Mati Carbon Removals

Carbon dioxide removal prepurchase application

Summer 2023

General Application

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

Public section

The content in this section (answers to questions 1(a) - (d)) will be made public on the Frontier GitHub repository after the conclusion of the 2023 summer purchase cycle. Include as much detail as possible but omit sensitive proprietary information.

Company or organization name

Mati Carbon Removals

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

Houston TX

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

Shantanu Agarwal

Brief company or organization description <20 words

Carbon removal with basalt based enhanced weathering in Indian rice paddy small-holder farms enabled by robust MRV and tracking technology.

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

[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.

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

Mati is a public-benefit corporation that is an affiliate of Swaniti initiative, a US non-profit 501(c)(3) entity. We are scaling basalt based Enhanced Weathering (EW) in Indian rice paddy small-holder farms to capture and sequester carbon. Our program is uniquely positioned to establish and enable EW with tools and technologies in small-holder farming setting across the global south.

Scientific description of CDR approach:
Enhanced Weathering (EW) is the practice of applying crushed rocks and minerals to agricultural land. When the gradual rock dissolution or "weathering" occurs, alkaline minerals containing cations such as calcium and magnesium (Ca^{2+} and Mg^{2+}) that comprise basalt act as a pH amendment to remediate acidic soil on farms (Beerling et al, 2020). In addition to balancing the pH of the soil, EW can remove carbon dioxide from the atmosphere and sequester carbon for geological timescales (NAS, 2019). CO_2 gas in the soil is converted to dissolved bicarbonate (HCO_3^-) in groundwater by weathering reactions involving carbonic acid. Carbonic acid is formed naturally in soils by plant respiration. Conversion of either of these dissolved carbon sources to bicarbonate draws CO_2 down from the atmosphere (Zeebe et al 2001).

As EW progresses, the newly dissolved bicarbonate in groundwater is inhibited from degassing back into the atmosphere as CO_2. Conversion of the dissolved carbon back to the gas phase is arrested because the bicarbonate ions (HCO_3^-) must balance the positive charge of the heterovalent cations (Ca^{2+}, Mg^{2+}, Na^+, etc.) released by the weathering basalt. As the positively charged cations percolate through the soil column with groundwater, bicarbonate ions continue to maintain the charge balance. The bicarbonate may then percolate into streams and rivers, from where it is delivered to the oceans. Carbon may reside in groundwater within the soil column as bicarbonate on timescales from decades to centuries. The eventual precipitation of bicarbonate as calcium carbonate in deep aquifers or after transport to the ocean stably sequesters carbon for >10,000 years (e.g. Berner, Lasaga & Garrels, 1983, Renforth and Henderson 2017, Kanzaki et al 2023).

A unique opportunity to unlock Indian rice paddies for EW projects:
In the current project, finely pulverized basalt is applied to rice paddies in the Indian state of Chhattisgarh. The style of farming rice paddies in India is different from industrial agriculture in the United States in several key respects. Most importantly, before rice transplantation, the paddies are completely flooded and vigorously tilled. This mode of wet-tilling results in a soil horizon that is much more homogeneous than in typical row crop farming. In Mati's basalt application protocol, the crushed rock is applied prior to homogenization of the topsoil in the rice paddy. During the vigorous wet-tilling procedure, Mati's basalt is mixed into the soil more evenly and completely than is possible for tilled row crops. After rice transplantation, the roots take hold in the wet-tilled soil containing the basalt amendment. This is extremely favorable for basalt weathering because CO_2 and carbonic acid concentrations are elevated where the crop roots respire. Therefore, the wet-tilling procedure in rice farming accelerates the EW reactions that convert CO_2 to bicarbonate (Deng et al 2023).

Beyond the tilling practices that are advantageous for EW and MRV, the water-intensive mode of rice farming and warm temperatures (Chhattisgarh has an average temperature of 82ºF) accelerate the water-rock reactions, making rice paddies in the region an ideal setting for the deployment of EW. The proximity of our deployments to Deccan Trap basalt deposits — one of the largest, easily accessible basalt formations in the world — allows for cheap, low-emission transport of basalt feedstock. Our basalt feedstock is sourced from Northwest Chhattisgarh, which lies an average of tens of kilometers away from most of our current deployments. Our partnered quarries produce significant basalt aggregates for construction. In the process of comminution for aggregate production, significant waste fines are produced (8 to 15 percent by weight). These fines are considered waste products because they are of limited commercial value. Mati is unique in its ability to leverage proximal basalt sourcing for crop amendments, manage the local supply chain, and farmer relations in the region of Chhattisgarh. Additionally, Mati is a deployment division of the Swaniti Initiative, which has a decade-long prior working relationship with local governments in India.

Mati's deployment strategy in Indian rice paddies directly addresses several priority innovation areas for EW identified in the Frontier RFP:
Mati can effectively leverage previous working relationships of Swaniti Initiative with local farmers and government

bodies in India, to scale EW rapidly. Mati obtains locally sourced basalt waste ideal for EW at a minimal cost while simultaneously minimizing emissions associated with rock transportation. The hot and humid environment and water intensive rice paddy farming practices provide a distinct new geographic setting for field trials where the EW kinetics will be enhanced at no additional penalty to net emissions. To this point, the field of EW has been biased towards engaging larger industrial land managers. However, Mati believes there is a need for CDR to begin engaging smaller, marginal farmers. Globally, 80% of farmers are considered "marginal farmers". Often, marginal farmers are unable to get fertilizers due to availability or affordability. Mati's project seeks to help with crop amendments that improve crop productivity and reduced pestilence at no additional cost to marginal farmers. Along with providing crop amendments, Mati also shares part of the CDR value as financial incentives to these sustenance farmers to help improve their economic security. The overall impact of Mati intervention, results in a significant increase in total earnings for these marginal farmers. This creates a unique pathway of providing climate justice from CDR economics to some of the most climate vulnerable farmers in the global south.

Mati is building uniquely robust and accurate Monitoring Reporting and Verification (MRV) tools to ensure the highest quality permanent carbon removal and storage:
While EW is a promising path to CDR at the gigaton scale, quantifying the amount of CO_2 drawdown at deployment sites remains a significant challenge for EW suppliers. To date, the most transparent and reliable methods for quantifying the potential removal of CO_2 from EW deployments are based on coupling direct measurements of soil composition in the field with accompanying modeling exercises for validation and verification (Puro EW protocol 2023). Mati tracks the abundance of mineral bound cations such as Ca^{2+} and Mg^{2+} and compares their relative abundance to minerals containing trace metals that are far less soluble and thus not as susceptible to weathering. At Mati, we believe that rice paddies could be an ideal natural setting to field test the MRV method proposed in this study: A new soil-based approach for empirical monitoring of enhanced rock weathering rates.

Mati's tech-stack also includes considerations for the downstream fate of the mineralized carbon after the initial point of capture on agricultural land where EW is deployed. This includes ongoing monitoring of river waters near EW deployment areas, groundwater modeling efforts, and leakage calculations to quantify the durability of bicarbonate storage in the oceans. We follow the chemistry of the river network downstream of our EW deployments to estimate the calcium and dissolved inorganic carbon cycling downstream of field deployment (in collaboration with Professor Zhang at Texas A&M). Our downstream measurements and modeling allow us to develop a framework that quantifies the durability of carbon removal in the form of dissolved inorganic carbon while it is transported to the ocean. Once bicarbonate has reached the ocean, the carbon removal should be quite durable. There is, however, a small portion of sequestered carbon that is lost to the atmosphere. We are currently collaborating with authors (Professor Reinhard, Professor Planavsky) of key peer reviewed studies and publicly available models (SCEPTER, cGENIE) to estimate this loss factor (Kanzaki et al 2022, Kanzaki et al, 2023)

b. **Project objectives:** What are you trying to build? Discuss location(s) and scale. What is the current cost breakdown, and what needs to happen for your CDR solution to approach Frontier's $100/t and 0.5Gt targets? What is your approach to quantifying the carbon removed? Please include figures and system schematics and be specific, but concise. Aim for 1000-1500 words.

Mati is building a farmer distribution and support network in the global south that will deliver carbon removal at millions of tons scale while providing co-benefits to farmers. To enable this scale of robust removal, we are building software, laboratory, and logistics infrastructure along with robust MRV that is being optimized for small-holder farmer setting. Our program uses ground basalt-based soil amendments marketed as "Mati" and distributed in rice paddy fields that catalyze conversion of CO_2 into dissolved inorganic carbon which flows through to rivers and eventually oceans and remains stable for >10,000 years.

The presence of significant water from flooding in the rice fields and higher temperatures of the sub-tropical regions creates an ideal environment for rapid and extensive weathering reactions. Mati provides beneficial effects on crop productivity and shares CDR economics through carbon removal incentives for farmers creating a strong driver for adoption.

We started our initial pilot in Raipur, in the rice paddy fields of Chhattisgarh state. The proximity to significant basalt deposits (range from a few km to 150km) and warm temperatures (Raipur temperature average of 82ºF) make it an ideal region for EW. The basalt quarries which we work with in the region already produce significant aggregates for construction; and in the process of crushing for aggregate production, significant fines are produced (8% to 15% by weight). These fines are a waste product that have limited commercial value.

We have since expanded to the northern region of Chhattisgarh in 2022 with deployments of about 1100 tons. In 2023 we are underway to deploy 20,000 tons in this northern Chhattisgarh region, of which 4000 tons should be deployed before end of June 2023. We are currently operating in northern Chhattisgarh from our offices in Pendra district. We plan to scale our operations here with the establishment of our first operating warehouse base that will support 130,000 tons per annum deployment. This pace of deployment shall begin in 2024 when our target is to have at least 100,000 tons of CDR materials. We will subsequently setup additional bases as we expand our operations into different part of India. Our target is to add 3 new bases every year in India growing to 1.5 million tons of deployments by 2028.

Currently our major cost heads are sourcing, transportation, personnel, and MRV. We have a very clear path to reduce our costs to below $100/ton CDR including cost to finance the post-deployment CDR delivery period and certification marketplace fee. We forecast substantial reduction in the cost to do MRV (lab testing and modelling) and reporting as we scale up. Similarly, our costs to transport should reduce, however we have kept it the same in the interest of being conservative in our current model. Our costs of sourcing materials may go up as we develop new regions which is reflected in the almost 15% increase shown in our model. The major initiatives that will result in these long-term cost reductions over time are already in place contractually and it's a matter of operating at scale to realize these lower costs. We only need financing and carbon removal purchases to enable this scale-up to achieve these lower costs. Details of cost breakdown are available in Appendix 1 and Section 6a.

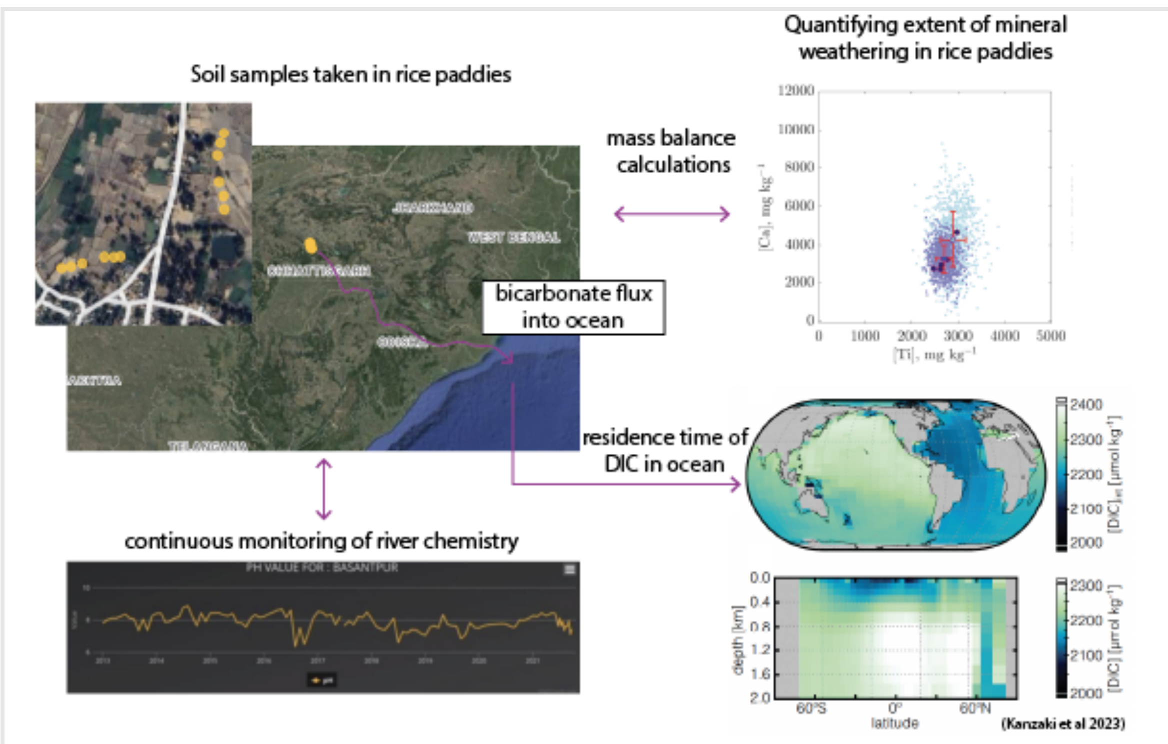

Figure 1b: Mati MRV process overview

Mati monitors differences in the soil concentration of key cations before rice planting, during the growing season and after harvest when weathering reactions have begun to take place. These "before, during and after" measurements provide the requisite information needed to conduct mass balance calculations that quantify the extent of enhanced rock weathering. Mati uses an isotope dilution method for soil sample preparation, which yields very high accuracy measurements for Ca^{2+} and Mg^{2+} concentration on commonly used mass spectrometers. Given our high measurement accuracy, the mass balance calculations are straightforward and robust with a measurement uncertainty of ~1%. Furthermore, Mati's soil sampling protocol uses sample-pooling procedures designed to reduce geospatial uncertainties and improves the counting statistics for compositional measurements.

Our highly accurate compositional measurements of the soil samples collected in the field allow us to quantify the extent of feedstock weathering and thus the amount of bicarbonate that Mati has introduced to the groundwater (see preprint of manuscript detailing mass balance calculation methodology here). Continuous monitoring of river chemistry at multiple site locations allows Mati to estimate the carbonate saturation of river water in the vicinity of EW deployments. This provides Mati a path to estimating potential leakage of captured carbon due to carbonate precipitation (Zeebe et al 2001). Mati is currently developing a river network model with collaborator Dr. Shuang Zhang to reduce uncertainty in future leakage predictions (support confirmed). Together, calculations for feedstock dissolution and DIC transport estimated from river network models and measurements allow us to estimate bicarbonate flux into oceans. We estimate leakage of sequestered carbon from the ocean over thousands of years with collaborators at Georgia Tech (support confirmed).

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

MRV Process:
The MRV process for EW remains a work in progress across all study groups, companies, and deployments. At Mati, we are working diligently to improve the quality of MRV for EW. We are operating using MRV techniques that have been site tested and de-risked by peer groups (e.g. Lithos). That said, Mati acknowledges the uncertainties inherent in the nascent monitoring technologies. We have developed numerous adaptations and improvements to the Yale MRV technique to make it more robust for Indian paddies. The novel setting of Indian rice paddies will provide invaluable data that will improve the understanding of our MRV and the MRV practices across the wider EW community. We at Mati look forward to playing an integral role in reducing the uncertainty of measurement based MRV thereby reducing uncertainty and financial risks for EW deployments.

Health and Safety Risks:
Concerns have been raised about the potential for metals to be released in agricultural soils because of EW deployments. In particular, metals such as Ni, Cr, Cu, Zn, Pb, As and Cd could have implications for crop and human health. The risk involves the loss of crops, contamination of crops for human consumption, and metal release to waterways that would result in damage to potable water sources and wider disturbance of the ecosystem. Although there is currently no long-term field trial data indicating a problem, there is potentially some risk of metal release that has been noted in the scientific literature (e.g. Edwards et al, 2017; Dupla et al 2023). However, it can be shown (see this helpful tool) that for realistic basalt application rates on farms, no harm will be inflicted on humans or local ecosystems for thousands of years even with continuous enhanced rock weathering deployments. When Mati makes compositional measurements of the soil to measure carbon removal, trace metal abundances are also measured. The US EPA provides technical guidelines and defines regulatory thresholds used for the application of solid waste to agricultural land, including products containing trace metals. Mati will monitor changes in the concentration of trace metals in fields guided by the EPA technical documentation. Additionally, Mati's efforts to monitor river water chemistry after EW deployments will provide another checkpoint for detecting potential water contamination of any unwanted dissolved metals. In all, this will allow Mati to provide peace of mind to farmers while mitigating potentially undetected downstream health risks.

The primary potential health risks associated with Mati's EW deployments are direct human consumption of rock dust and worker exposure to elevated dust. These two concerns that are common to all powdered agricultural inputs such as fertilizers or agricultural lime. Mati mitigates these potential health risks by promoting a safe and professional working environment with partnered farmers.

Farmer reception and EW reputational risk:
Mati project is executed amongst small-holder farmers. The understanding of EW being safe and beneficial amongst farmers is very important for Mati to deploy and scale. Introducing these new CDR materials to their fields requires a significant amount of social trust for farmers to add risk to their livelihood. However, these sustenance farmers have typically had positive experiences with the government agricultural extension network bringing in new varieties of seeds and fertilizers in the past. Mati is working with the support of local government leveraging this trust for helping farmers understand and adopt this new material in their field. We continue to diligently manage the various stakeholders in the local farmer groups, and government ecosystem by frequent presentations and ensure awareness of the Mati's co-benefits delivery to the farmers.

Cost dependencies risks:
We have done a detailed analysis of the transportation costs and accounted for the carbon emissions for fuel used in moving materials. As transportation remains one of the major cost components, its cost variability can have a large impact. We estimate an impact potential of $10 to $30 / tons CDR based on fuel price movement. The long-term goal would be to eliminate dependence on fossil fuel-based transportation altogether and move to electric / hydrogen bulk movers.

Price and financing risks:
Mati is deploying EW materials which deliver CDR over a period of 5 years from the deployment. The majority of the costs for Mati are prior to deployment; however the revenue is distributed over a subsequent 5-year period. This time differential needs a financing solution and eats into the economics of EW. Mati currently allocates about 10% of its long-term target price of $100 towards this financing cost. However, the risks remain on the final price achievable for this type of CDR and the financing costs. Mati is currently in final stages of its diligence with marketplaces like puro.earth and Carbonfuture to become a certified provider of carbon removal credits. Mati will leverage the off-take and financing offered by such marketplaces to sign long term contracts to ensure that price and financing costs are predictable.

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)*	5000 tons (From 26,642 CDR tons from our GPM base in deployments from Dec 2022 to Dec 2024)
Delivery window *(at what point should Frontier consider your contract complete? Should match 2f)*	Jan 2023 to Dec 2029
Levelized Price ($/ton CO_2)* *(This is the price per ton of your offer to us for the tonnage described above)*	$300/ton CDR (Our price in the long run will go down to $100)

** 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).*