact the economics.	Optimization of the reactor design parameters and required residence time at each stage of scale up to ensure adequate performance.
Post-processing of output materials proves harder at scale than expected.	Our team is well versed on techniques for separating and processing large amounts of materials economically as well as developing processes to do so. We will be focused on developing this on a continuous basis.
Performance of materials we create proves insufficient for customers.	Continuous performance testing and optimizations to ensure delivery of desired properties

Execution

Risk	Mitigation Strategy
Hiring of key team members is delayed, or we fail to hire and manage team well from competence and fit aspect	Ensure culture is well defined early on to ensure fit. Manage company well using well established management techniques such as OKR's and 4DX.

Competition for our feedstocks drives price up	Strategic partnerships with key suppliers. Ensure our reactor can work with a diverse set of feedstocks. We will be working to innovate constantly on this.
Ability to co-locate with willing CO_2 suppliers and in the longer term mining companies is difficult	Continuously develop partnerships to work with a range of biogenic suppliers and DAC suppliers Target mining companies with the right infrastructure to allow us to integrate from a land space and transport point of view.

Financial

Risk	Mitigation Strategy
Cost of logistics for moving large amounts of material proves higher than expected	This risk is relevant for both sourcing of our feedstocks as well as delivering our finished products. For the former we will be focused on ensuring location is accessible for key feedstocks (ideally multiple suppliers). For the latter we will focus on locating where we know we can transport large amounts of material to economically.
Cost of energy increases such that process becomes uneconomic	In the longer term at scale, we may be of sufficient size to enter into power purchase agreements directly to lock in long term cost of energy. Furthermore, we will be looking to utilize waste heat in our process. Our engineers have high awareness on where this can be from their

	previous careers and it will be a guiding criteria in deciding locations of plants.

Sourcing

Risk	**Mitigation Strategy**
We are unable to source sufficient CO_2 from biogenic and DAC suppliers to hit our sequestration goals	We will be actively and continuously developing partnerships with suppliers to ensure continuous supply

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)*	950
Delivery window *(at what point should Frontier consider your contract complete? Should match 2f)*	End 2025
Levelized Price (\$/ton CO_2)* *(This is the price per ton of your offer to us for the tonnage described above)*	\$500 / 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).*