Andes

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](https://github.com) 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

Andes Ag, Inc.

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

Alameda, CA

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

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Brief company or organization description <20 words

Andes uses beneficial soil microorganisms to accelerate silicate weathering and permanently remove CO2 from the atmosphere.

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

Proposed technology and preliminary data:
Enhanced weathering (EW) offers a promising path to permanent carbon dioxide removal at scale with many co-benefits (e.g., improved food and soil security, reduced ocean acidification), but faces

[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.

significant challenges to reach its potential of removing 2-4 gigatons per year [1]. To date, EW project developers have been dealing with the uncertainty from slow weathering rates, limited access to waste feedstock, and analytical lab capacity, all of which complicate delivery timelines and risk ability to reach scale. According to literature dating back to the 1990s, "microorganisms modify rates and mechanisms of chemical and physical weathering and clay growth, thus playing fundamental roles in soil and sediment formation" [3]. Accelerating the weathering of minerals through biological processes has long been an area of interest in academia because of its potential to increase the efficiency of carbon removal at scale. Furthermore, it has been proposed that the biological increase of chemical weathering rates could allow for a greater variation in grain sizes, which would reduce the costs associated with crushing the rock in very fine particles [2, 3].

To de-risk EW as a prominent CDR pathway, Andes has been working on the combination of silicate-weathering microbes and enhanced weathering. Frontier has also encouraged Andes and the CDR space broadly to prioritize this innovation area in order to study and deploy EW with microorganisms to liberate alkalinity from the feedstock. This process entails applying Andes silicate-weathering microbes along with an exogenous basalt feedstock to slightly acidic agricultural soils. From a biological process perspective, our thesis is that Andes microbes enhance silicate weathering by forming a biofilm at mineral surfaces and regulate the chemical environment at the biofilm-mineral interface to accelerate weathering. Data has demonstrated that Andes microbes can increase the weathering rate of silicates in soils. Specifically, Andes preprint scientific paper references mesocosm data (Table 3 in supplementary information) whereby the weathering rates of silicates using Andes microbe (MP1) is over 6 times faster than UTC or untreated control, under the same conditions [4]. We also have data from mesocosm studies of our microbes + basalt feedstock which suggests Andes microbes accelerate weathering of the applied rock powder feedstock.

While this mesocosm and lab data is compelling, Andes is applying to this prepurchase from Frontier in order to ensure that this translates to similarly compelling results in the field over a longer period of time and with a higher *p*CO2. If successful, this innovation to traditional EW has the potential to increase demand broadly. Buyers have expressed concerns over the uncertainty of weathering rates in EW, a gap Andes' microbially-accelerated EW can reduce. In mesocosm studies, with the addition of Andes' microbial strains, we have observed a statistically significant increase of 97.7% in soil DIC accompanied by an increase in pH and base cations on both the soil's exchangeable sites and the leachate. These results are promising and a future implementation of Andes' microbes broadly could increase the scale potential for the EW pathway for individual companies as well as the CDR sector as a whole.

Durability

In terms of durability, the bicarbonate generated by the dissolution of the added feedstock of silicates will reach the water table and then long-lived reservoirs, including groundwater, rivers, and the ocean. Once reaching the ocean, the durability of the majority of the captured carbon (~90%) is estimated to be on the order of 10,000 years or more [5]. Kanzaki et al. (2023) determined that the long-term storage of captured carbon as DIC in the ocean interior is ~90% efficient, and that leakage of initially captured through ERW back to the atmospheric CO_2 pool on decadal timescales is well-constrained and is significantly below that currently assumed [6].

High Throughput MRV

Andes is working on a high throughput method to measure inorganic carbon from soil and liquid samples (e.g., soil pore water and leachates) via gas chromatography, which will be used to complement the EW MRV requirements of registries such as Isometric at a higher speed and lower cost than previously achieved. The combination of accelerating EW and increasing analytical lab capacity are two areas that many EW startups and catalytic buyers have identified. To date, the CDR industry has seen limited innovation around utilizing microbes for carbon removal, but Andes hopes to change that. The use of microbes for CDR is gaining traction within the academic community, as evident by LLNL's recent Roads to Removal report and research from University of Colorado.

What differentiates us / priority innovation areas identified in the RFP
Andes has been studying the interaction of microbes with plants and the soil environment since late 2016. Given the team's expertise across soil science, geochemistry, and environmental microbiology, and external collaborators, such as Eric W. Slessarev (Yale), Jennifer Pett-Ridge (LLNL), Noah Fierer (CSU), Kazem Zamanian (Leibniz U.) and Dan Breecker (U. Texas) Andes is well-positioned to develop the best-in-class microbially-accelerated EW solution.

In addition to academia emphasizing the potential for microbial inoculants in EW, Andes has surveyed many EW startups and discussed potential collaborations over the past year. They have also expressed slow weathering rates as a barrier to scale for them. Andes is well-positioned to unlock microbially-accelerated EW, given our experience in the production, distribution, and application of microbial products and our knowledge base on the mechanism of action by which microbes are able to accelerate silicate weathering. This furthermore positions Andes well to, if necessary, improve the performance of the microbes through strain sourcing and/or genetical engineering. This is part of an ongoing partnership with Lawrence Livermore National Laboratory and other elite academic institutes through the DOE-funded Terraforming Soil Energy Earthshot Research Center (EERC). Within the EERC Andes is working closely with foremost experts in the field to enhance the natural ability of microbes in weathering silicates for the purpose of CDR. Ultimately, Andes plans to publish all this data in a scientific paper so that institutions can continue to expand the scientific understanding of microbially-accelerated EW.

Several accelerated EW solutions are exploring utilizing enzymes, such as carbonic anhydrases, to increase weathering rates. The stability of an enzyme in the soil environment still needs to be proven and we expect it to be a major implementation challenge. Additionally, we expect the cost of producing, transporting and applying recombinant enzymes at a field scale will considerably increase the cost of implementing the CDR solution. Andes microbial inoculant currently has a marginal cost of $2 per acre/season. Lastly, Andes has intellectual property surrounding the strategy of utilizing microbes and silicates for the purpose of CDR in agricultural land, whether native or exogenously added. Mechanical, thermal, and chemical treatments are also promising options to accelerate EW, but they come with difficult logistical challenges and higher price points per tonne.

In addition, the robustness of Andes microbes is remarkable. Through multiple field trials on more than 90,000 acres across 6 states in the U.S., Andes has collected empirical evidence to demonstrate its microbes can accelerate the weathering of naturally-available silicates in the soil that have not been artificially crushed and have remained unweathered for thousands of years [4]. The proposed solution of microbially-accelerated EW in fields with exogenously added silicates should also be very efficient, a strategy that we've confirmed at a mesocosm level.

Andes founders, Gonzalo and Tania, are both from Chile and Andes will run a microbially-accelerated EW pilot there before starting the project in Wisconsin. The team will leverage previous working relationships with Chilean farmers, feedstock providers, laboratories, and government actors in order to deploy this pilot in October 2024. Frontier has expressed interest in deploying projects in Latin America and other regions outside of the US and this is also a high priority for Andes, given the team's connections to the region, as well as Africa and Asia.

Finally, Andes has the support from the biggest global seed company and the biggest global agricultural commodity trader. By leveraging on these established partnerships, Andes can quickly scale the microbially-accelerated EW CDR pathway globally, while building and serving the CDR credit demand from a growing group of corporate buyers.

References:
[1] https://doi.org/10.1038/s41558-023-01604-9
[2]https://orca.cardiff.ac.uk/id/eprint/60901/1/Carbon%20dioxide%20efficiency%20of%20terrestrial%20enhanced%20weathering.pdf
[3] https://www.pnas.org/doi/abs/10.1073/pnas.96.7.3404
[4] https://www.researchsquare.com/article/rs-4244369/v2 (Andes preprint)
[5] https://www.sciencedirect.com/science/article/abs/pii/S0167880912001582?via%3Dihub
[6] https://pubmed.ncbi.nlm.nih.gov/37096198/

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

Andes is developing 1. A microbial solution to accelerate the weathering of alkaline materials and 2. A high throughput gas chromatography method to be able to measure inorganic carbon contained in soil, soil pore water and leachate samples at a low cost and short turnaround times. This combination has the potential to drastically unlock EW as a scalable solution to reach gigatonne scale carbon removal. Simply put, EW can be deployed faster. Ultimately, Andes would like to partner with any EW company who wants to accelerate their deployments. This will require pilots to be conducted in numerous regions of the world to ensure the efficiency is similar among different soil types, pH, crops, management practices, etc. before deploying at scale. Given the variability in CDR yield and weathering rates in academia for traditional EW, it is even more vital to broaden the application of microbially-accelerated EW across many geographies, feedstock types, and crop types. In addition, speeding up the rates of weathering within the first years of feedstock application will be catalytic in bringing more CDR buyers into the ecosystem.

Location and Scale: Andes is conducting an initial microbially-accelerated EW pilot in October 2024 in Chile on approximately 45 acres with basalt feedstock from a nearby mining operation. This pilot will be instrumental in providing lessons to the Andes R&D and operational teams that will later implement the microbially-accelerated EW project in Wisconsin for the 2025 growing season deployment. After successful results in Chile and Wisconsin, our expansion will continue throughout Wisconsin and more pilots will be conducted in South America, starting in Uruguay. In tandem, Andes will collaborate with other EW startups to deploy the microbially-accelerated EW innovation and compare to their existing weathering rates to build a robust data set of field deployments.

The project in Wisconsin will be conducted within a 50 mile radius of Andes mining partner on 650 acres applying a total of 5,200 tonnes of basalt feedstock (8 t/acre) on corn and soybean fields (rotation scheme). Andes will deploy the microbial inoculant in combination with the plant seed at the moment of planting, either as a seed treatment (e.g., soybean) or in-furrow (e.g.,corn).

Costs: Currently, the cost is $396/tCO_2$ for the project in this application. In Chile, the cost is significantly lower at present, as material sourcing, and logistics / transportation are much cheaper. Our costs for microbially-accelerated EW will come down significantly over time. Currently, our marginal cost of adding the microbe to the EW solution is $2/tCO_2$, so the high cost today is due to traditional EW CapEx and OpEx costs that will reduce over time. Currently, our major costs are basalt feedstock, transportation, and MRV. Andes has a clear path to reduce its costs to below $100/ton CDR and experience executing programs with farmers in the Midwest. For feedstock, as we expand into other regions and increase volumes, we know there are cheaper options for basalt and potentially even free sources. In addition, we expect to increase the amount of basalt mines we partner with in

[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.

order to decrease transportation costs and emissions. Andes initial field deployments will be very rigorous from an MRV perspective and our high throughput gas chromatography method will help keep costs down initially. With more data and future deployments, Andes will rely increasingly more on modeling to be able to reach mega and gigatonne scale. This reduction in the frequency of infield measurements might take a couple years, but it will decrease costs to a large extent.

How we reach 0.5 $GtCO_2$ of CDR: Andes plans to leverage operational partners in the US and partner with existing EW startups to scale up microbially-accelerated EW throughout regions of the country where the soil characteristics are suitable. We intend to own the MRV, microbial component, farmer relationship, and CDR sales for microbially-accelerated EW and partner with other groups to lead all other aspects. Andes plans to position itself as the de-facto microbial additive for companies looking to increase weathering of their EW solution.

For expansion into South America, we plan to own more of the operational aspects of the business, given our founders experience in the region. This region is poised for growth in EW because of abundance of basalt, large land areas, and transformational agricultural co-benefits.

Quantification approach: Andes plans to conduct rigorous MRV for this microbially-accelerating EW project. We will implement the project in accordance with Isometric's Enhanced Weathering in Agriculture protocol and follow guidance from Frontier's "Guidance for assessing quantification plans and deliveries for enhanced weathering." Specifically, Andes will conduct the following measurements / techniques to ensure the most robust MRV strategy:

- Andes will follow Isometric's Determination 1, which includes a combination of soil and porewater measurements
  - Weathering: Andes will conduct direct soil samples at 30 cm depth with 8-10 soil cores at each sampling location. Andes will stratify each field based on soil texture and soil pH and will take 3-5 soil samples per stratum. Each soil sample will be a soil composites comprising 8-10 core samples from the top 30 cm of soil collected in a radius of 3 meters from the center point. The center points will be defined by an algorithm that randomly selects points within each stratum, and coordinates will be recorded to return to the exact location in every sampling event. Andes will measure the abundance of an insoluble elemental or isotopic tracer and its ratio to soluble base cations in the feedstock on a yearly basis up to the end of the reporting period. The decision on which approach to use will be taken closer to the deployment time based on the feedstock composition and the soil characteristics.
  - Biomass Loss: Andes will take plant samples on control and treatment plots. Base cation concentrations and total mass will be measured. These measurements are extrapolated over the project area to calculate CO_2e Biomass Loss due to uptake of cations into the plant.
  - Net New Carbonate: Andes will measure soil inorganic carbon (SIC) using Pressure Calcimetry to determine the net change in SIC between the start and the end of the reporting period.
  - Net Sorption: Andes will measure cation exchange capacity (CEC) and base cation saturation to observe any sorbed to cation exchange sites, indicating potential outgassing of CO_2.
  - Non Carbonic Acid Neutralization: Andes will obtain fertilizer composition and application rates from enrolled growers, then use these values to estimate the non-carbonic acid weathering in the soil via the US Geological Survey's PHREEQC software. Anion concentrations including nitrate, sulfate, and chloride will be measured at select sites to ground-truth calculations. Nitrate values will be compared to calculations in PHREEQC, while sulfate and chloride will be included in Hydrus 1-D models of the physical soil profile.
  - Riverine Loss: Andes will use a model to account for all losses that will occur in rivers downstream of in-field activities, including formation of new carbonate minerals and outgassing due to re-equilibration of DIC system.
  - Marine Loss: Andes will use a PHREEQC model to account for losses in the 1. Formation of new carbonate minerals and 2. Outgassing of CO_2 due to re-equilibration of DIC system.
  - Aqueous measurements: To be conservative, Andes will conduct redundant aqueous

measurements at a higher spatial resolution to increase confidence in calculated CDR. Specifically, lysimeters will be installed at depths of 30 cm. These water samples will then be analyzed for major cations, anions, pH, and bicarbonate. These measurements will be collected at a density of 3 lysimeters per field stratum for the control (EW plots) and treatment (mEW plots). A lower spatial resolution will be applied for the deployment plots. Following Isometric's EW protocol, the lysimeters will be installed at a depth of 30 cm and at a spatial density of 1 device per field when the field is smaller than 123 acres or 1 device for every 123 acres of land. Andes has experience conducting lysimeter field work and has over 24 lysimeters deployed on agricultural land in the Midwest.

- Treatment vs. control: Andes will take a 3-plot control approach in order to compare traditional ERW with Andes microbially-accelerated EW on agricultural land using the same feedstock.

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

Operational execution: EW is an operationally complex CDR pathway that many startups have built operational capability to scale, especially around partnerships with quarries for sourcing feedstock. In order to mitigate this risk, we are hiring a part-time consultant on operations for this pilot, specifically around sourcing of feedstock. The Andes operations and field team have 4 years of experience working on CDR with over 50 farmers covering 90,000 acres to date across 6 different states in the US. Our field team consists of 17 people, many who have worked closely with farmers throughout their careers.

Uncertainty around MRV for EW: A major challenge with all EW solutions is that weathering outcomes depend on hard-to-control variables like temperature, rainfall and soil type. Reversal risk, or the escape of CO_2 to the atmosphere, is specifically a risk for EW solutions. Andes plans to implement the same processes that are required under the Isometric EW protocol and we are also exploring alkalinity flux sensors to complement the requirements of Isometric, ensuring the highest rigor for MRV. An uncertainty discount will be applied to account for any additional uncertainty that cannot be quantified.

Reliance on external parties to produce microbe: In order to decrease the dependency on one collaborator, Andes will increase the number of contract manufacturing organization (CMOs) partnerships that produce our microbe. Specifically, we will diversify the locations of CMOs to cover more regions around the US, which are subject to different supply risks.

Financial / ecosystem: Andes is well-capitalized and has substantial commercial traction / partnerships, but a shift from focusing solely on microbial carbon mineralization (MCM) to commercializing microbially-accelerated EW is a risk to the business. Also, the market size for $300-400/ tonne CDR is small. To mitigate this, Andes will leverage existing CDR buyer relationships developed over the past 2 years for purchase for microbially-accelerated EW. Initial conversations with buyers indicate a strong appetite for this solution, especially with Isometric as the registry partner.

Microbial performance risk in field: Performance of the microbe exhibits high variance in the field compared to controlled-environment studies (i.e. mesocosm studies) due to high variability environmental factors and soil heterogeneity. This would lead to lower than expected acceleration of EW and yield. To mitigate this, Andes intends to utilize the dataset obtained from this upcoming field trial and the large dataset collected on the performance of the microbe from previous field deployment for MCM to narrow down field conditions which optimize for microbial performance and EW.

Evaluating / quantifying impact of the microbe compared to traditional ERW: In order to scale up this approach, control plots are crucial. Not only must we compare Andes solution to the baseline

(control), but also include a treatment in the field with just ERW (no microbes). This will complicate logistics / operations and increase cost, but it will be necessary to assess which part of the carbon capture is due to microbially-accelerated EW vs traditional ERW.

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)*	(1,560 tCO_2 - 89.13 tCO2) = 1,470.87 1,470.87-(0.333*1,470.87) = 981.1 **981.1 tonnes CO_2**
Delivery window *(at what point should Frontier consider your contract complete? Should match 2f)*	The delivery window is Dec 2025 until Dec 2029.
Levelized cost ($/ton CO_2) *(This is the cost per ton for the project tonnage described above, and should match 6d)*	$396
Levelized price ($/ton CO_2)[3] *(This is the price per ton of your offer to us for the tonnage described above)*	$455.40/tonne, assuming a 15% margin.

[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).