[Aspiring Materials]

Carbon dioxide removal prepurchase application

Summer 2024

General Application

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

Public section

The content in this section (answers to questions 1(a) - (d)) will be made public on the Frontier GitHub repository after the conclusion of the 2024 summer purchase cycle. Include as much detail as possible but omit sensitive and proprietary information.

Company or organization name

Aspiring Materials

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

Christchurch, New Zealand

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

Mark Chadderton

Brief company or organization description <20 words

Aspiring Materials has revolutionized rock processing to deliver zero-carbon materials for industries to affordably achieve emissions-reduction targets and mineralize CO2.

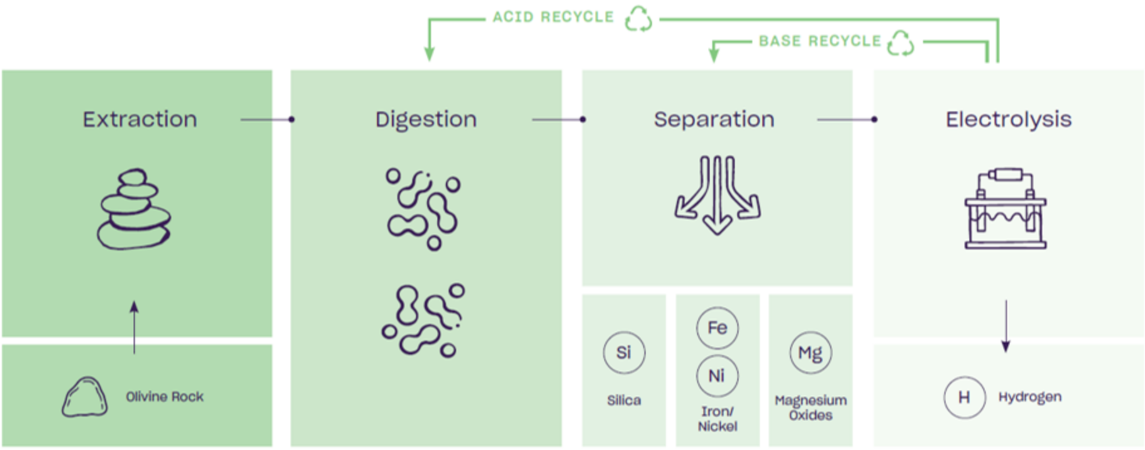
1. Public summary of proposed project[1] to Frontier

a. **Description of the CDR approach:** Describe how the proposed technology removes CO_2 from the atmosphere, including how the carbon is stored for > 1,000 years. Tell us why your system is best-in-class, and how you're differentiated from any other organization working on a similar approach. If your project addresses any of the priority innovation areas identified in the RFP, tell us how. Please include figures and system schematics and be specific, but concise. 1000-1500 words

The Aspiring Process uses ultramafic rock, like olivine, as the feedstock to our unique (patented) rock-fractionation process. This rock type has no inherent/trapped carbon (unlike Basalt) so any materials produced from the rock are carbon-free.

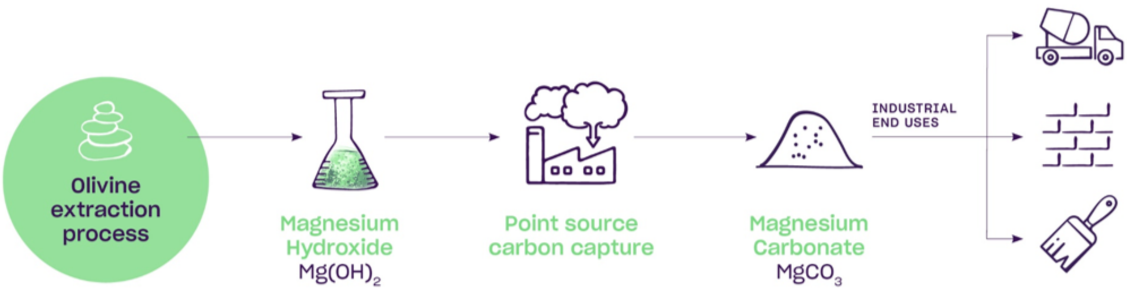
[1] We use "project" throughout this template, but the term is not intended to denote a single facility. The "project" being proposed to Frontier could include multiple facilities/locations or potentially all the CDR activities of your company.

Using one elegant process, the rock is broken into its individual mineral components, producing carbon-free iron-oxide, silica, magnesium hydroxide (Mg(OH)2), a nickel:cobalt mixed hydroxide product and hydrogen. These are materials essential for a range of industries: integral to sustainable development, climate adaptation and economic growth in steel, energy, cement and agriculture.



CDR: The patented carbon-capture technology details how the Mg(OH)2 reacts and bonds with CO2 to form a stable, solid carbonate material (MgCO3). The Mg(OH)2 is capable of sequestering up to 2/3 of its own weight in CO2. To date we have completed a series of trials which have demonstrated:

1. The capability to remove CO2 from air,
2. The capability to remove CO2 from concentrated point sources (over a range of CO2 concentrations 7%-100%), and
3. Use of a range of unit operations to achieve this: solid state contactor (moisture needed to ensure the reaction occurs), spray and bubble columns.



Mg(OH)2 Carbon mineralization testing – example of the work conducted to date:

Slurry point source CO2 capture: A slurry consisting of Aspiring Materials' Mg(OH)2 is dissolved into water to a target concentration at ambient pressure and temperature. CO2 gas at 99.9% purity was bubbled into the solution at 5 SCFM. The solutions pH changes over time as the CO2 is bubbling through the solution. The decrease in pH correlates with an increase of carbonates present. Aspiring has been able to develop reaction kinetic data for different solution and CO2 concentrations – and these have correlated well with historical data.

Verification: The slurry from the test was dried and put into a thermogravimetric analyser (TGA). The TGA measurements of the magnesium carbonate produced from the Aspiring Mg(OH)2 were compared to the TGA measurements of a standard hydro-magnesite (MgCO3.H2Ox) sample. The similar energy losses as the same temperatures indicates the two samples are both hydromagnesite, with our sample being a slightly different hydrated form. The presence of carbonates was also confirmed using XRD. These tests verify the use of $Mg(OH)_2$ in a slurry as a method of point-source CO_2 capture.

From this work we have been able to establish fundamental reaction kinetic data and are scaling the design of a range of carbon removal units to meet the needs of industry, or a broader DAC play.

Captured emissions can be quantified simply and accurately through laboratory analysis and a mass balance based on the remaining/residual magnesium carbonate (and input $Mg(OH)_2$) – similar to that carried out in the previous laboratory work. That makes this a transparent, verifiable method of carbon capture. Industrial operations using this carbon capture method can have absolute certainty in their emissions reductions.

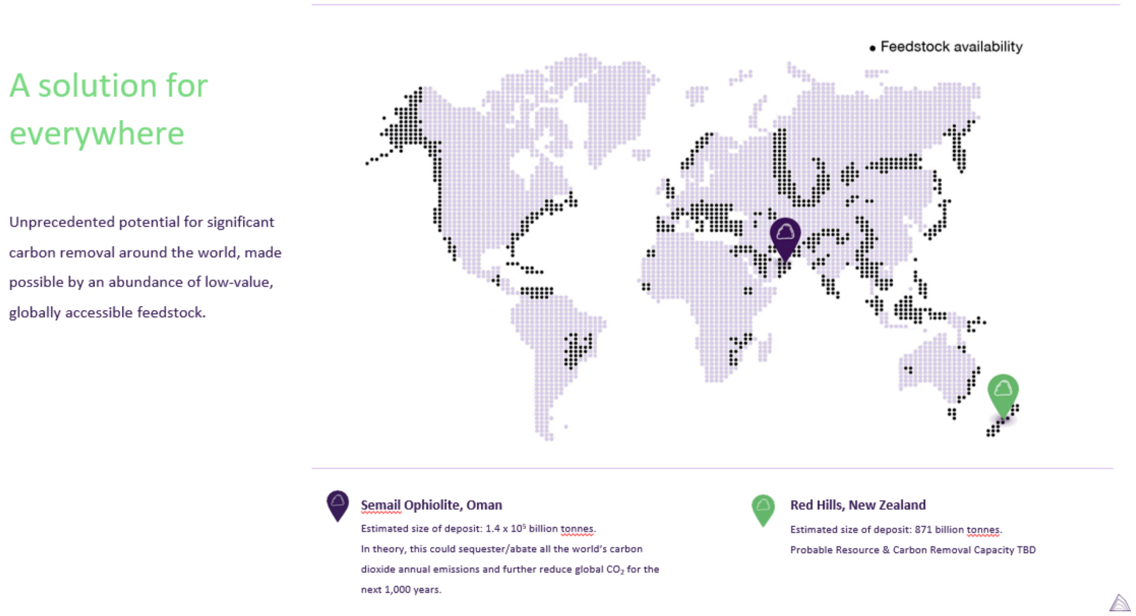
Storage and permanence: Carbon is locked away in a stable magnesium carbonate and prevented from entering the global environment – outcomes that few other processes can achieve in a sustainable manner. $MgCO_3$ is stable across all ambient / typical pH ranges and temperatures – only in extreme circumstances (pH <1.0, temperatures >1200oC) will the CO_2 be released – which guarantees the permanence of the removal if the $MgCO_3$ is put into storage. However, Aspiring see's greater value in using the resultant $MgCO_3$ as an industrial product, where it can be used in cement (up to 5%), in building materials, coatings etc.

Priority innovation areas: The Aspiring Proposal provides a science based, quantifiable pathway to carbon removal – but is more than that:

Global Emission Reduction through offsets: Offsets are generated when the clean/zero emissions products from the Aspiring process replace products being manufactured using standard industrial processes and fossil fuels. Of particular significance are the emissions from existing MgO and Ni production, which can range from 2.5 – 4tCO2-e and 8 – 32tCO2-e respectively. The Aspiring process could significantly reduce total emissions if deployed globally, which is achievable at the megaton scale.

Additional revenue streams: In the process of extracting magnesium for carbon capture, Aspiring's process simultaneously yields iron (US$120/t), silica (US$150+/t), nickel:cobalt (>>US$10k/t), and hydrogen with no entrained CO_2. These low-carbon products can replace carbon-intensive products within essential industries such as cement, steel, batteries, agriculture, therefore playing a role in the green transition. On top of the sale of magnesium for carbon capture the sale of these byproducts can generate substantial revenue, making it possible to bring the cost of CDR <<$50/t. By contrast, our competitors' revenue is derived from the capture of CO_2 only, the price for which is volatile and may not be sustainable.

APAC/Global Applicability: Aspiring has established itself in New Zealand, and has an incorporated subsidiary in the US. We have also established partnerships with a number of entities as we see our solution (like our feedstock) going global. This is illustrated by the feedstock map below. Aspiring has trialled material from different locations to ensure the technology can be deployed in multiple locations.



Local environmental and economic co-benefits: MgO Market Case Study: New Zealand - The agricultural sector is the largest user of MgO in New Zealand, using up to 50 ktpa. Less magnesium (Mg) and more calcium (Ca) in pasture plants increases the risk of clinical hypomagnesaemia (grass staggers) in lactating dairy and beef cows. These effects are greatest in late winter and spring, coinciding with late pregnancy and early lactation. To prevent this farmers apply MgO (typically in powder form) to feed over the spring period. This creates a short-duration, high-demand period for the product, which has previously strained supply chains. Additional testing is typically required for heavy metals as the vast majority of the product comes from kilns fired using coal, which can contain arsenic, mercury, lead, and cadmium. The Aspiring process can provide a clean (no heavy metals), zero emission replacement that is better for the farmer, the livestock, the end consumer and the environment (up to 250ktCO2e/yr).

Point of difference: Aspiring has a patented process that enables the production of near zero-emissions products that have direct market applicability and value. The direct mineralisation of CO2 eliminates the need for energy intense DAC solutions, and can be applied across a range of brown-field industrial facilities (with minimal CAPEX and OPEX). This will be demonstrated at a facility in NZ 4Q24 – where flue-gases will be mineralised using our patented CDR process.

a. **Project objectives:** What are you trying to build? Discuss location(s) and scale. What is the current cost breakdown, and what needs to happen for your CDR solution to approach Frontier's cost and scale criteria?[2] What is your approach to quantifying the carbon removed? Please include figures and system schematics and be specific, but concise. 1000-1500 words

Purpose of the Pilot Plant Project – as a lead in to larger scale CDR: Aspiring is part-way through the first stage of our pilot plant build in Christchurch, New Zealand, which will establish how to extract mineral products from Olivine rock at scale, undertake CDR at scale and better understand how the current lab-scale reactions can be sized up to a commercial scale. To show this, the plant must prove that the process can be

[2] We're looking for approaches that can reach climate-relevant scale (about 0.5 Gt CDR/year at $100/ton). We will consider approaches that don't quite meet this bar if they perform well against our other criteria, can enable the removal of hundreds of millions of tons, are otherwise compelling enough to be part of the global portfolio of climate solutions.

operated in batch (250kg/d) & continuous (1t/d) modes. Initially the facility will comprise one process train (where a "train" comprises all the unit operations associated with a single product separation stage) utilising a series of reactors and recycling seed material between stages. Future expansion will add additional, identical process trains in series in order to simultaneously perform the multiple product separations required (i.e. silica, iron/nickel/cobalt and magnesium hydroxide).

Aspiring Materials will use operational data from the pilot plant to refine our modelled mass and energy flows for the commercial scale facility, and inform choices on materials selection, utility selection, equipment sizing and operational controls. The pilot plant will also be used for demonstration of the process, manufacturing Mg(OH)2 for CDR and the production of other materials for commercial trials.

Stage 1 Plant Design: The plant has been designed to be configurable and customizable to allow for testing and trialing different operations/units/feedstocks/configurations. Initial plant design, which is now complete, has focus on the digestion/precipitation/separation equipment with the intention that the electrolysis equipment can plug into the provided gap following this first stage of development. This means that initial plant operation will require the raw chemicals that will be eventually generated by electrolysis to be supplied in bulk form.

The design has five overarching objectives:

1. Safety – the facility must operate in a safe manner, minimizing risk to operational personnel, the community and the environment.

2. Operability – the process must be easy to operate (start, ramp-up/down, control, stop and clean), whilst finding a suitable balance between automation and human interaction.

3. Reliability & Repeatability – the process must operate reliably to ensure steady-state operation, that suitable "hold-points" can be achieved, and quality operating data (limited noise) can be captured.

4. Product Quality – the process must be able to produce high quality, representative products for testing and commercial trials (e.g. Mg(OH)2 for PepsiCo trial).It must also ensure high conversion of Mg(OH)2 to the carbonated product.

5. Data Gathering & Analysis – will play a pivotal role in the successful development, optimization, and scaling of the process, and illustrating the commerciality of the aspiring process.

These objectives form the foundation for the process control strategy for the pilot plant, that has in turn been built into the facility design.

Aspiring has a fully detailed capital budget for the batch and continuous process, which will be in the order of $4m by the entire plant is constructed, commissioned & fully operational. The major costs include the vessels, ancillary plant, I/E & Mechanical scopes and in the continuous operating phase the electrolysis plant (5kW).

Frontiers Target: Our modelling (considering local and international parameters) shows that as the project scales costs will come down. It also means that the co-poducts can be placed in the market to generate cash flow – which provides a genuine pathway to bring the cost of CDR to below $100/tCO2. By reducing the cost of capital & project financing it should be possible to generate significant returns – making this more attractive than projects purely dependent on the sale of carbon credits for revenue.

The clean feedstock means no CO2 is emitted during the manufacturing process, unlike project founded on basalt which releases varying amounts of entrapped CO2 as it breaks down. The wide distribution of olivine makes establishing product possible across the globe, minimising supply-chains and maximising the availability of this decarbonising technology to every corner of the globe.

By producing large quantities of Mg(OH)2 it is possible to quickly and efficiently capture CO2 – which reacts to form a stable magnesium carbonate. This locks the CO2 away in a mineral that is stable and will last for thousands of years. The efficacy of the CDR process developed by Aspiring can be quickly demonstrated (on a continuous basis) through simple laboratory analysis of the Mg(OH)2 before being introduced to the point-source contactor, and the resultant carbonated product. The % conversion allows for the calculation of the CO2 captured and removed, and does not need further monitor/or inference from other field data.

b. **Risks:** What are the biggest risks and how will you mitigate those? Include technical, project execution, measurement, reporting and verification (MRV), ecosystem, financial, and any other risks. 500-1000 words

Primary Risk: Process Design.
As with all FOAK process developments there are technical risks – especially as we move out of the lab. To minimise this risk we have done extensive testing in the lab to map out the key operating parameters and conditions – which have been incorporated into the plant design.
The plant design was undertaken in a collaboration between BECA's Engineering (New Zealand's leading engineering firm – the lead engineer has 30yrs experience in hydrometallurgical processes analogous to the Aspiring process) and Aspiring's engineering team. A full series of design reviews, HAZOPs and 3rd party reviews (conducted by independent engineering firms – DETA and Greenfern Dynmaics) were conducted as part of the design process.

Secondary Risks: Plant Operations
As we move to operate the plant we have to anticipate problems (as with all scaling activities). As such we have deliberately sized equipment to allow for a gradual ramp-up of scale – such that we can move in 2x,3x increments. This makes the process easier to manage and allows the operations team more time to analyse changes and respond accordingly.
The plant design incorporates significant additional instrumentation – which will greatly enhance the quantity of data being gathered. This intern improves fault finding and process troubleshooting & ensures we don't get bogged down when things don't necessarily go as planned.

Financial Risk: Aspiring has had strong support from investors, Breakthrough Energy (through the fellowship), government and secondary contracts. In the next 6months the company is targeting a US$7m equity raise (syndicated), but has also secured additional funding of US$500k (SAFE) and US$300k (contracted work), and will also look to secure US$500k (government grant). This will meet the costs of the pilot facility and give a runway well into 2025 – so the equity raise will become important in 2025 to ensure full plant capacity can be achieved.

Electrolysis Plant: Aspiring has identified three potential technology partners for the next stage of the scale-up, and have recently commissioned a 300W unit (which is out-performing expectations). The next unit will be 5kW in size, so true performance at the next scale is unknown and could negatively influence the overall economics/energy efficiency. The primary objective of this development stage is to ensure reliable operation, identify the safe operating envelop and demonstrate the plant operating in a fully closed loop state. The performance of the electrolysis plant is key to this.

c. **Proposed offer to Frontier:** Please list proposed CDR volume, delivery timeline and price below. If you are selected for a Frontier prepurchase, this table will form the basis of contract discussions.

Proposed CDR over the project lifetime (tons) *(should be net volume after taking into account the uncertainty discount proposed in 5c)*	63.2
Delivery window *(at what point should Frontier consider your contract complete? Should match 2f)*	4Q2026
Levelized cost (\$/ton CO_2) *(This is the cost per ton for the project tonnage described above, and should match 6d)*	\$25755
Levelized price (\$/ton CO_2)[3] *(This is the price per ton of your offer to us for the tonnage described above)*	\$25755

[3] This does not need to exactly match the cost calculated for "This Project" in the TEA spreadsheet (e.g., it's expected to include a margin and reflect reductions from co-product revenue if applicable).