Carbin Minerals

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

Carbin Minerals Inc.

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

Vancouver, Canada

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

Sean Lowrie, Peter Scheuermann

Brief company or organization description

Carbin Minerals partners with metals and minerals producers to transform mining waste ("tailings") into large-scale carbon sinks.

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.

Carbin Minerals is working to reimagine how we unlock the potential of one of the largest carbon storage reservoirs on Earth, ultramafic rocks. Ultramafic rocks are silicate rocks rich in magnesium. Magnesium (Mg) dissolves from the rocks and combines with carbon dioxide to form benign and

[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.

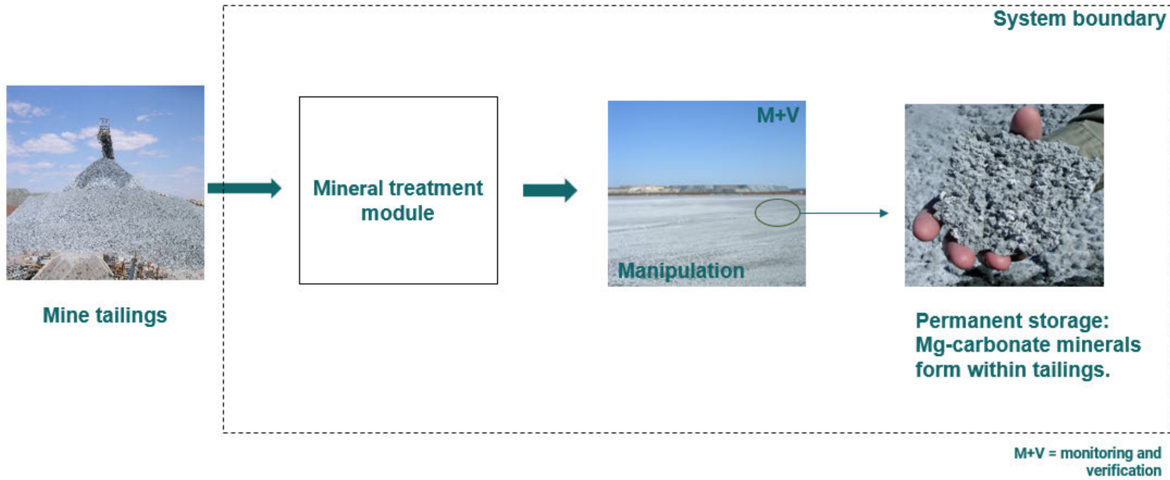
extremely durable (>1,000 years) magnesium carbonate minerals. Mining provides a mechanism by which ultramafic rocks are brought to the surface to react with CO2 in the atmosphere. Production of ultramafic mine tailings is projected to increase to 3.5 Gt/yr by 2100 (Renforth, 2019) from critical and battery metal production, creating feedstock for carbon mineralization at the hundreds of megatonnes to gigatonne CO2 scale. Left alone, ultramafic tailings will capture only a small fraction of their full potential. This is because only a thin slice of tailings on the surface is exposed to air and therefore able to form carbonate crystals. Moreover, tailings are continually produced by a mine operation, and will bury pre-existing tailings in a storage facility before their mineralization potential is realized.

Historically, carbonation of ultramafic rocks has required high temperature-pressure reactors, resulting in prohibitively high energy costs, as well as requiring a concentrated stream of CO2. Carbin Minerals' technology involves a multi-stage approach that first increases the reactivity of tailings to the point that they react readily with CO2 in air, and then accelerates and optimizes the ongoing capture and mineralization over time. This approach will allow us to harness the massive carbon sequestration potential of the growing feedstock of ultramafic mine tailings waste at a rate commensurate with their production by mining. Mine tailings become 'air-contactors' to capture and permanently store atmospheric CO2 in magnesium carbonate minerals.

Our complete removal system consists of two components:

1. Mineral treatment technology that significantly increases both (a) the capacity of certain mine tailings to store CO2 (kg CO2/kg tailings) and (b) the rate at which mine tailings mineralize carbon. Our preliminary results also suggest that our treatment technology may yield significant energy savings as compared to conventional approaches. (We will not be taking into consideration any mineralization achieved through this technology in this pre-purchase application given its early stage in development.)

2. Tailings surface manipulation. This portion of the system involves deployment of autonomous rovers in a tailings dam to manipulate the tailings surface in order to maintain an elevated rate of CO2 capture over baseline. Adjacent undisturbed tailings will provide baseline data. Surface manipulation has been demonstrated numerous times at the lab and field scale as part of research in Prof. Dipple's lab at UBC. As a company, we are improving upon this existing research by developing purpose-built rovers. We are also developing methods to accurately and rapidly measure key chemical and physical parameters. The data collected by these sensors feed into proprietary algorithms that relate the rate of CO2 capture to the key parameters. We will therefore be able to optimize when, where and how we manipulate the tailings surface in order to achieve maximum CO2 capture. (This pre-purchase application refers only to CDR that we will achieve with this technology).



It is important to highlight that certain types of mine tailings naturally react with CO2. In the near term we will use these naturally reactive sites for deployment of component (2) of our system. Successful and safe deployment of component (2) will be essential in demonstrating our value to mining company partners.

Our first deployment will be at an operating nickel mine. In early 2023 we will be given access to a 0.75 km2 portion of the tailings storage facility (TSF), upon which we will deploy component (2). We expect to be generating CDR credits by mid-2023.

Carbin Minerals is based on the world leading research of Prof Greg Dipple, our Chief Scientific Officer. Greg's lab at UBC has published numerous papers on carbon mineralization in mine tailings and he is a well-known and respected figure in the mining industry. Greg and several of his lab staff have moved over to the company. Our leadership team also has direct experience building high growth organizations in emerging industries. We are a strong and well-functioning team with a combination of commercial and scientific experience. Our work has already been recognized with awards from the XPRIZE Foundation and Sustainable Development Technology Canada.

Our system is best-in-class because our team has been at the leading edge of this technological area for over 10 years. Mining operations from around the world send samples of their tailings to Prof Dipple's lab for analysis of its mineralization potential. Through this, we have developed a database of the most promising mine sites for carbon mineralization globally, and continue to update it with new information.

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.

The technology we will be deploying within this pre-purchase agreement is at TRL 7.

We have demonstrated elevated rates of CO2 capture for three consecutive months during field experiments. The field experiments were between 2-6 m2 and utilized mine tailings with very similar mineralogy as is present at the active nickel mine. These experiments have involved the same monitoring instrumentation that we will deploy in this project.

The monitoring equipment we use is produced commercially (TRL 9) and we have operated them continuously for up to six months.

The rovers operate commercially (TRL 9) at active mines. Optimizing the rovers for our specific application lowers their overall TRL level to 7.

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?**
Rate of CO2 capture over baseline	1-5 (kg CO2/m2 yr) transient	4 (kg CO2/m2 yr), continuous	We have achieved the current values using off the shelf churning equipment. Optimization of our equipment as we scale will yield better performance.
Emissions ratio	0.03 (calc.)	0.02	A low emissions ratio is possible due to use of a waste stream (tailings).

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?

We are a strong and well-functioning leadership team with a combination of commercial and scientific experience:

CEO Paul Needham is a multi-time company founder and CEO, with multiple successful exits. Board member and senior advisor in the environmental markets sector. Built and sold India's largest rural rooftop solar leasing company.

CSO and co-founder Prof Greg Dipple is the global leader in the field of carbon capture in mine tailings. He works extensively with mining industry partners and has connections to 30+ companies interested in carbon capture in tailings.

CTO and co-founder Peter Scheuermann invented our breakthrough mineral treatment process and leads our technology R+D. He holds a doctorate in aqueous geochemistry.

COO and co-founder Bethany Ladd holds a master's degree in Hydrogeology and has many years experience managing large scale applied R&D projects.

VP Public Affairs Sean Lowrie has deep experience in system change, government relations, policy and fundraising, recently having raised over $400 million for an international network of charities he created. This year we will bring on 4 junior technical staff with specific experience in our technology. When we launch our project, we will bring on 3-4 more operational and scientific staff. An as of yet unfilled recruitment priority is people with direct experience directing field teams on mine sites.

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**
Major nickel producer	Owner and operator of the Tailings Storage Facility (TSF)	High - confirmed project partner

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?

We plan to deploy and set up during Q1-Q2 2023. CDR will begin as soon as we enhance the rate of CO_2 capture in the tailings. Fulfilling the tonnage (see 3a) in this agreement will require 12-15 months.

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.

CDR will start as soon as we begin churning the tailings (we plan for this to occur by the end of Q2 2023) and will continue for the duration of the project which will conclude no later than Q4 2024. The rate of CDR will be affected most by churning frequency and climate. Since we will be monitoring the rate of CDR in real time, we will intervene in order to maintain rates that are elevated over baseline.

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	500-1000
2024	1000-2000
2025	>2000

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	Site access agreements in place	Q4 2022
2	Equipment and staff deployed to site	Q1 2023
3	Technology deployment	Q2 2023-Q4 2024

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

The University of British Columbia owns the IP that was generated by the Company founders while they were employed by the University. We have negotiated a license agreement with UBC that grants the Company a world-wide exclusive license for that IP. Recently a provisional patent application for the above-mentioned mineral treatment process was submitted.

We see many opportunities for the generation of new IP in our domain, for the optimization of energy use, for increasing the reactivity of minerals to CO_2, for advancing the monitoring and verification technologies and more. We will use a mix of patents and trade secrets to protect future IP.

k. How are you going to finance this project?

We will use four financing options for this project:

1. A commercialization grant from a Canadian private foundation (currently under review).
2. Existing company capital
3. This pre-purchase agreement, if awarded.
4. Existing CDR removal contracts

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.).

Yes, we have a pre-purchase agreement in place with Shopify., so the first 200 tonnes of removals will be delivered under that contract.

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.

We will capitalize upon Canadian R&D tax credits that are available to our Company.

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
Execution risk 1 The long distance between the mine site and Vancouver could present project management and control challenges to a start-up company like ours.	This project will be our main operational priority for the next year. We will focus the company's resources on the deployment of our technology and quantification equipment at this site so we can begin to deliver CDR in the near-term. Also, see response immediately below.
Ecosystem risk 1 We may face questions about why a Canadian Company is involved in this project at the expense of local talent and resources.	We will hire local staff and establish a local subsidiary.
Ecosystem risk 2 Currently no verification protocol for mineralized CO2 capture and storage exists in any jurisdiction, which may create a barrier to adoption in both voluntary and compliance markets due to lack of standardization.	Due to Dr. Dipple's expertise and leadership in this field, our strategy is to maintain relationships with government and industry stakeholders to be intimately involved in the development of such standards and protocols. We will proactively engage with leading standards organizations, join working groups, sit on panels and maintain our current position of thought-leadership in the industry.
Technical Risk 1 Mineralization rates may be lower than predicted.	If the rate of mineralization (above the baseline) is less than predicted, the time needed to reach the total tonnage will increase. In mitigation, we will work with the mining company to increase the amount of tailings we can access to capture the same tonnage faster.

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?

> Brucite-rich tailings form magnesium carbonate minerals when exposed to air. Carbonate minerals are extremely stable at Earth surface conditions and can store CO2 for greater than 1,000 years. There is little uncertainty regarding the storage term. We take samples of the tailings and analyze them using thermogravimetric analysis and x-ray diffraction, techniques which identify which minerals are present in a sample. Identification of Mg-carbonate minerals indicates a durability of greater than 1,000 years.
>
> Ref: Lackner, K. S., Wendt, C. H., Butt, D. P., Joyce, E. L. & Sharp, D. H. Carbon dioxide disposal in carbonate minerals. Energy 20, 1153–1170 (1995).

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?

> Our project faces negligible physical durability risks. Mg-carbonate minerals are very stable.

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	1800
Describe how you calculated that value	In August 2022, we visited the mine site where the CDR will occur. A 0.75 km2 area was chosen for the pilot and samples from depth were collected. These samples indicate 2 wt% brucite. The 0.75 km2 area has not been resurfaced with fresh tailings in more than 5 years. Thus, we assume passive mineralization is complete and the 2 wt% brucite will remain until we begin deployment. Based on our experience, compacted tailings weigh ~225 kg per 0.15 m3 (1 m2 x 15 cm deep). 15 cm is the depth to which we expect to churn the tailings. Given these values, the total mass of available brucite is 3375 tonnes. Complete conversion of the brucite to Mg-carbonates (5:4 Mg:CO2 ratio) results in 2038 tonnes of CO2. [1.66 tonnes brucite per 1 tonne CO2, Power, I. M. et al. Carbon Mineralization: From Natural Analogues to Engineered Systems.

	Reviews in Mineralogy and Geochemistry 77, 305–360 (2013)]. However, we discount the total amount by ~10% to account for uncertainties outlined in section 4c.

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.

We have captured (and therefore permanently stored) approximately ~10kg of CO_2 as part of research conducted at UBC.

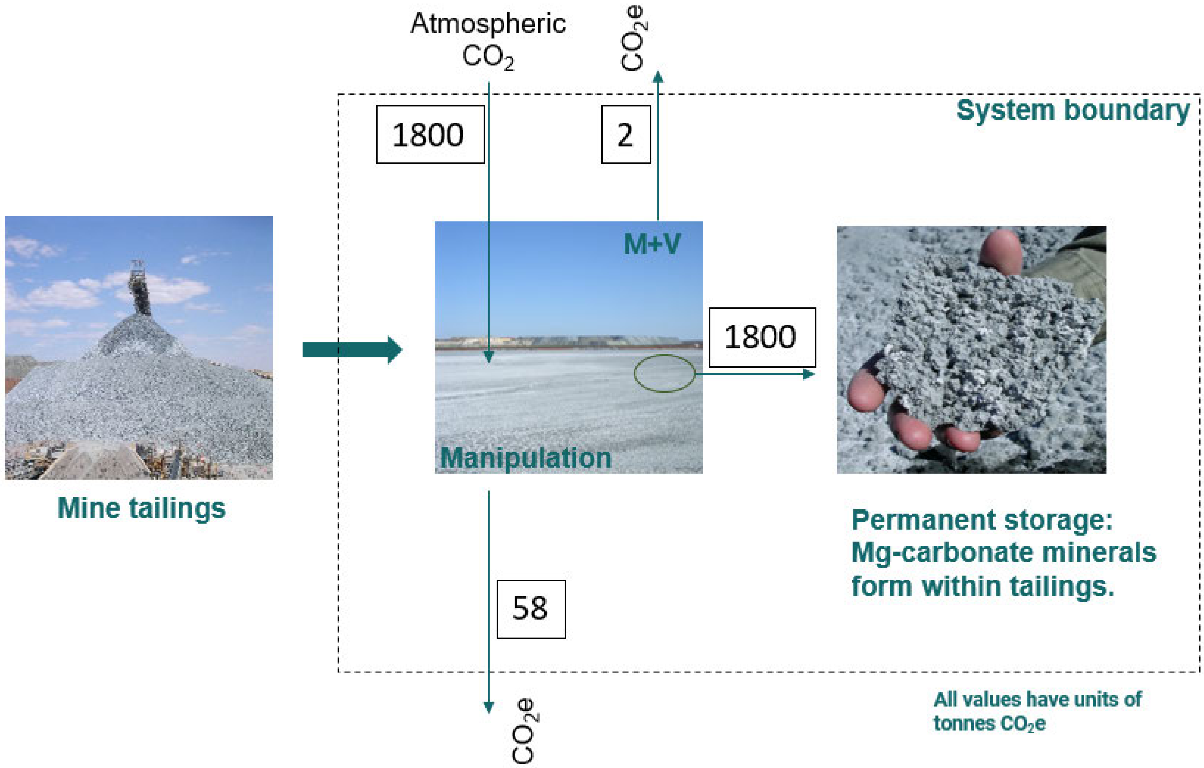
c. If applicable, list any avoided emissions that result from your project. For carbon mineralization in concrete production, for example, removal would be the CO_2 utilized in concrete production and avoided emissions would be the emissions reductions associated with traditional concrete production. 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)*	60
Emissions / removal ratio *(gross project emissions / gross CDR–must be less than one for net-negative CDR systems)*	0.03
Net CDR over the project timeline *(gross CDR - gross project emissions)*	1740

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:



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?

> Our boundaries encompass our on-site activities related to carbon removal. Because the mine is active and the tailings are a true waste output of operations we do not include any emissions associated with ongoing mining activity.

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.
Manipulation equipment	58	Emissions calculated for manipulation equipment are broken into the energy required to transit and the energy required to churn. We use vendor data for energy consumption during transit for the rovers. For churning energy, we have taken vendor data from existing industrial equipment. In both cases, the energy usage is multiplied by the size of the area (0.75 km2)

		and a churning frequency of once per week. The fuel source at the mine site is a mix of solar and natural gas. We use a 50/50 mix with the solar and NG emission factors of 0.025 kgCO2e/kWh and 0.41 kgCO2e/kWh, respectively.
Monitoring and verification equipment	2	The equipment manufacturer publishes energy consumption per system per day. We have calculated total emissions by considering our number of systems (3) and the higher end of expected operating days (350). We use the emissions intensity of stationary diesel (1.37 kg CO2e/kWh) as given by the GHG Emissions Factors Hub (U.S. EPA)

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 pre-purchase stage.

We have developed a robust method for monitoring CO2 capture and mineralization in mine tailings using three existing techniques that operate at various temporal and spatial scales. We use eddy covariance (EC) towers (measurement area of 1000s m2) and CO2 flux chambers (measurement area of 10s m2) to measure the rate of CO2 capture in real time. Agreement between the two methods increases confidence in the overall measurement of captured CO2. We will be using these two methods continuously (24/7) and they will be moved around the entire project area. The third monitoring technique involves subsampling the tailings at regular intervals (weeks to months) and measuring the increase in total inorganic carbon (TIC) content. Agreement between TIC measurements and EC and chambers increases confidence in the total amount of carbon we have captured.

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.)*

As previously explained, Mg-carbonates are extremely durable at Earth surface conditions and retain carbon in excess of 1000 years.

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.
Mineral application	Low (1-5%): for this project we rely on dissolution of the mineral brucite which has been shown in numerous studies to readily dissolve at Earth surface conditions.
Mineral weathering	Low (1-5%): our monitoring approach is such that we measure the rate of CO2 capture into the tailings in real time and then compare with the increase in the total inorganic content of the tailings.
Alkalinity loss	Negligible (<1%): The mine tailings we work with are ultrabasic and abiotic. Additional sources of acidity are negligible.
Secondary mineral formation	Negligible (<1%): The chemical composition of ultramafic mine tailings are such that the thermodynamic drive for formation of *non* Mg-carbonate (e.g., clay) mineral formation is low. This assertion is reinforced by numerous studies of weathered mine tailings that did not find abundant clays present.
Surficial carbonate precipitation	Negligible (<1%): Our data from field experiments demonstrate that Mg-carbonate precipitation is not a key control on the rate of CO2 capture from air.
Leakage	Negligible (<1%): For this project, the tailings we use can be considered a closed system, with the exception of the atmosphere (which we continuously measure). The issue of leakage will become more important for us to consider as we scale, even though mine tailings storage facilities are engineered to be closed systems with respect to surrounding groundwater.

Material	Low (1%): The tailings we use would be produced regardless of our work. The emissions related to construction of the non-consumed equipment are difficult to calculate accurately. However, an estimate can be arrived at for construction of the rovers by using their weight (400 kg) and the emissions intensity of their primary component, steel (1.85 tCO2/ 1 tSteel) = 0.74 tCO2 per rover.
Energy	Low (5%): The energy available at the mine site is a mix of natural gas and solar. We do not know, however, what percentage of each will be available during our first deployment. Our calculations indicate that going from a 50-50 mix to 100% NG would increase our emissions by 50 tCO2e.
Surficial carbonate durability	Low (1%): By continuously monitoring the flux of CO2 into the tailings and measuring increases in TIC we can account for any dissolution of Mg-carbonates.

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?

In aggregate we think 10% of the net CDR should be discounted.

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.?

We believe mineralization in mine tailings is currently a novel CDR solution, for which standards do not currently exist. Our approach to quantification contains three different sub-components that together allow us to obtain a highly accurate real-time understanding of the rate and volume of mineralization. This is necessary so we can adjust and iterate our manipulation technologies in order to maximize mineralization.

Our monitoring involves: a) Real-time monitoring of CO2 capture using eddy covariance (EC) towers (measurement area of 1000s m2) and b) CO2 flux chambers (measurement area of 10s m2) to measure the rate of CO2 capture in real time. A third monitoring technique involves c) subsampling the tailings at regular intervals (weeks to months) and measuring the increase in carbon content. Together, the three monitoring techniques provide the data necessary to robustly quantify the total amount of carbon we have captured.

With this explanation in mind, we are highly confident that this project will help advance quantification approaches for this CDR pathway.

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)?

> A standardized protocol does not yet exist for our technology. Our Chief Scientist Dr Dipple already does contribute to various efforts to create standards and protocols, and we will continue to support the creation of a protocol for mineralization. Until such a time as that protocol is developed, we will rely on our own self-developed protocol, and will naturally be open to a third-party auditor to verify delivery, and will collaborate with that auditor to ensure the methodology is effective.

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).

> $1566/tonne CO_2
>
> This price includes the uncertainty discount as identified in question 4d.

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

Component	Levelized price of net CDR for this project ($/tonne)
Capex	$1213
Opex (excluding measurement)	$336
Quantification of net removal (field measurements, modeling, etc.)[2]	$17
Third party verification and registry fees (if applicable)	NA
Total	$1566

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

[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.

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?
Rate of CO2 capture over baseline	1-5 (kg CO2/m2 yr), transient	4 (kg CO2/m2 yr), continuous	We have achieved the current values using off the shelf equipment. Optimization of our equipment as we scale will yield better performance. Future deployment of our Activation technologies show potential to increase capture rates by at least 10x
Emissions ratio	0.03 (calc)	0.02	A very low emissions ratio is possible when the energy source is renewable.
Size of tailings facility	0.75 km2	15 km2	Large storage facilities reach this size (surface area).
Duration of project deployments	1 year	25 years	Mine life can exceed 25 years. CAPEX can be spread over 5-10 years.

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

Infrastructure required to approach near autonomous rover operation.

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.).

Costs in the TEA are generally consistent with our own models. For our first deployment, certain costs related to set up and operations may be covered by our mining partner. We will, however, take over these costs over time.

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 market demand for zero-carbon critical metals. Today, only a few major nickel buyers are asking mines to get to net-zero, but we see this market pull growing quickly. .

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.

Each mining operation will have a unique set of contextual factors, not simply the geology of the deposits, or the topography of the earth's surface where the mine is located, but also the regulatory regime and stakeholders will be unique. We also know that stakeholder relationships are fundamentally critical to every mining company. They need a social license to operate. Moreover, mining companies carry significant long-term liabilities associated with their tailings storage facilities. When a mine is depleted, the company must make its TSF permanently stable and safe. Within this context, our work on any TSF will be carefully assessed by the mining company, which cannot afford to lose its social license to operate, nor can it afford to risk an environmental disaster from a TSF. Mining companies will therefore be primarily responsible for any stakeholder relationships with input and support from Carbin Minerals as warranted.

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.*

Not directly applicable. Our mining partner will be primarily responsible for stakeholder engagement. We will support those initiatives wherever possible and needed.

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, it is unlikely that the structures and dynamics described in (a) and (b) will change.
>
> That said, when our company is delivering at the megaton or gigaton scale, our profile will be significant, and our implied responsibilities with mine operation stakeholders may escalate to such an extent as to require action. With that in mind, we will invest in general audience communications from our website and social media channels. We are a values and impact-driven company, and will communicate transparently with the public and offer opportunities to receive and respond to stakeholder feedback.

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.

> Our Company acknowledges that in general the communities most vulnerable to the egregious negative effects of climate change (i.e. the poorest) are those that are responsible for the least amount of GHG emissions.
>
> We are also a young and small company. Our intention is to operate ethically so we are choosing our partners carefully. We work exclusively with mining companies with demonstrated commitments to ESG and public disclosure.

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

> It is unlikely that we will have opportunities to engage with stakeholders of the mining operation where this project will occur. Yet we hope that this CDR project will be the first step in a long but necessary journey to restore the biosphere for all its inhabitants.

[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

8. Legal and Regulatory Compliance

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

> None. Our mining partner holds regulatory compliance responsibilities. Our project will operate within that framework.

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.

> We will undergo a risk assessment process with our mining partner, which will not allow our project to operate without assurances that we will not create additional health and safety, environmental or stakeholder liabilities.

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?

> No

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.

> N/A

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.

> We will apply for tax credits with the Canadian Federal and Provincial authorities in the jurisdictions where we are incorporated. These tax credits will be claimed based on our role as an innovative technology company, not based on any carbon credits we may generate. Therefore, double counting will not be an issue for this project.

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) *(should be net volume after taking into account the uncertainty discount proposed in 4(c))*	320
Delivery window *(at what point should Frontier consider your contract complete? Should match 1(f))*	Q4 2024
Levelized Price ($/metric tonne CO_2) *(This is the price per tonne of your offer to us for the tonnage described above)*	$1566

Application Supplement: Surface Mineralization and/or Enhanced Weathering

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

Source Material and Physical Footprint

1. What source material are you using, and how do you procure it?

The source material will be brucite-bearing mine tailings from an active nickel mine. We will be allowed to work on the TSF as part of our agreement with the mining company

2. Describe the ecological impacts of obtaining your source material. Is there an existing industry that co-produces the minerals required?

Our project does not impart any ecological impacts from obtaining our source material beyond those produced by the mining operation.

3. Do you process that source mineral in any way (e.g., grinding to increase surface area)? What inputs does this processing require (e.g. water, energy)? You should have already included their associated carbon intensities in your LCA in Section 3.

We will manipulate the tailings in order to increase the surface area. This manipulation will be in the form of churning, conducted by autonomous rovers, which will run on batteries. The energy demand from the manipulation has been previously calculated.

4. Please fill out the table below regarding your project's physical footprint. If you don't know (e.g. you procure your source material from a mining company who doesn't communicate their physical footprint), indicate that in the table below.

	Land area (km^2) in 2021	**Competing/existing project area use (if applicable)**
Source material mining	0.75 km2, We operate on an existing industrial footprint and do	n/a

	not require any additional land use.	
Source material processing	Same as above	n/a
Deployment	Same as above	n/a

5. How much CDR is feasible globally per year using this approach? Please include a reference to support this potential capacity.

We estimate a large nickel mine can capture and mineralize 90,000 t/yr using the technology outlined in this application (component 2 described in 1a). Extrapolating known mines to global nickel production indicates ten such mines exist globally, yielding a total CDR capacity of 0.9 Mt/yr.

Current forecasts indicate that ultramafic mine tailings production will reach 3.5 Gt/yr by the end of this century. This volume of tailings provides feedstock necessary for our technology (components 1 and 2 described in 1a) to reach Gt/yr carbon removal.

Franks D. M., Stringer M., Torres-Cruz L. A., Baker E., Valenta R., Thygesen K., Matthews A., Howchin J. and Barrie S. (2021) Tailings facility disclosures reveal stability risks. Sci Rep 11, 5353.

Renforth P. (2019) The negative emission potential of alkaline materials. Nature Communications 10, 1401.

Wilson S. A., Harrison A. L., Dipple G. M., Power I. M., Barker S. L. L., Ulrich Mayer K., Fallon S. J., Raudsepp M. and Southam G. (2014) Offsetting of CO2 emissions by air capture in mine tailings at the Mount Keith Nickel Mine, Western Australia: Rates, controls and prospects for carbon neutral mining. International Journal of Greenhouse Gas Control 25, 121–140.

6. If you weren't proceeding with this project, what's the alternative use(s) of your source material? What factors would determine this outcome?

The source material will lie dormant in the TSF if our project does not proceed.

Human and Ecosystem Impacts, Toxicity Risk

7. What are the estimated environmental release rates of heavy metals (e.g. Cr, Ni, Pb, Hg)? Dust aerosol hazards? P loading to streams? How will this be monitored?

No additional environmental release from our processes

8. If minerals are deployed on croplands, what are the estimated effects on crop yields? Include citations to support this claim. How will actual effects be monitored?

n/a

9. How will you monitor potential impacts on organisms in your deployment environment? (e.g. health of humans working in agricultural contexts, health of intertidal species, etc.)

We will follow all health and safety protocols given to us by our mining partner.