E-quester

Carbon Dioxide Removal Purchase Application

Fall 2022

General Application - Prepurchase

(The General Application applies to everyone; all applicants should complete this)

Company or organization name

E-quester

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

Toronto

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

Shijie Liu, Celine Xiao

Brief company or organization description

E-quester developed a patent pending electrochemical DAC technology powered by renewable electricity and produces pure CO_2 for sequestration and storage.

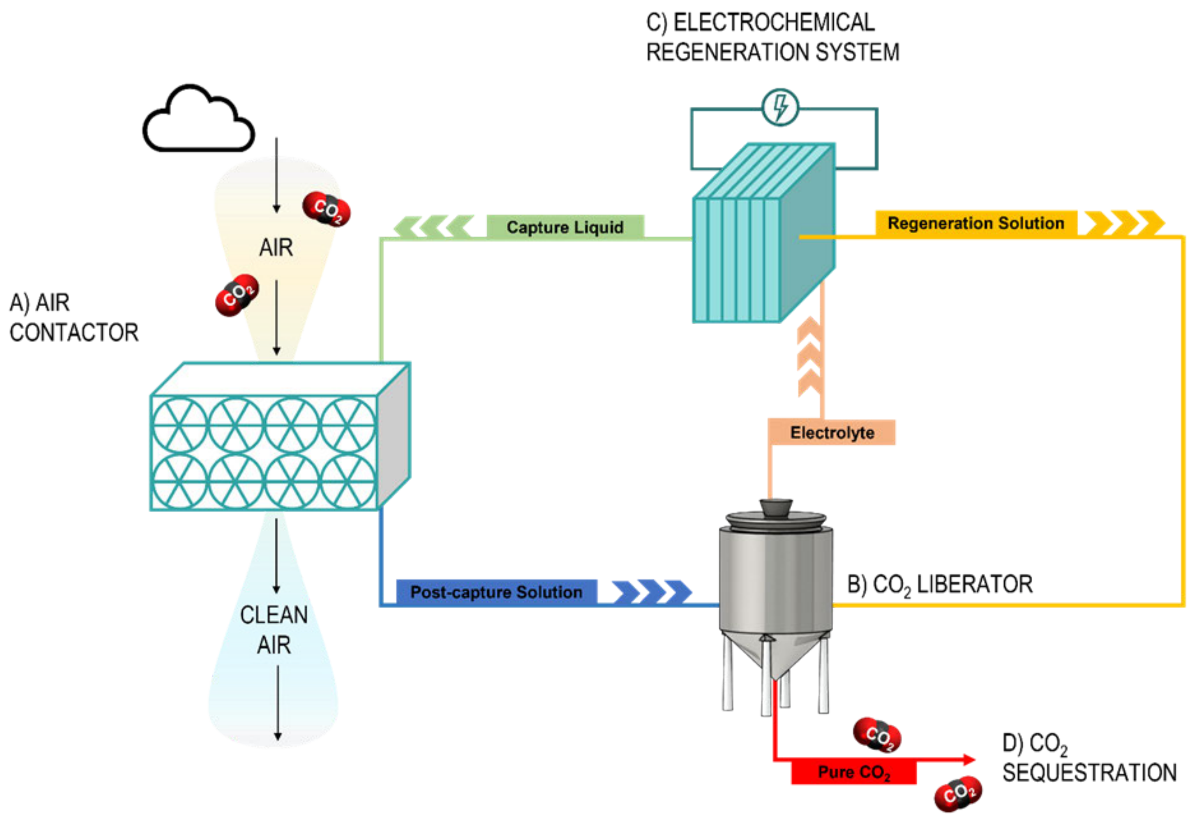
1. Project Overview[1]

a. Describe how the proposed technology removes CO_2 from the atmosphere, including as many details as possible. Discuss location(s) and scale. Please include figures and system schematics. Tell us why your system is best-in-class, and how you're differentiated from any other organization working on a similar technology.

E-quester has developed a direct air capture system that captures atmospheric CO2 with an alkaline capture liquid (Process A), such as sodium hydroxide (NaOH), and produces a pure, concentrated stream of CO2 when the post-capture solution, such as sodium carbonate (Na2CO3), is mixed with the

[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.

regeneration solution (Process B), such as hydroiodic acid (HI). The CO2 stream is then prepared for geological sequestration (Process D). Using our novel electrochemical approach, we fully regenerate the capture capacity of our capture and regeneration liquids (Process C).



Our DAC system uses only electricity, allowing us to leverage renewable electricity sources and minimize our carbon footprint. The electrochemical regeneration system allows us to skip the energy-intensive steps of conventional DAC methods and significantly improve our energy efficiency. Our competitive advantage include:

1. Fully renewable-electricity-driven DAC. Our system requires only electrical inputs and operates at atmospheric temperatures and pressures. When considering operational emissions, we emit about 11 kg CO2 when capturing one tonne of CO2. In current solvent-based DAC systems, the regeneration of the capture media and liberation of CO2 typically requires high temperatures >900°C. This high-grade heat involves the combustion of fossil fuels which emit CO2 in the process, resulting in 0.3 – 0.5 tCO2 emitted per tCO2 captured. Our innovation allows us to be 36x more carbon efficient than our commercial competitors.

2. Low energy consumptions. Our demonstration prototype requires an energy input of 1667 kWh/tCO_2, well below the energy requirement reported by other similar technologies.

3. Resistance to oxidative degradation. Due to the high concentration of oxygen in the air, many capture materials traditionally used in point-source capture lose their capture capacity after prolonged DAC. The alkaline capture liquid in our system has excellent oxygen tolerance and proven physical stability.

4. Large capture capacity. Our electrochemical regeneration system operates at industrially relevant current densities which allows us to produce high volumes of alkaline capture liquid for DAC.

5. Simple materials and equipment. The chemicals used in our system are store-bought and used without further purification or modification. Our core components can be purchased off the shelf and have already successfully demonstrated large-scale deployment in other fields.

6. Modular, scalable, and space efficient. Our electrochemical units are modular and scale linearly once they reach an optimal size. Due to the compact nature of electrochemical systems, our systems can stack efficiently.

We expect the price of our technology to decrease as the project develops and scales. Similar to batteries and water electrolyzers, improvements in efficiency, material, scale, and renewable electricity prices will all contribute to lowering the DAC cost.

The proposed project will remove 100 tonnes of CO_2 per year and will be located at a geological sequestration site in partnership with an existing CO_2 injection operation. The sequestration site currently under consideration is Aquistore, a deep saline CO_2 storage demonstration located in the Canadian province of Saskatchewan and managed by the Petroleum Technology Research Centre. Dried and compressed CO_2 will be tied into Aquistore's existing CO_2 pipeline and injected 3400 meters underground in supercritical form. It is expected that CO_2 will dissolve in the underground water, in the form of aqueous CO_2, carbonate, and bicarbonate ions. Over time, CO_2 becomes more immobile as the storage progresses from structural to mineral trapping. Without intervention or active management, the CO_2 remains stable deep underground, protected from leakage by layers of shale above the injection point.

b. What is the current technology readiness level (TRL)? Please include performance and stability data that you've already generated (including at what scale) to substantiate the status of your tech.

Currently, our technology is at TRL 3. We have demonstrated the feasibility of the electrochemical regeneration system in our lab. At a scale that can capture 2 gCO2/day, we demonstrated 100 hours of stability. (Please see addendum Section 1 for detailed data).

c. What are the key performance parameters that differentiate your technology (e.g. energy intensity, reaction kinetics, cycle time, volume per X, quality of Y output)? What is your current measured value and what value are you assuming in your nth-of-a-kind (NOAK) TEA?

Key performance parameter	Current observed value (units)	Value assumed in NOAK TEA (units)	Why is it feasible to reach the NOAK value?
Total Energy Intensity	3050 kWh/tCO_2	2724 kWh/tCO_2	The future system will be optimized to achieve higher capture efficiency (90 to 95%) and lower energy consumption in the electrochemical regeneration system (10% energy reduction).
Capture Efficiency	90%	95%	The capture efficiency can be improved via system and fluid design.
Electrochemical Regeneration Process Energy	1667 kWh/tCO_2	1501 kWh/tCO_2	Through improvements in our catalyst design, electrolyte composition, and efficiencies in scale.

d. Who are the key people at your company who will be working on this? What experience do they have with relevant technology and project development? What skills do you not yet have on the team today that you are most urgently looking to recruit?

Our core team consists of Prof. David Sinton (University of Toronto Professor), Celine Xiao (Ph.D. researcher), and Shijie Liu (Ph.D. researcher). Professor Sinton is an expert in electrocatalytic systems and has a strong track record in scaling-up and commercializing lab technologies. Celine and Shijie were both involved in the Carbon XPRIZE competition on Team CERT (top 10 finalists), where they worked on an electrochemical CO_2 conversion pilot plant (40000 cm2 total electrolyzer area). The core

team combined the research group's expertise in electrochemistry and experience in scaled-up systems to develop an electrochemical DAC system that is ready to scale.

The team is currently urgently looking for a full-time business lead who can help the team secure the partnerships and funding needed to further scale the technology and demonstrate its real-world feasibility.

e. Are there other organizations you're partnering with on this project (or need to partner with in order to be successful)? If so, list who they are, what their role in the project is, and their level of commitment (e.g., confirmed project partner, discussing potential collaboration, yet to be approached, etc.).

Partner	Role in the Project	Level of Commitment
Aquistore	CO_2 sequestration	Discussing potential collaboration
Carbon Engineering	Air contactor	Discussing potential collaboration

f. What is the total timeline of your proposal from start of development to end of CDR delivery? If you're building a facility that will be decommissioned, when will that happen?

Q4/2022 – Q4/2026

g. When will CDR occur (start and end dates)? If CDR does not occur uniformly over that time period, describe the distribution of CDR over time. Please include the academic publications, field trial data, or other materials you use to substantiate this distribution.

Q4/2025 – Q4/2026

The distribution is uniform due to the continuous nature of our operation. (Please see addendum Section 1 for detailed data).

h. Please estimate your gross CDR capacity over the coming years (your total capacity, not just for this proposal).

Year	Estimated gross CDR capacity (tonnes)
2023	0

2024	0
2025	0
2026	100
2027	100
2028	100
2029	1000
2030	1000

i. List and describe at least three key milestones for this project (including prior to when CDR starts), that are needed to achieve the amount of CDR over the proposed timeline.

	Milestone description	**Target completion date** (eg Q4 2024)
1	Electrolyzer scale up (1cm2 -> 800 cm2)	Q2/2023
2	Multiple electrolyzers integrated with air contactor and CO_2 liberation	Q3/2024
3	Sequestration partnership finalized	Q3/2024
4	In-field pilot plant commissioned	Q4/2025

j. What is your IP strategy? Please link to relevant patents, pending or granted, that are available publicly (if applicable).

E-quester has submitted a US provisional patent for our DAC technology (No. 63/396,563).

We anticipate the generation of new IP as we develop new catalyst formulations, including the use of novel materials and nanostructures. We also anticipate new IP in our systems design as we optimize our various reactor systems.

k. How are you going to finance this project?

Currently, we are leveraging research grants and non-dilutive funding targeted at pre-seed companies. We have already raised $250k from the XPRIZE Carbon Removal Competition. In 2023 – 2024, we will build out a strong team and move towards seed funding stage to raise an additional $5M for project capital cost and technology development.

l. Do you have other CDR buyers for this project? If so, please describe the anticipated purchase volume and level of commitment (e.g., contract signed, in active discussions, to be approached, etc.).

No.

m. What other revenue streams are you expecting from this project (if applicable)? Include the source of revenue and anticipated amount. Examples could include tax credits and co-products.

Earlier in 2022 the Canadian government announced a tax credit of up to 60% for direct air capture projects. This credit is intended to curb the cost of investing in a capital-intensive technology. Our estimated capital cost for this project around $260k, making us eligible for tax returns around $100k (Department of Finance Canada). We expect there to be additional incentives introduced to reflect those in the recent US Inflation Reduction Act.

n. Identify risks for this project and how you will mitigate them. Include technical, project execution, ecosystem, financial, and any other risks.

Risk	Mitigation Strategy
Material cost and availability	Our current system uses materials that are available only through select suppliers which may increase our supply chain risks. We are concurrently developing strategies in the lab that will allow us to replace these materials with widely available and more economical alternatives.
Partnership	We have yet to formally secure a sequestration partner to complete the carbon removal cycle. Our strategy is to communicate with our potential partners and secure formal agreements as early as possible. We will also explore international sequestration partners and not limit ourselves to the location of the CDR demonstration.
Renewable electricity availability	Our system is entirely powered by electricity thus the cleanliness of the grid will impact our net benefit. We will form partnerships with local renewable electricity generators and new developers to increase the total renewable electricity capacity. The intermittency of renewable electricity availability will also be considered when designing the pilot plant.

Capital	The proposed project will be capital intensive, like all DAC projects. Most of the cost is attributed to equipment, hardware, and electrolyzer components. We plan to mitigate some of this risk by fundraising through multiple stages of technological development. With each stage, we will demonstrate improvements in scale, CO_2 capture capacity, and stability of our system to provide our investors with increasing confidence in the technology. We are seeking funding from government grants, angel funds, accelerators, competitions, and venture capitals.
Scale up	Taking the technology from the benchtop to the real world always involves uncertainties. Our core technology shares many fundamental principles with mature and developed electrochemical systems such as fuel cells and water electrolyzers. We can follow best practices in these industries to improve our system design. Our team has previous experience scaling up systems developed in our labs (scaling 10,000x, from benchtop to pilot plant). We will apply the lessons learned to this project and collaborate with industry experts to mitigate some scale-up risks.

2. Durability

a. Describe how your approach results in permanent CDR (> 1,000 years). Include citations to scientific/technical literature supporting your argument. What are the upper and lower bounds on your durability estimate?

> Our DAC system will be tied into Aquistore's existing CO_2 injection operations where the pure CO_2 produced in our system can be dried, compressed, and pumped underground. It is expected that 99.9% of the total injected CO_2 will remain sequestered after 100 years. Aquistore's injection zone is a saline aquifer comprised of sandstones of the Winnipeg and Deadwood formations, which are the deepest units within the sedimentary sequence (Energy Procedia 63 (2014) 3202 – 3208). There is a thick and laterally extensive shale above these sandstones, the Icebox Member, which acts as the primary seal to vertical migration. Aquistore has reported no signs of CO_2 seepage after 1 year of injection activity based on no detection of injection-induced seismicity, and unchanged post-injection groundwater and soil gas sampling (Energy Procedia 114 (2017) 5624 – 5635). In a numerical study, Alcalde et al. found that well-regulated onshore storage leaked a cumulative amount of 0.0861% after 100 years and 2.1% after 10000 years (Nat. Comm. (2018) 9:2201).

b. What durability risks does your project face? Are there physical risks (e.g. leakage, decomposition and decay, damage, etc.)? Are there socioeconomic risks (e.g. mismanagement of storage, decision to consume or combust derived products, etc.)? What fundamental uncertainties exist about the underlying technological or biological process?

The major risks leading to CO_2 re-emission include leak points in the wellbore, injection-induced earthquakes triggering fault displacement and endangering the security of the reservoir, and pressure build up in the reservoir that results in caprock hydraulic fracturing. Experience to date has shown that injection-induced micro-seismic events occur in crystalline basement rocks far below the storage reservoir and pose no risks to the storage integrity of the reservoir (Energy Procedia 63 (2014) 4264 – 4272). CO_2 re-emission risk management relies primarily on the monitoring of CO_2 plume migration, pressure in and above the reservoir, induced seismicity, chemistry of nearby freshwater aquifers and soil gas, amongst other MMV techniques (Front. Clim. 1 (2019) 9).

3. Gross Removal & Life Cycle Analysis (LCA)

a. How much GROSS CDR will occur over this project's timeline? All tonnage should be described in **metric tonnes** of CO_2 here and throughout the application. Tell us how you calculated this value (i.e., show your work). If you have uncertainties in the amount of gross CDR, tell us where they come from.

Gross tonnes of CDR over project lifetime	100
Describe how you calculated that value	In Q1/2022, our team successfully demonstrated a 1cm2 lab-scale Electrochemical Regeneration System of 100-hour stable operation. From Q2/2022 to Q2/2023, our team is implementing our strategy in an 800cm2 lab-scale system. The CO_2 capture capacity is estimated by thermodynamic calculation using Faraday's Law with 90% overall efficiency, which is calculated to be 1t/yr. From Q2/2023 to Q3/2024, we expect to stack ten cells in a parallel configuration as one stack with 10t/yr CO_2 capture capacity. At the same time, we will finalize our upstream and downstream partnerships. From Q3/2024 to Q4/2025, we aim to start constructing a commercial DAC plant with a 10-stack operating system. Eventually, we aim to demonstrate a fully functional carbon removal system with a CDR gross tonne of 100 per year between Q4/2025 and Q4/2026.

b. How many tonnes of CO_2 have you captured and stored to date? If relevant to your technology (e.g., DAC), please list captured and stored tons separately.

Alkaline solution-based DAC is one of the most established, most tested approaches to date. Our approach is built on that foundation, employing the established technologies for the contactor etc. Our key innovation is electrifying the most costly and energy-intensive step, the capture fluid regeneration step. We have demonstrated at the lab scale, but have not captured tonnes of CO_2 to date.

c. If applicable, list any avoided emissions that result from your project. For carbon mineralization in concrete production, for example, removal would be the CO_2 utilized in concrete production and avoided emissions would be the emissions reductions associated with traditional concrete production. Do not include this number in your gross or net CDR calculations; it's just to help us understand potential co-benefits of your approach.

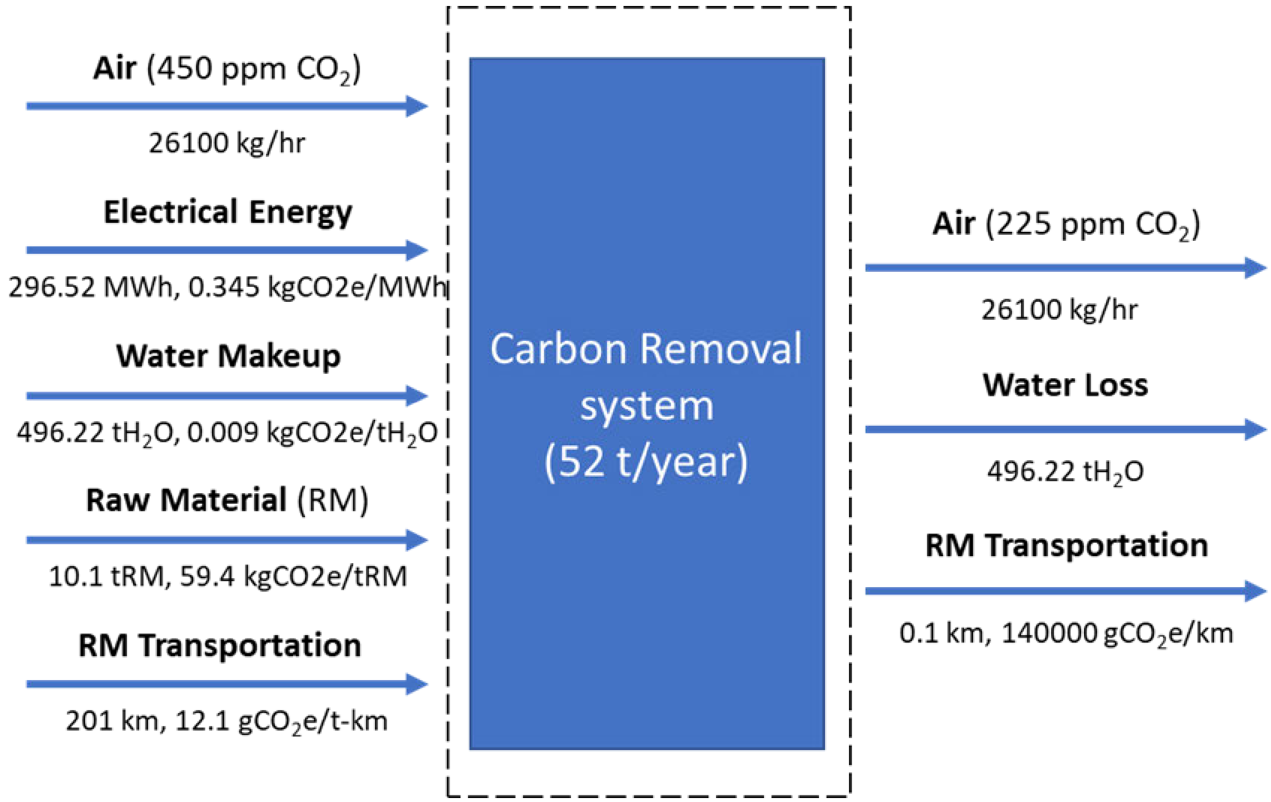
N.A.

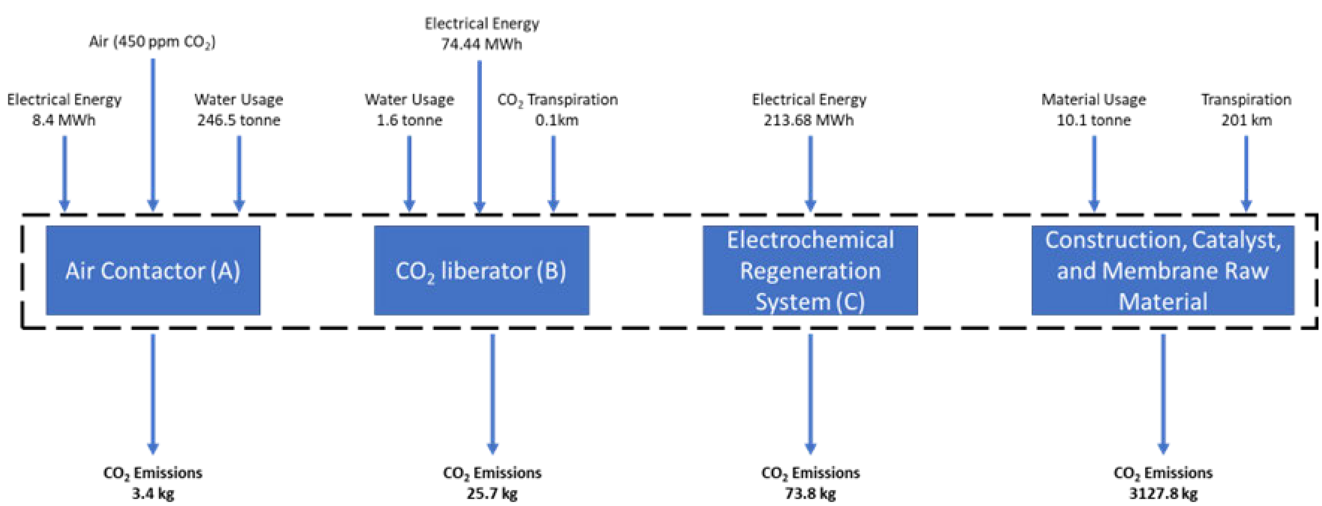
d. How many GROSS EMISSIONS will occur over the project lifetime? Divide that value by the gross CDR to get the emissions / removal ratio. Subtract it from the gross CDR to get the net CDR for this project.

Gross project emissions over the project timeline *(should correspond to the boundary conditions described below this table)*	3.23
Emissions / removal ratio *(gross project emissions / gross CDR–must be less than one for net-negative CDR systems)*	3.23 / 100 = 0.032
Net CDR over the project timeline *(gross CDR - gross project emissions)*	100 - 3.23 = 96.77

e. Provide a process flow diagram (PFD) for your CDR solution, visualizing the project emissions numbers above. This diagram provides the basis for your life cycle analysis (LCA). Some notes:

- The LCA scope should be cradle-to-grave
- For each step in the PFD, include all Scope 1-3 greenhouse gas emissions on a CO_2 equivalent basis
- Do not include CDR claimed by another entity (no double counting)
- For assistance, please:
    - Review the diagram below from the CDR Primer, Charm's application from 2020 for a simple example, or CarbonCure's for a more complex example
    - See University of Michigan's Global CO_2 Initiative resource guide
- If you've had a third-party LCA performed, please link to it.





f. Please articulate and justify the boundary conditions you assumed above: why do your calculations and diagram include or exclude different components of your system?

E-quester's commercial DAC plant will build near the CO_2 sequestration site. The concentrated CO_2 outlet will connect to the main sequestration system via a 100m gas pipeline. Therefore, the sequestration-relevant emission is not considered within our boundary condition. The new facilities that are required includes an air contactor (A), a CO_2 liberator (B), and our Electrochemical

Regeneration system (C). Considered within our boundary are: the electrical energy input, water consumption, CO_2 & raw materials transportation; and raw material consumption emission factors.

g. Please justify all numbers used to assign emissions to each process step depicted in your diagram above. Are they solely modeled or have you measured them directly? Have they been independently measured? Your answers can include references to peer-reviewed publications, e.g. Climeworks' LCA paper.

Process Step	CO_2(eq) emissions over the project lifetime (metric tonnes)	Describe how you calculated that number. Include references where appropriate.
Electrical Energy	102.4 kg	The scope of the electrical energy includes the air contactor (A), electrochemical regeneration system (C), and the associated cooling energy for the electrochemical regeneration system (C) & CO_2 liberator (B). The total electrical energy is estimated to be 296.5 MWh. (Please see addendum Section 4 for detailed data).
Water Consumption	0.5 kg	The scope of the water input includes the air contactor (A) and CO_2 liberator (B). The total water usage is estimated to be 496.2 tonne. (Please see addendum Section 4 for detailed data).
Raw Materials (RM)	3088.3 kg	The scope of the input of the raw materials includes the air contactor (A), CO_2 liberator (B), and electrochemical regeneration system (C). The total raw material weight is estimated to be 10 tonnes. (Please see addendum Section 4 for detailed data).
RM Transportation	25.5 kg	The scope of the RM transportation includes 200 km of rail transportation and 1 km of truck transportation from Regina to our DAC plant. (Please see addendum Section 4 for detailed data).
CO_2 Transportation	14.0 kg	The scope of the CO_2 transportation includes a 100m gas pipeline, which connects our DAC plant to the sequestration site. (Please see addendum Section 4 for

		detailed data).

4. Measurement, Reporting, and Verification (MRV)

Section 3 above captures a project's lifecycle emissions, which is one of a number of MRV considerations. In this section, we are looking for additional details on your MRV approach, with a particular focus on the ongoing quantification of carbon removal outcomes and associated uncertainties.

a. Describe your ongoing approach to quantifying the CDR of your project, including methodology, what data is measured vs modeled, monitoring frequency, and key assumptions. If you plan to use an existing protocol, please link to it. Please see Charm's bio-oil sequestration protocol for reference, though note we do not expect proposals to have a protocol at this depth at the prepurchase stage.

Our CDR quantification strategy can be broken down by process as follows: 1. Air Contactor. Emissions calculated from measured water use on a continuous basis. The pH and volume of the capture liquid before and after the air contactor will be used to calculate the captured CO2 content. 2. CO2 Liberator. Fugitive emissions measured on a continuous basis. A mass flow meter will be used to measure the liberated CO2 amount. 3. Electrochemical Regeneration System. Emissions calculated from electricity use on a continuous basis. The emissions associated with electrolyzer component replacement will be modelled on a per replacement basis. 4. CO2 dehydration and compressions. Fugitive and energy-associated emissions measured on a continuous basis. A mass flow meter will be used to measure the amount of CO2 going into the injection pipeline. The difference between mass measurements before and after CO2 processing is considered to be fugitive emissions. 5. CO2 injection. Fugitive and energy-associated emissions measured on a per well basis. Fugitive emissions will be monitored by various geological sequestration MMV techniques. Additionally, the emissions associated with the manufacturing and transportation of large equipment will be accounted for via modelling during the construction phase of the project.

b. How will you quantify the durability of the carbon sequestered by your project discussed in 2(b)? If direct measurement is difficult or impossible, how will you rely on models or assumptions, and how will you validate those assumptions? *(E.g. monitoring of injection sites, tracking biomass state and location, estimating decay rates, etc.)*

Our DAC system produces a pure stream of CO_2 for geological sequestration. There are a variety of

injection site monitoring techniques used by Aquistore, our prospective sequestration partner. For in-situ monitoring, a parallel observation well houses pressure gauges and seismic sensors in the layers immediately above the injection zone. Real-time fluid sampling, pressure and temperature sensing, and cross-well monitoring are currently in operation. For surface-based monitoring, a variety of devices and techniques have been used to monitor the CO_2 plume, ground deformation, and leakage. This includes a permanent seismic array for time-lapse imaging, electromagnetic and gravity sensors, GPS, tiltmeters, groundwater and soil gas monitoring, and carbon isotope profiling.

c. This tool diagrams components that we anticipate should be measured or modeled to quantify CDR and durability outcomes, along with high-level characterizations of the uncertainty type and magnitude for each element. We are asking the net CDR volume to be discounted in order to account for uncertainty and reflect the actual net CDR as accurately as possible. Please complete the table below. Some notes:

- In the first column, list the quantification components from the Quantification Tool relevant to your project (e.g., risk of secondary mineral formation for enhanced weathering, uncertainty in the mass of kelp grown, variability in air-sea gas exchange efficiency for ocean alkalinity enhancement, etc.).
- In the second column, please discuss the magnitude of this uncertainty related to your project and what percentage of the net CDR should be discounted to appropriately reflect these uncertainties. Your estimates should be based on field measurements, modeling, or scientific literature. The magnitude for some of these factors relies on your operational choices (i.e., methodology, deployment site), while others stem from broader field questions, and in some cases, may not be well constrained. We are not looking for precise figures at this stage, but rather to understand how your project is thinking about these questions.
- See this post for details on Frontier's MRV approach and a sample uncertainty discount calculation and this Supplier Measurement & Verification Q&A document for additional guidance.

Quantification component Include each component from the Quantification Tool relevant to your project	**Discuss the uncertainty impact related to your project** Estimate the impact of this component as a percentage of net CDR. Include assumptions and scientific references if possible.
Storage	We assume the CO_2 storage component (the injection of CO_2 into underground reservoirs) has negligible uncertainty and can be quantified directly by a mass flow controller.
Leakage	Based on post-injection data reported by Aquistore, there has been no signs of CO_2 leakage after 1 year of injection. The best estimate we could find for long term storage security was the numerical study by Alcalde et. al (Nat. Comm. (2018) 9:2201). They estimate a well-regulated onshore storage

	would leak 0.27% after 1000 years. This is equivalent to 0.28% of our net CDR.
Materials	The chemical compounds used as capture and regeneration liquids are considered as capital cost because they are in a closed-loop system and do not need to be replaced. The materials that require periodic replacement such as our catalysts and membranes have already been considered in our LCA.
Energy	Our system is entirely powered by electrical energy and the emission associated have already been considered in the LCA. One assumption we made was that we are able to consistently use renewable energy with low carbon intensity.
Secondary impacts of energy demand	Our system is robust and does not involve an intensive startup or shutdown procedure. It also runs continuously and is not negatively impacted by running at a lower capacity. This means we can take advantage of the electrical demand troughs and operate at max capacity when renewable electricity is the most available. If we assume 5% of our operations will take renewable electricity away from the grid (15800 kWh), then the CO_2 emissions associated would be 7.6 tCO_2 (assuming 486 gCO_2e/kWh for natural gas derived electricity), or 7.9% of our net CDR.
Storage monitoring and maintenance	By partnering with an existing CO_2 injection operation, we can rely on their expert monitoring, measurement, and verification (MMV) systems. The Aquistore site presently has a reported injection of 370kt of carbon dioxide over approximately 6 years despite well confirmed acceptance of up to 2.4 $ktCO_2$/day, which equates to approximately 7% utilisation (Field-Based Observations for CO_2 Geological Storage from 6 Years of CO_2 Injection at Aquistore). Tying in our operations will not pose a significant load on the existing system. Therefore, we assume negligible impact from this component.

d. Based on your responses to 4(c), what percentage of the net CDR do you think should be discounted for each of these factors above and in aggregate to appropriately reflect these uncertainties?

> Taken together, we suggest that 8% of the net CDR should be discounted to account for uncertainty in associated emissions.

e. Will this project help advance quantification approaches or reduce uncertainty for this CDR pathway? If yes, describe what new tools, models or approaches you are developing, what new data will be generated, etc.?

> No. Our technology focuses on reducing the energy intensity and cost of the CDR pathway. The CO_2 quantification methods we plan to use are well developed.

f. Describe your intended plan and partners for verifying delivery and registering credits, if known. If a protocol doesn't yet exist for your technology, who will develop it? Will there be a third party auditor to verify delivery against that protocol or the protocol discussed in 4(a)?

> Our plan for carbon credit development relies on directly quantifiable amounts of CO_2 we are collecting from our system and injecting into the ground. A comprehensive emissions tracking will need to be completed to measure our net CO_2 removed. We plan to work with partners such as Guardyan to validate and verify credits to be registered and issued.

5. Cost

We are open to purchasing high-cost CDR today with the expectation the cost per tonne will rapidly decline over time. The questions below are meant to capture some of the key numbers and assumptions that you are entering into the separate techno-economic analysis (TEA) spreadsheet (see step 4 in Applicant Instructions). There are no right or wrong answers, but we would prefer high and conservative estimates to low and optimistic. If we select you for purchase, we'll work with you to understand your milestones and their verification in more depth.

a. What is the levelized price per net metric tonne of CO_2 removed for the project you're proposing Frontier purchase from? 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), but we will be using the data in that spreadsheet to consider your offer. Please specify whether the price per tonne below includes the uncertainty discount in the net removal volume proposed in response to question 4(d).

> 4145 \$/tonne CO_2

b. Please break out the components of this levelized price per metric tonne.

Component	Levelized price of net CDR for this project ($/tonne)
Capex	1600
Opex (excluding measurement)	2533
Quantification of net removal (field measurements, modeling, etc.)[2]	12
Third party verification and registry fees (if applicable)	N. A.
Total	4145

c. Describe the parameters that have the greatest sensitivity to cost (e.g., manufacturing efficiencies, material cost, material lifetime, etc.). For each parameter you identify, tell us what the current value is, and what value you are assuming for your NOAK commercial-scale TEA. If this includes parameters you already identified in 1(c), please repeat them here (if applicable). Broadly, what would need to be true for your approach to achieve a cost of $100/tonne?

Parameter with high impact on cost	Current value (units)	Value assumed in NOAK TEA (units)	Why is it feasible to reach the NOAK value?
Catalyst and membrane cost	$21291/m^2	$3010/m^2	The NOAK value is estimated by the NREL study [Mayyas et al., 2019] large scale-up cost and the industrial cost-to-capacity estimation [Maxwell, 2022]. The NOAK potential cost reduces with the more advanced process, including automated manufacturing, roll-to-roll catalyst-coated membrane technique. (Please see addendum Section 3 for detailed data).
Chemical cost	$110888/t	$55444/t	The NOAK value of the chemical cost is estimated using a cost-to-capacity method [Baumann, 2014]. The price trend to reduce with industrial amounts purchase and the future chemical

[2] This and the following line item is not included in the TEA spreadsheet because we want to consider MRV and registry costs separately from traditional capex and opex.

			production cost will also be reduced. (Please see addendum Section 3 for detailed data).
Electrical energy	\$85.5/tCO_2	\$64.3/tCO_2	The NOAK value is estimated with a 10% reduction on electrical energy. The carbon removal system efficiency is expected to increase, and overall energy can be reduced with further system optimization. Additionally, the electricity price is expected to decrease in the future. (Please see addendum Section 3 for detailed data).

d. What aspects of your cost analysis are you least confident in?

The Electrochemical Regeneration System material cost is the most uncertain. The current catalyst and membrane costs from lab-scale to pilot-scale were determined using a cost-to-capacity method with a 0.6 scale-up factor. The current PEMWE systems can operate up to 40,000 hours [N.Danilovic, 2016]. The overall cost is expected to significantly reduce per unit with more advanced manufacturing technology when scaling from the small-scale system to the industrial production of large-scale units. Several assumptions were made for an ideal case, based on the electrolyzer scale-up literature. (Please see addendum Section 3 for detailed data).

e. How do the CDR costs calculated in the TEA spreadsheet compare with your own models? If there are large differences, please describe why that might be (e.g., you're assuming different learning rates, different multipliers to get from Bare Erected Cost to Total Overnight Cost, favorable contract terms, etc.).

The CDR costs calculated in the TEA spreadsheet are higher than our internal models. The 100 t/yr scale system cost is estimated to be \$2995/tCO_2 captured in our internal model. Specifically, \$204/tCO_2 for the Bare Erected Cost and \$2791t/CO_2 for the total operational cost. The significant difference is in the Levelized capital expenditure. Our internal model only considered 10% capital contingency and different BOP estimation factors for various components. The indirect cost, Engineering, and other project costs are lower in our internal model.

f. What is one thing that doesn't exist today that would make it easier for you to commercialize your technology? (e.g., improved sensing technologies, increased access to X, etc.)

> Increased access to low-cost renewable electricity. Our plant location was selected near the Aquistore sequestration site. The existing local renewable electricity sources are wind and geothermal. The wind energy cost is \$0.053/kWh and the geothermal energy cost is \$0.05/kWh today. The carbon removal cost reduces with low renewable electricity cost.

6. Public Engagement

In alignment with Frontier's Safety & Legality criteria, Frontier requires projects to consider and address potential social, political, and ecosystem risks associated with their deployments. Projects with effective public engagement tend to:

- Identify key stakeholders in the area they'll be deploying
- Have mechanisms in place to engage and gather opinions from those stakeholders, take those opinions seriously, and develop active partnerships, iterating the project as necessary

The following questions help us gain an understanding of your public engagement strategy and how your project is working to follow best practices for responsible CDR project development. We recognize that, for early projects, this work may be quite nascent, but we are looking to understand your early approach.

a. Who have you identified as relevant external stakeholders, where are they located, and what process did you use to identify them? Please include discussion of the communities potentially engaging in or impacted by your project's deployment.

> When identifying our external stakeholders, we consider the people who will be directly affected by the resources we consume during our CDR process (water and electricity) and any resources we need to build to support our process (land, materials, and labor), as well as any groups that may be indirectly impacted. Some key external stakeholders are identified below:
>
> 1. The city of Estevan. This is the closest city to Aquistore and provides support to the CO_2 sequestration operation as well as the power plant and carbon capture unit it's connected to. We will engage the municipality to ensure we have long-term, sustainable plans around the use of local resources such as labor, water, and electricity.
> 2. SaskPower. SaskPower has exclusive right and obligation to supply electricity in almost all of the province of Saskatchewan, where Aquistore is located. They are an important stakeholder to engage due to our large demand for renewable electricity.
> 3. Local community. We recognize that CO_2 and chemical leakage into the aquifer is an environmental concern. Therefore, we will engage the local community early and ensure our investment in safeguard is adequate and informed. Environmental justice will also be

considered when engaging the community with regards to equitable distribution of project benefits, workforce development, and resource use.

b. If applicable, how have you engaged with these stakeholders and communities? Has this work been performed in-house, with external consultants, or with independent advisors? If you do have any reports on public engagement that your team has prepared, please provide. *See Project Vesta's community engagement and governance approach as an example and Arnestein's Ladder of Citizen Participation for a framework on community input.*

We have not yet engaged these stakeholders. So far, our conversation with Aquistore has been limited to the Aquistore team and has not involved any of their external stakeholders.

c. If applicable, what have you learned from these engagements? What modifications have you already made to your project based on this feedback, if any?

N.A.

d. Going forward, do you have changes to your processes for (a) and (b) planned that you have not yet implemented? How do you envision your public engagement strategy at the megaton or gigaton scale?

Going forward, our priority is to formalize our sequestration partnership so we can engage our external stakeholder early. At the Mt or Gt scale, our core stakeholders will still include the local communities who are supporting our project and most directly affected by it. The stakeholder group will also expand to include larger bodies such as the Canadian government and investor. The public engagement strategy will include in-person components as well as online such as our website, social media, and newsletters.

7. Environmental Justice[3]

As a part of Frontier's Safety & Legality criteria, Frontier seeks projects that proactively integrate environmental and social justice considerations into their deployment strategy and decision-making on an ongoing basis.

a. What are the potential environmental justice considerations, if any, that you have identified associated with your project? Who are the key stakeholders? Consider supply chain impacts, worker compensation and safety, plant siting, distribution of impacts, restorative justice/activities, job creation in marginalized communities, etc.

[3] For helpful content regarding environmental justice and CDR, please see these resources: C180 and XPRIZE's Environmental Justice Reading Materials, AirMiners Environmental and Social Justice Resource Repository, and the Foundation for Climate Restoration's Resource Database

When considering environmental justice in our project, we currently focus on the stakeholders that we have identified above in 6.a. The nature of geological CO_2 sequestration mandates our operation in a rural area. This means a resource-intensive project will have a large impact on the local community. We will include environmental justice considerations in our project planning, with focus on the following:

1. Minimizing our water and electricity load on the community
2. Integrating equity, diversity, and inclusion in our workforce
3. Ensure safety standards are met in project design and workplace practice. Ensure the lifecycle of the materials used are considered.
4. Support transition towards net-zero pathways in other local industries (electricity grid, agricultural practices, CO_2-intensive industries)

b. How do you intend to address any identified environmental justice concerns and / or take advantage of opportunities for positive impact?

Throughout the planning and design of our project, we will be sure to consider the environmental justice to all members of the local community by establishing and maintaining an open dialogue. We will plan to build the largest, most obtrusive components of our project (the air contactor) far enough away from the city of Estevan and the community's major resources (farmland, etc.) to minimize any additional burdens to the local community.

A large-scale plant will provide many benefits such as more job opportunities to the communities, better air quality, and wealth creation. We will work with the community to ensure benefits of the carbon removal solution are equitably distributed and invested into the community. The employment opportunities that we will offer will be based on increasing equitable workforce development practices to provide procedural and distributive justice to the community.

We plan to work with local agricultural groups to help promote transformative justice by supporting the conversion of industrial scale agricultural systems to regenerative practices that can provide additional carbon removal.

8. Legal and Regulatory Compliance

a. What legal opinions, if any, have you received regarding deployment of your solution?

N.A.

b. What permits or other forms of formal permission do you require, if any, to engage in the research or deployment of your project? What else might be required in the future as you scale? Please clearly differentiate between what you have already obtained, what you are currently in the process of obtaining, and what you know you'll need to obtain in the future but have not yet begun the process to do so.

Important permits that need to be acquired include a Municipal Development Permit and a Municipal Building Permit. These permits need to be obtained by before the commencement of construction. Within these permits, environmental and safety assessments, mechanical and electrical drawings, and site plans need to be submitted. Additionally, all pressurized equipment needs to be certified by a regulatory authority, such as the Technical Safety Authority of Saskatchewan (TSASK), before the demonstration site can be commissioned. Currently, we have not yet begun the process of obtaining any permits.

c. Is your solution potentially subject to regulation under any international legal regimes? If yes, please specify. Have you engaged with these regimes to date?

N.A.

d. In what areas are you uncertain about the legal or regulatory frameworks you'll need to comply with? This could include anything from local governance to international treaties. For some types of projects, we recognize that clear regulatory guidance may not yet exist.

We are based in Canada and are currently receiving interest from an international audience. We are uncertain how the carbon credits will be regulated across the border.

e. Do you intend to receive any tax credits during the proposed delivery window for Frontier's purchase? If so, please explain how you will avoid double counting.

The Canadian government announced a tax credit claim of up to 60% for direct air capture projects. This credit applies to the capital cost of building the facility and will not be double counting the CO_2 removed.

9. Offer to Frontier

This table constitutes your **offer to Frontier**, and will form the basis of contract discussions if you are selected for purchase.

Proposed CDR over the project lifetime (tonnes)	89

(should be net volume after taking into account the uncertainty discount proposed in 4(c))	
Delivery window *(at what point should Frontier consider your contract complete? Should match 1(f))*	Q4/2026
Levelized Price ($/metric tonne CO_2) *(This is the price per tonne of your offer to us for the tonnage described above)*	2000

Application Supplement: DAC

(Only fill out this supplement if it applies to you)

Note: these questions are with regards only to air capture: e.g. your air contactors, sorbents or solvents, etc. Separately, there exist Geologic Injection and CO_2 Utilization supplements. We anticipate that most companies filling out this DAC supplement should ALSO fill out one of those supplements to describe their use of the CO_2 stream that's an output of the capture system detailed here.

Physical Footprint

1. What is the physical land footprint of this project, and how do you anticipate this will change over the next few years? This should include your entire physical footprint, i.e., how much land is not available for other use because your project exists. Also, what is the estimated footprint if this approach was removing 100 million tons of CO_2 per year?

Land footprint of this project (km^2)	0.00005
Land footprint of this tech if scaled to 100 million tons of CO_2 removed per year (km^2)	170.2

Capture Materials and Processes

1. What material(s) is/are you using to remove CO_2?

We use an alkaline capture liquid (sodium hydroxide) to capture CO_2 from the atmosphere, which turns the CO_2 into a chemically stable post-capture solution (sodium carbonate). Then, the post-capture solution is combined with an acidic regeneration solution (hydroiodic acid) to produce a pure stream of CO_2.

2. How do you source your material(s)? Discuss how this sourcing strategy might change as your solution scales. Note any externalities associated with the sourcing or manufacture of it (e.g., hazardous wastes, mining, etc.). You should have already included the associated carbon intensities in your LCA in Section 3.

E-quester considered the strategy of metal hydroxide liquid to capture CO_2 from the air and release the captured CO_2 through a pH-swing mechanism. We designed a closed-loop system that recycles and reuse all the capture liquid, regeneration solution, and electrolyte with 100% electricity input to lower the overall energy consumption and process CO_2 emission.

The input chemical is considered to lower system energy consumption for the lab-scale system with high material durability and stability. For the proposed 100t/yr scale, our team will focus on low-cost materials with high energy efficiency, high material durability, and no environmental hazards.

3. How much energy is required for your process to remove 1 net tonne of CO_2 right now (in GJ/tonne)? Break that down into thermal and electrical energy, if applicable. What energy intensity are you assuming for your NOAK TEA?

The proposed 100t/yr scale carbon removal system is estimated to be 11 GJ/tonne CO_2 capture with 100% electrical energy input. The NOAK 1Mt scale carbon removal system evaluates 9.8 GJ/tonne CO_2 capture with 100% electrical energy input.

4. What is your proposed source of energy for this project? What is its assumed carbon intensity? How will this change over the duration of your project? (You should have already included the associated carbon intensities in your LCA in Section 3).

Hydroelectricity produced by Hydro Quebec is considered for this project. The carbon intensity is assumed to be 0.096 $kgCO_2e/GJ$, and the data is obtained from the Hydro Quebec website. Hydroelectricity is a renewable source with low carbon intensity. It will not affect the duration of the proposed project.

5. Besides energy, what other resources do you require (if any, such as water)? Where and how are you sourcing these resources, and what happens to them after they pass through your system? (You should have already included the associated carbon intensities in your LCA in Section 3).

Cooling water and process water are required for the carbon removal system. Specifically, 4.74 tonnes of cooling water are required per tonne of CO_2 captured for air contactor evaporative losses [Keith et al., 2018]. The process water is calculated with 3.1kg per tonne CO_2 capture for system water usage. The cooling water enters the atmosphere in vapor form. The process water is in the outlet gas stream and sent to the sequestration site along with output CO_2.

6. Do you have experimental data describing how your system's CDR performance changes over time? If so, please include that data here and specify whether it's based on the number of cycles or calendar life.

Our system's CDR performance doesn't change over time since our process is a continuous operation with high stability. (Please see addendum Section 1 for detailed data).

7. What happens to your capture medium at end-of-life? Please note if it is hazardous or requires some special disposal, and how you ensure end-of-life safety.

> Our carbon removal system is a close-looped system. The capture medium will be regenerated to metal salt electrolyte and enter the Electrochemical Regeneration System as the input chemical.

8. Several direct air technologies are currently being deployed around the world. Why does your DAC technology have a better chance to scale and reach low cost than the state of the art?

> E-quester has multiple advantages over competing technologies. Firstly, our process uses only electricity, allowing us to leverage renewable electricity sources and minimize our carbon footprint. The core technology, Electrochemical Regeneration system allows us to skip the energy-intensive steps of traditional CO_2 capture methods and significantly improve our energy efficiency. From our experimental results, the lowest Electrochemical Regeneration System energy requirement is 4.7GJ/tCO_2 captured, which is approximately 25% lower than commercial solvent-based DAC systems. Secondly, our process is a closed-loop operation system, which all the chemicals can be recycled and regenerated internally with minimum chemical loss. The chemicals used are store-bought and used without further purification or modification. The core equipment can be purchased off the shelf and have already successfully demonstrated large-scale deployment in other fields. Thirdly, our system requires only electrical inputs and operates at atmospheric temperature and pressure. In current solvent-based DAC systems, the regeneration of the capture media and release of CO_2 typically requires high temperature. This high-grade heat involves the combustion of fossil fuels which emit CO_2 in the process. Our carbon removal process allows us to be 10x less carbon emission than our commercial competitors.

Application Supplement: Geologic Injection

(Only fill out this supplement if it applies to you)

Feedstock and Use Case

1. What are you injecting? Gas? Supercritical gas? An aqueous solution? What compounds other than C exist in your injected material?

The CO_2 from our system will be injected in supercritical form. There are no compounds other than C.

2. Do you facilitate enhanced oil recovery (EOR), either in this project or elsewhere in your operations? If so, please briefly describe.

No.

Throughput and Monitoring

3. Describe the geologic setting to be used for your project. What is the trapping mechanism, and what infrastructure is required to facilitate carbon storage? How will you monitor that your durability matches what you described in Section 2 of the General Application?

Dried and compressed CO_2 will be tied into Aquistore's existing CO_2 pipeline and injected 3400 meters underground in supercritical form. It is expected that CO_2 will dissolve in the underground water, mostly in aqueous CO_2 form and partially as carbonate and bicarbonate ions (Nature Reviews Earth & Environment volume 1, pages 90–102 (2020)). Over time, CO_2 becomes more immobile as the storage progresses from structural to mineral trapping. This progression happens over 10000 years. Without intervention or active management, the CO_2 remains stable deep underground, protected from leakage by layers of shale above the injection point.

To facilitate CO_2 storage, we would need pipelines to tie our CO_2 output into Aquistore's existing operation. At a larger scale, we would have our own dehydrator and compressor and tie into Aquistore's operations further downstream, near the injection point.

We will monitor the durability of our injected CO_2 via Aquistore's existing, extensive MMV system.

4. For projects in the United States, for which UIC well class is a permit being sought (e.g. Class II, Class VI, etc.)?

N.A.

5. At what rate will you be injecting your feedstock?

Due to the continuous nature of our operations, we will be injecting our CO_2 as we capture it. Removing 100 tonnes of CO_2 over 1 year requires an injection rate of 0.27 tonnes per day.

Environmental Hazards

6. What are the potential environmental impacts associated with this injection project, what specific actions or innovations will you implement to mitigate those impacts? How will they be monitored moving forward?

CO_2 leak from the reservoir would be the largest potential environmental impact. In the unlikely event of CO_2 leakage, continuous monitoring systems would detect an anomaly and immediate alert site operators. First, CO_2 injection operation in the vicinity of the leak would be shut off, preventing further pressure build in in the reservoir and reducing the leakage rate by an order of magnitude (International Journal of Greenhouse Gas Control 47 (2016) 86–100).

Hydraulic controls would be implemented after shutoff of injection to completely terminate the leak. Long term CO_2 leakage remediation strategies include extracting mobile phase CO_2 from the reservoir, removing both gas phase and aqueous phase CO_2 from groundwater in the case of aquifer contamination, or injecting an aqueous solution into the fracture that chemically reacts with CO_2 to form a precipitate that fills the fracture (International Journal of Greenhouse Gas Control 20 (2014) 310–323).

The design of the carbon removal project will include emergency stops to immediately halt CO_2 injection and resources needed to perform the above remedial actions.

7. What are the key uncertainties to using and scaling this injection method?

Geological storage via injection of supercritical CO_2 has been studied extensively over the past few decades and can be considered one of the more mature CO_2 sequestration methods. However, we recognize that the effectiveness of CO_2 storage is site dependent and requires various monitoring techniques over a long period of time. The key uncertainty in our project plan would be the super-long-term security of injected CO_2 and whether global seismic shifts or change in underground landscapes would have a large impact on the CO_2 security in the future.

We do not anticipate difficult challenges in the scale of this technology due to the current widespread deployment of CO_2 injection operations, large global geological storage capacity, and maturity of the technology and associated MMV techniques.