Varaha

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

Varaha ClimateAg Private Limited

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

Gurgaon, India

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

Ms. Ankita Garg

Brief company or organization description <20 words

Varaha develops and scales high-quality carbon removal projects such as Enhanced Rock Weathering (ERW) in India and other smallholder farming economies.

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

[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.

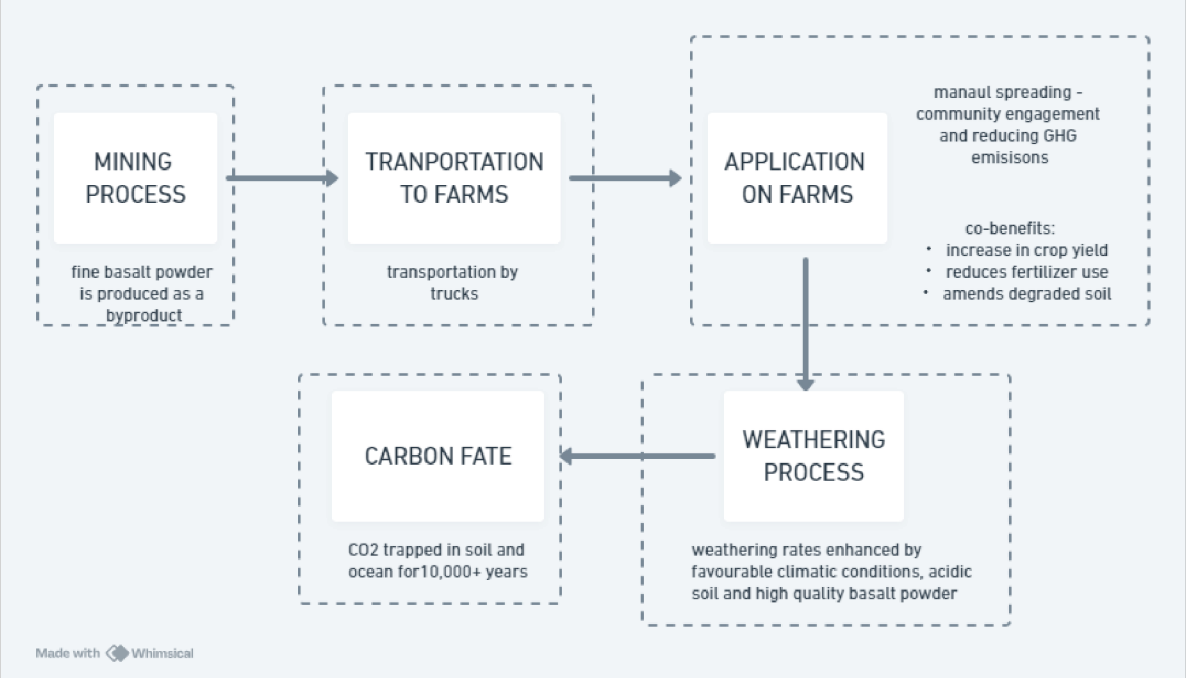
priority innovation areas identified in the RFP, tell us how. Please include figures and system schematics and be specific, but concise. 1000-1500 words

Enhanced Rock Weathering

Enhanced rock weathering (ERW) is a technique that mitigates climate change by accelerating the natural process of mineral weathering. This involves applying finely ground basalt to agricultural fields to increase the rate at which the minerals react with atmospheric CO_2, converting it into dissolved bicarbonates. These bicarbonates can be sequestered as stable carbon sinks in soils or transported to the oceans, where they lock away CO_2 permanently. Additionally, ERW improves soil fertility by providing essential nutrients such as calcium, magnesium and potassium, benefiting agricultural productivity and ecosystem health. Enhanced weathering offers a scalable solution for significant atmospheric CO_2 sequestration and climate change mitigation (e.g., Hartmann et al., 2013; Campbell et al., 2022)

Project Overview

Varaha's project facilitates enhanced rock weathering (ERW) by applying finely crushed basalt rock powder (**particle size <150 microns**) to tropical acidic agricultural soils. This method effectively sequesters CO_2, ensuring its storage in a stable form for over 10,000 years. The basalt rock powder is sourced from a quarry in Khargone, Deccan Traps, India, where it is produced as a byproduct of the construction industry. Given small particle size, additional grinding is unnecessary. It is subsequently transported to nearby agricultural fields for manual application. Regular sampling and monitoring are conducted to assess weathering progress and optimize the process. Varaha has also set up a network of soil sensors, weather stations, and lysimeters to collect data at a frequency of every few hours, which are highly valuable for geochemical model development.



In the first instance of the project, we spread 6k tons of basalt powder in the fields. This year we plan to spread 244k more tons of basalt powder onto the fields.

Differentiation from other organizations in ERW

- A strategic partnership that enables access to <150 micron basalt rock powder at zero upfront cost:

Leveraging our existing reach and experience with smallholders, we have established a strategic partnership with one of the largest basalt rock quarries in India. This quarry is located under 100 km from farms already engaged on Varaha projects. Varaha has secured exclusive access to basalt rock powder with a particle size <150 microns, produced as a byproduct of the quarry's multiple crushing stages for mineral sand in the construction industry. The quarry generates over 100,000 tons of basalt powder per year, which can be used to cover approximately 12,000 acres of farmland annually. Additionally, we are in ongoing negotiations with four other basalt quarries in India. This would further increase the project's potential to 370,000 metric tons of rock powder this year, capable of covering 46,000 acres of land.

Importantly, Varaha has negotiated a distinct partnership model in which the quarry supplies basalt rock to the project at no upfront cost, in exchange for a revenue-share once verified credits are generated and sold. This contributes to what we believe to be the lowest cost per ton ERW project globally.

- Existing scale and relationships:

Varaha's current operations in projects like Agroforestry and Biochar cover over 600,000 audited acres and involve more than 100,000 smallholders. We have achieved this scale with the support of 100+ implementation partners, including the Syngenta Foundation, Terviva, IPL Biologicals, and numerous NGOs. Our projects are supported by our end-to-end MRV platform (developed in-house by our software engineering team), which can define farm boundaries, onboard smallholders within approximately two weeks, trace the movement and spreading of rock powder, and conduct sampling. Varaha's MRV platform is customized to farmers and implementation partners and incorporates the use of remote sensing-based machine learning models.

- "Measure and measure" MRV approach:

We are implementing a "measure and measure" MRV approach underpinned by the Isometric v1.0 protocol to quantify the amount of permanently removed carbon from in-field measurements of soils, soil pore waters and gaseous phases. These detailed measurements allow us to precisely determine the amount of carbon permanently removed from the atmosphere, ensuring reliable and verifiable carbon sequestration (see Section 5).

- Net Negativity and Sustainable Sourcing:

This project adopts a "net negativity" approach. Varaha uses finely crushed basalt, a byproduct of quarrying for mineral sand, eliminating the need for additional crushing energy. The quarry's proximity to farmlands (within 100 km) reduces transportation emissions. Additionally, manual labor is used to spread the basalt powder on farmlands, avoiding the energy consumption associated with machinery. This holistic method ensures minimal energy use and lower emissions throughout the process.

- Community Involvement:

We employ local farmers to spread the basalt rock powder onto the farmlands. Basalt rock powder is transported from the quarry to the farmlands in 44-ton batches, then loaded onto 5.5-ton trolleys using a backhoe loader. 22 local farmers were involved in different parts of the logistical operations for successful execution. Thus, the project creates additional streams of income for farmers and fosters a sense of community involvement in the process.

- Evidence of Farmer Income Increase and Climate Adaptation:

The use of basalt powder generates both short-term and multi-year increased farmer incomes due to increased productivity (owing to balanced soil pH and increased soil organic carbon) and reduced input costs.

The methodology established by Isometric requires maintaining control plots (i.e. plots that are monitored but not treated) alongside plots where basalt rock powder is applied. Before finalizing plot boundaries, we carefully assess the heterogeneity of the project area, taking into account variations in soil characteristics, topography, and microclimate. This approach allows us to strategically locate control and treatment plots to ensure they are representative of the overall project area and can be used to accurately extrapolate findings to a larger deployment zone.

Using control plots also enables Varaha to turn smallholders to ERW advocates, prompting others in their communities to join and accelerate the project scale-up. We intend to collaborate with academic

partners to publish these results, aiming to influence the transition of smallholders towards adopting basalt rock powder as a soil amendment beyond the scope of Varaha's projects.

Key focus areas identified in the RFP

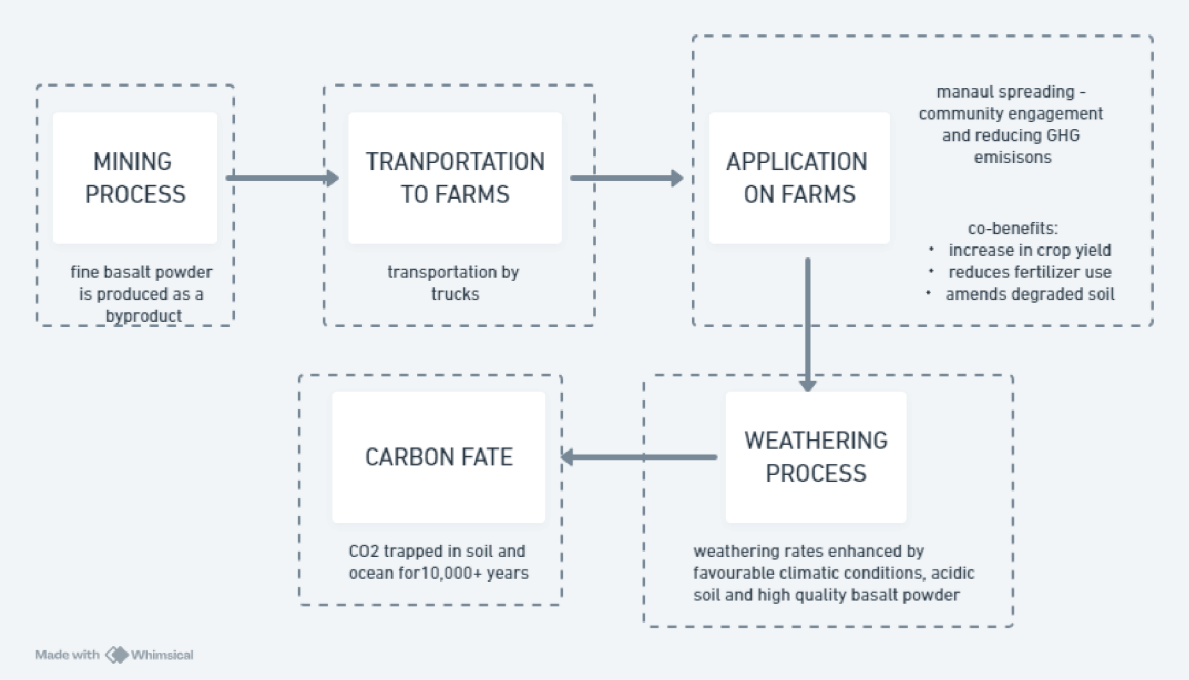
- Industrial integration: We are achieving industrial integration by collaborating in a revenue-sharing model with an existing quarry. As part of this collaboration, we are utilizing the byproduct of basalt rock powder, which is produced as a byproduct of the quarry's multiple crushing operations for the construction industry.
- Underrepresented geographies: Our project focuses on underrepresented geographies. Traditionally, the Global South has received limited funding for Carbon Dioxide Removal (CDR) initiatives due to the high costs involved. However, we believe that working with smallholders on ERW offers a scalable solution uniquely suited to the Global South, beginning in India. Varaha is also one of the few companies in the space founded by a woman from the Global South, dedicated to making a difference in this region.
- Additional revenue sources: We aim to secure a premium for the crops grown on farms managed sustainably through the application of basalt rock powder on the farmlands.
- Environment co-benefits: This approach provides several co-benefits, including a reduction in the use of chemical fertilizers, carbon removal through Enhanced Rock Weathering (ERW), and an increase in farmers' net income from higher yields and reduced costs.
- EW innovation: Varaha has established a deep partnership with a quarry in the Deccan Traps of India, to procure the basalt rock powder (<150 microns) at zero upfront cost under a revenue-sharing agreement. This partnership allows us to offer the lowest-cost permanent carbon removal project globally, with the cost of a credit projected to be approximately $204 per tCO_2 this year. Eventually, we believe our model can deploy ERW for $86 per tCO_2, once our project scales to 200,000+ tons of rock powder deployed annually.

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

We are pioneering an Enhanced Rock Weathering (ERW) solution aimed at achieving the lowest operational costs globally. Our operations begin by acquiring basalt powder from local quarries without any initial expenditure. This finely crushed basalt is transported to acidic agricultural fields located within 100 kilometers of the quarry. Our focus area is the Deccan traps, specifically in the district of Khargone, Madhya Pradesh, India. This strategic location allows us to efficiently deploy our

[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.

solution to enhance soil health and mitigate climate impacts

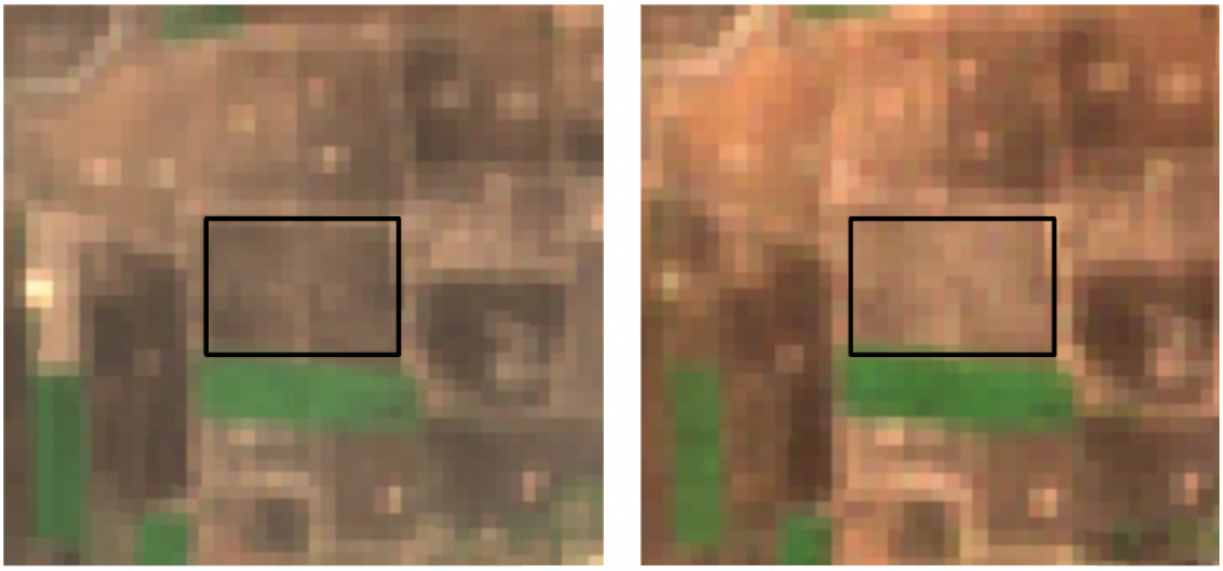


Below is the KML file of the farms wherein the ERW application has taken place successfully, with all details captured through an in-house track and trace mechanism at each smallholder farm level.

https://drive.google.com/file/d/1o4kxKDcnYjeTqAl81w-k6BqGb59K9U2t/view?usp=drive_link

Mineral application is also confirmed via the use of remote sensing technology, for which Varaha built models using satellite data. This allows for another layer of traceability and validation. Below are the sample satellite images of farms before and after application of farms.
In case of the applied basalt farms, the images post application illustrate a grey coloured pixels that matches with the shade of the farm on the ground post application

Model used: Catboost (ML)
Satellite data: Sentinel 2



Pre-application | Post application

Costing

The current cost per credit is USD 204, with 80% allocated to project Opex and Capex, and 20% retained as a margin for Varaha. As we scale to 200,000+ tons of basalt powder (which can generate 52,000 tons of CO_2 eq. credits), we estimate the cost of the credit to USD 86 per ton in lieu of economies of scale.

Scale

We plan to expand to a climate-relevant scale and generate 20 Mn+ tons of credits annually beyond 2030 by spreading 100Mn+ tonnes of basalt powder in India and other geographies that Varaha already has presence in, across South Asia and Sub-Saharan Africa.

1. We plan to procure the basalt powder for the same from quarries. We have already struck a partnership with quarries that can supply 500,000 tons of basalt powder every year and are in conversation with 20 additional quarries. We will partner with 100s quarries to enable such scale and believe that we can leverage our existing staff, partnerships, experience, to achieve the same.
2. We already have >500,000 hectares of agricultural land onboarded with us for our Regenerative Agriculture project and aim to onboard 50 million hectares of agricultural land by 2030. Apart from that, we have existing contractual partnerships with more than 120 agribusinesses, NGOs, farmer cooperatives, which we will leverage to expand rapidly.

Approach

We are implementing a “measure and measure” MRV approach underpinned by the Isometric v1.0 protocol to quantify the amount of permanently removed carbon from in-field measurements of soils, soil pore waters and gaseous phases. These detailed measurements allow us to precisely determine the amount of carbon permanently removed from the atmosphere, ensuring reliable and verifiable carbon sequestration (see Section 5).

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

MRV

There are inherent challenges with measuring a weathering signal in the field, however we are operating under optimal weathering conditions (tropical acidic soils, high total annual precipitation) and fast weathering feedstock (high proportions of fast weathering mineral such as pyroxene and plagioclase, particle size < 150 micron), so we anticipate being able to quantify that weathering is taking place at our MRV sites, especially within our 'research' treatment plots, that have a higher application density of ~100t/ha, and higher sampling density and frequency. Further, we are continually innovating with the scientific approaches we are using, both in the field, and using remote sensing techniques in order to be able to accurately quantify CDR. We are monitoring soil processes down to 30 cm and 1 m depth In our deployment and research MRV sites respectively. This will allow us to investigate the time lag between weathering reactions in the soils and export of weathering products through the watersheds (Kanzaki et al., 2024). In addition to monitoring bicarbonate and soil inorganic carbon, we are monitoring other forms of carbon (such as soil organic carbon (SOC)) as well as GHGs such as methane, and CO_2 and N_2O at our research MRV sites in order to be able to have a holistic view of the net climate benefits within the system.

Field heterogeneity

Heterogeneity in soils can lead to significant variability in feedstock weathering rates, as well as rates of transport of weathering products through soil. To capture this heterogeneity, we have MRV sites containing both control and treatment plots that are representative of the deployment area, totaling 5% of the project area. At these sites, we measure soils, soil pore waters. Additionally, we have one high-resolution research plot every 1,000 hectares with a high application density of ~100 t/ha. At these research plots, soils, soil pore waters, and gaseous phases are measured more frequently. We also have a local weather station installed at these plots.

Downstream losses

Accurately measuring and reporting CO_2 sequestration, and quantifying downstream losses in rivers and oceans is challenging (Zhang et al., 2024). In order to further the field of ERW, particularly with respect to calibrating and validating weathering models, we will be making our field trial data open source. We will continue collaborating with Cascade Climate, Isometric, and other academic partners to build on their work in developing standards and methodologies, aiming to enhance scientific rigor.

Quantification of in-field weathering rates

A potential geochemical risk is that field weathering rates are slower than laboratory weathering rates. We will monitor in-field weathering rates at our MRV sites in order to accurately quantify CO_2 sequestration. Additionally, we will be monitoring any feedstock heterogeneity via routine quality

control sampling of our feedstock every 5000 tons of rock.

Ecosystem risks:

Basalt weathering can release potentially toxic elements (PTEs) like nickel, chromium and copper, contaminating soil, water, and crops (Dupla et al., 2023). To mitigate this risk, we screen feedstock materials using ICP-MS to ensure PTE concentrations are below recommended limits and monitor PTEs at our MRV sites, as well as deployment sites with high natural PTE background concentrations. In watersheds with large-scale basalt deployment, we will also monitor for potential contamination and ecosystem effects.

Although basalts generally have low levels of asbestiform or radioactive minerals, we will monitor these during routine feedstock characterization using XRD and ICP-MS.

To mitigate any aerosol risks from spreading <150 micron basalt, we will ensure workers use protective equipment and apply basalt during low wind conditions to minimize dispersion.

Natural Factors:

Natural variability in rainfall and temperature can affect the weathering process and overall project outcomes. Through the collection of empirical data at our weather stations installed at our MRV sites, along with gridded data from nearby meteorological stations, can provide detailed information on variations in climate parameters. This data helps us understand the influence of local climate conditions on weathering rate and CDR.

Impact on Crops:

We are investigating the role of enhanced weathering of basalt on cotton crop growth and yield through a combination of in-situ measurements at our MRV site, and remote sensing techniques in our deployment area to monitor and mitigate any potentially adverse impacts, and to quantify any crop yield improvements.

Access to Feedstock:

A potential risk is fluctuations in the construction industry's demand, which could impact the production of basalt byproducts despite the abundance of basalt available. To mitigate this risk, we will expand to multiple countries, increase the number of quarries to the hundreds, and decentralize the risk profile of our projects to ensure a continuous and reliable supply.

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

Proposed CDR over the project lifetime (tons) *(should be net volume after taking into account the uncertainty discount proposed in 5c)*	2,444 tons (From the phased deployment of 10,000 tons of which 6,000 tons has already been spread on the ground)

Delivery window *(at what point should Frontier consider your contract complete? Should match 2f)*	December 2024 to December 2026
Levelized cost ($/ton CO_2) *(This is the cost per ton for the project tonnage described above, and should match 6d)*	164
Levelized price ($/ton CO_2)[3] *(This is the price per ton of your offer to us for the tonnage described above)*	204 (To reduce to $ 86 / ton at TRL9; expect to reach there by end of 2025)

[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).