# Andes

## 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

| |
|---|
| Andes |

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

| |
|---|
| Kaitlyn Baab |

Brief company or organization description <20 words

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|---|
| Andes uses beneficial microorganisms to 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

[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.

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. Aim for 1000-1500 words.

Andes utilizes bio-mineralization to permanently remove carbon dioxide from the atmosphere. This pathway involves the application of microbes on agricultural land to accelerate the generation of soil inorganic carbon (SIC), specifically bicarbonate and carbonate minerals (measured as calcium carbonate equivalent, CCE). Andes partners with farmers who apply the microbe during planting, a process that seamlessly integrates with existing agricultural practices. The resulting mineral generation occurs over the course of an agricultural season and is directly measured through high-intensity soil sampling. By leveraging the power of biology and the existing installed capacity of agriculture, this unique pathway has the potential to be deployed at an exceptional speed, scale and price point distinct from existing CDR approaches.

Andes CDR pathway utilizes a naturally occurring microbe that has been isolated, identified and extensively studied by the Andes team. This microbe grows and thrives with plant roots, which supply the microbe with atmospheric $CO_2$. This $CO_2$ is originally taken up by plants from the atmosphere through photosynthesis. As part of natural respiratory processes, plants, soil micro and macro fauna release $CO_2$, resulting in high $CO_2$ levels ($pCO_2$) close to the roots and rhizosphere (10 to 100 times higher than the atmospheric $CO_2$ concentration (Hillel, 1980; Bremner and Blackmer, 1982)). This provides an ideal environment for $CO_2$ drawdown performed by the Andes' microbe. The Andes microbe locks the $CO_2$ that is released by respiration into bicarbonate and carbonate minerals. Specifically, the microbe first accelerates the formation of soluble bicarbonate from atmospheric $CO_2$ and water (equation 1). At the right pH and with an available source of cations, Andes' microbe will precipitate the bicarbonate molecules (produced in equation 1) into carbonate minerals, such as calcium carbonate (e.g., equation 2).

$$CO_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow HCO_3^- + H^+ \qquad (1)$$

$$Ca_2^+ + 2HCO_3^- \leftrightarrow CaCO_3 + H_2O + CO_2 \qquad (2)$$

The generation of bicarbonate and carbonate minerals mediated by the Andes' microbe has been observed in lab, soil column, growth chamber, greenhouse, and field conditions. This includes controlled environment lab experiments with labeled $CO_2$ gas, where Andes has observed the incorporation of the labeled $CO_2$ in solid carbonate minerals precipitated by colonies of the Andes microbe. In terms of tonnes removed, three years of field trial data with over 55k+ data points showed that across different soil types, carbon dioxide was captured at an average of 1 to 3 tonnes/acre/season. Additional details on the mechanism of action and associated experimental results are shared in the response to question 2a.

While reaction 1 above results in bicarbonate, the overall reaction of Andes' microbe drives the reaction towards the precipitation of carbonate minerals (see section 2a for further details). Carbonate minerals are a durable form of $CO_2$ removal in the environmental conditions where Andes technology is applied. Although carbonate minerals in the soil can have complex dynamics of dissolution and reprecipitation, there is a high likelihood of long-term durability of 10,000+ years, as Andes microbes are applied on soils with near-neutral to alkaline pH (Schlesinger, 1985; Lindsay, 1979; Chay et al., 2023). The permanence of the resulting carbonates does not depend on the reapplication of microbes in future seasons. Though, additional carbon removals can be generated by re-applying microbes on the same land in subsequent years and thereby generating additional durable carbonate minerals.

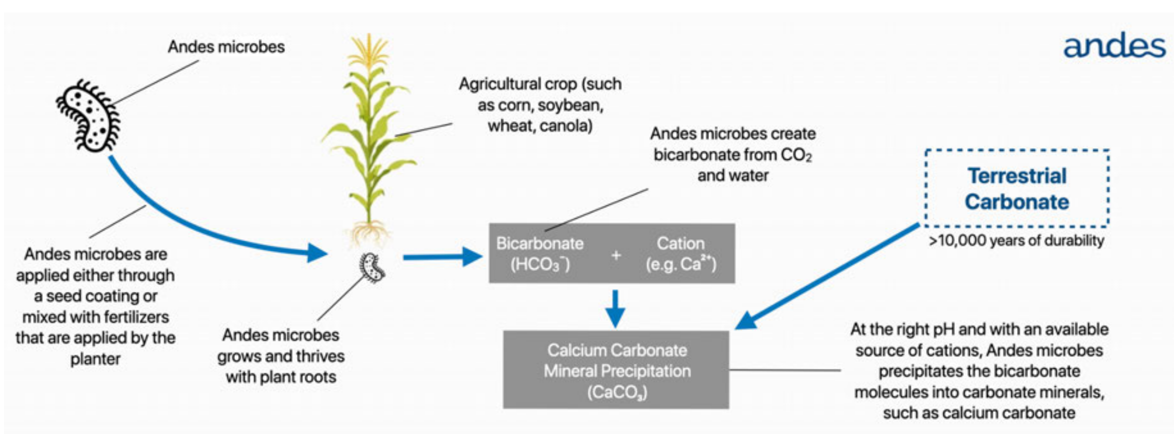
One distinct component of this pathway is its ability to scale. This technology can be rapidly scaled to additional acres due to Andes microbial technology integrating seamlessly with farm operations and leveraging existing arable land that is already being used for agriculture production. Andes technology requires no investment from farmers or multi-year commitments. In fact, Andes compensates farmers to apply Andes microbes on their fields with a fixed cash payment at the end of the season, in exchange for rights to the carbon removed. The application of the microorganism requires minimal effort from farmers, as it is applied either through a seed coating or mixed with fertilizers that are applied by the planter. As the technology relies on existing installed capacity of farm operations, Andes' approach has minimal CapEx requirements and low marginal costs. The result is a program that has demonstrated sustainable, rapid growth. Andes field trials have grown by more than 35x in the last three years, initially covering approximately 1.3k acres during 2021, 25k acres in 2022 and 50k acres in 2023. During 2022 Andes removed ~50k tonnes of $CO_2$ (pending verification from 3rd party validation) and for 2023 Andes estimates ~100k tonnes of $CO_2$ removal. This rapid growth will continue in years ahead, as there are millions of suitable acres of existing agricultural land. Specifically, there are roughly 200 million acres in the US, over 40 million acres in Canada, and more than 150 million acres in South America that are applicable for the deployment of Andes technology. This easy-to-adopt technology is highly scalable, enabling the removal of 1 million tonnes of $CO_2$ by 2025 and 0.5 Gt/yr per year by 2035.

Beyond the ability to scale, Andes' robust Measurement, Reporting and Verification (MRV) approach differentiates the technology. Andes relies exclusively on direct measurement of SIC through a high-intensity soil sampling process. Further details on Andes' MRV approach are outlined in responses to questions 1b and section 5.

Another advantage of Andes' CDR pathway is the benefits the microbe contributes to the soil. The increase of carbonate minerals in soils due to Andes' microbes has a positive effect on soil health. It has been reported in literature that the presence of carbonate minerals positively affects the aeration and water permeability of soils, which in turn reduces pathogen pressure (Raza et al., 2021). Moreover, carbonate minerals, in particular calcium carbonate, aid in the stabilization of organic matter (Rowley et al., 2018), which also improves soil health and ultimately plant health.

Andes is also incredibly unique in its approach to carbon dioxide removal. Based on publicly available knowledge, Andes is the only company using microbes to increase soil inorganic carbon for the purpose of carbon dioxide removal. This novel pathway both leverages the incredible abilities of microorganisms and employs existing agricultural land and processes to generate durable, verifiable and scalable CDR.

***Figure 1:*** *Andes' CDR Pathway*




Bremner, J M  and Blackmer, A M  1982  Composition of soil atmospheres  p 873-901  In: *A. Klute and A.L. Page (eds.) Agronomy.*

Chay, F , Klitzke, J , Hausfather, Z , Martin, K , Freeman, J , & Cullenward, D  (2023)  *CDR verification framework.* CarbonPlan https://doi org/10 5281/zenodo 7803151

Hillel, D 1980 Fundamentals of soil physics *Academic*, San Diego

Lindsay, W L (1979) Chemical equilibria in soils *John Wiley and Sons Ltd.*

Raza, S , Zamanian, K , Ullah, S , Kuzyakov, Y , Virto, I , & Zhou, J (2021) Inorganic carbon losses by soil acidification jeopardize global efforts on carbon sequestration and climate change mitigation *Journal of Cleaner Production*, 315, 128036

Rowley, M C , Grand, S , & Verrecchia, É P (2018) Calcium-mediated stabilisation of soil organic carbon *Biogeochemistry*, 137(1-2), 27-49

Schlesinger, W H (1985) The formation of caliche in soils of the Mojave Desert, California *Geochimica et Cosmochimica Acta*, 49(1), 57-66

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.

Andes is building microbial technology to permanently remove $CO_2$ from the atmosphere, in addition developing a deployment network to enable the requisite scale and a robust MRV to ensure verifiability.

A core component of Andes' CDR solution is the microbial technology, as it both efficiently captures $CO_2$ and integrates seamlessly with existing agricultural practices. As described in responses to 1a and 2a, the Andes microbe accelerates the conversion of atmospheric $CO_2$ in soils into bicarbonate and carbonate minerals. A key characteristic of Andes technology is that the microbes can easily be applied in agricultural settings, and thus the technology relies on existing installed capacity of farms around the globe. Andes microbial product formulation is shelf stable up to 3 years and is easy to transport, as a 2.5 gallon container of the product covers approximately 2,000 acres of corn or 640 acres of soybean. The application of the microbial product also seamlessly integrates with existing agricultural practices and thus does not require any special equipment to use effectively. These properties of the Andes microbial technology enable effective, widespread deployment in agricultural settings.

In addition to the microbial technology itself, Andes is building a deployment network to enable the large-scale removal of $CO_2$ unique to the Andes' pathway. Andes currently partners with farmers in the Midwest of the United States who grow corn, soybean, wheat, sunflower and/or canola to apply the microbe during the annual planting process. This agreement permits Andes to take soil samples at numerous geographic points and multiple time intervals during the growing season to directly measure the generation of soil inorganic carbon (SIC). Andes works closely with farmers to understand their needs and constraints, and continuously improves the program based on their feedback. These strong relationships have resulted in continued growth of farmers interested in participating on the Andes Carbon Program, evidenced by an oversubscription of the 2023 season equivalent to four times the available capacity. Currently, Andes partners with farmers covering 50k acres in North Dakota, South Dakota, Minnesota and Wisconsin. In the future, Andes plans to expand to additional geographies within the United States, Canada and South America, projecting the application of Andes' technology on 100,000 acres in 2024, 500,000 acres in 2025, and 1,500,000 acres in 2026.

In addition to Andes' microbial technology and deployment network, an essential component of Andes' program is its robust Measurement, Reporting and Verification (MRV) approach. A key part of Andes' MRV is its quantification approach, relying on direct measurement of the generation of soil inorganic carbon (SIC). Andes calculates SIC, through the measurement of calcium carbon equivalent (CCE) (Fonnesbeck et al, 2012; Sherrod et al, 2002), which represents all inorganic carbon molecules. To measure CCE, Andes collects soil samples through a rigorous protocol following industry standards (e.g., USDA soil sampling protocols). First, each field is divided into strata based on USDA soil texture and slope. Second, sampling points are randomly selected for each field strata. Third, samples are taken at each sampling point multiple times throughout the growing season. Each sampling point consists of a soil composite of 8-12 sub-samples (cores) taken in a radius of 10 ft around the center point (i.e., sampling point) at a depth of 12 inches. These soil samples and corresponding measurements are collected on both fields treated with the Andes microbe and untreated control fields. The tonnes of $CO_2$ removed is determined by the difference between the newly generated CCE values of treated field strata and control field strata with similar key properties. Specifically, it involves subtracting the average newly generated CCE throughout the growing season (e.g., post harvest CCE values less pre plant CCE values) on control field strata from the average newly generated CCE on treated field strata. This calculation represents the newly generated CCE throughout the growing season directly attributable to the treatment, which is converted into tonnes of $CO_2$.

This rigorous soil sampling process comes with operational complexities, which Andes is simplifying through the development of software and automation. Andes has developed proprietary software to assist in-field operations and house all related data and workflows. This software is Andes' single source of truth for all the field stratifications and sampling locations, supports the management of in-field sampling logistics, and streamlines data processing to ensure verifiability. It also provides a historical reference for enrolled fields' current and past management practices (e.g., fertilizers and herbicides application, tilling, etc). In addition to software development, Andes is automating the soil sampling (e.g., ATVs with hydraulic probes), sample processing (e.g., drying and grinding) and soil sample analysis (e.g., gas chromatography) components of the MRV process. These improvements will enhance operating efficiency of the entire MRV process, resulting in significant cost savings.

Andes' efforts on MRV development includes not only the direct measurement and quantification, but also scientific understanding of the biological and geochemical processes involved. Developing a deep knowledge of the mechanisms associated with Andes CDR pathway has been a central focus of the team and will continue to be moving forward. In the past six months alone, significant progress has been made in the understanding of the mechanism of action, with further details contained in the response to question 2a. Andes will continue to study the biogeochemical processes involved to reduce uncertainties associated with the CDR pathway. Specifically, one planned experiment involves evaluating SIC buildup in different soil types to confirm the importance of factors that influence the SIC generation (i.e., soil texture, cations, pH, initial CCE, among others) and the interactions between them. Additionally, Andes plans to build on existing mesocosm column studies to answer questions related to SIC generation and percolation rates under different rainfall regimes and environmental conditions (e.g., soil properties, climatic components, plant developmental stages).

In regards to cost, given Andes CDR technology leverages the power of biology and existing installed capacity of farm operations, there are minimal CapEx requirements and relatively low marginal costs. Andes' current price is $300 / tonne of $CO_2$ removed, a competitive price in today's CDR market and one that will only be reduced with increased efficiencies. The costs associated with the technology are currently dominated by those associated with MRV and cash payments to farmers. The major MRV costs today are soil sampling (which requires going into each field), soil processing and soil analysis. These costs are expected to decrease significantly as Andes implements planned automation improvements across all channels. With these improvements in costs, coupled with developments in the microbial technology to increase the number of tonnes removed per acre applied, Andes plans to reach the $100 / tonne price point in the next 24 months.

Fonnesbeck, B B et al Improving a Simple Pressure-Calcimeter Method for Inorganic Carbon Analysis *Soil Sci. Soc. Am. J.* 2012, 77: 1553-1562

Sherrod, L A et al Inorganic Carbon Analysis by Modified Pressure-Calcimeter Method *Soil Sci. Soc. Am. J* 2002, 66: 299-305

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.

| Risk | Mitigation Strategy |
|---|---|
| **Measurement, reporting and verification (MRV)** | |
| *Long-term monitoring of terrestrial carbonate durability:* Due to the complexity and variability around the percolation of soil inorganic carbon (SIC), we cannot precisely monitor the percolation of newly generated SIC below 12 inches due to a low signal-to-noise ratio (for our project areas, the SIC content typically is higher in deeper soil horizons). | 1. According to the literature, there is a high likelihood of long-term durability as the project will be implemented on soils with near-neutral to alkaline pH. See section 3 for more information and literature on durability.<br>2. Andes will focus on studying the percolation of carbonates in various soil types and conditions through mesocosm studies to further understand the durability of our solution<br>3. Given the open system nature and the complex interaction of carbon fluxes in soil, an "uncertainty discount" has been incorporated into Andes' methodology |
| *Heterogeneity in soils*: Heterogeneity exists in soil inorganic carbon (SIC) within fields. While rigorous soil sampling procedures following industry standards can be conducted, there remains heterogeneity in the soil that is unable to be captured. | 1. Andes will increase the number of untreated control (UTC) fields year after year.<br>2. Follow rigorous soil sampling protocols including: stratify fields based on soil texture, randomly determine sampling locations and collect composites of 8-12 cores for each sampling location |
| **Project execution** | |
| *Sampling, processing, and analyzing large quantities of soil samples at scale*: logistical complexities, increased variability with more staff collecting samples, execution quality, etc. | 1. Software: Andes proprietary software assists field operations, enables barcoded labeling and tracking of all soil samples, and streamlines data processing to ensure verifiability.<br>2. Automatiomation: Andes is focused on automating soil sampling (e.g., ATVs with hydraulic probes), sample processing (e.g., drying and grinding) and soil sample analysis (e.g., gas chromatography) components of the MRV process<br>3. Quality assurance: Andes works with a third party to analyze the samples and stores a copy of |

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| | all soil samples in-house for a minimum of 5 years for potential re-testing. |
| *Reliance on external party to produce microbe* | 1. 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. |
| **Technical:** | |
| *Field management practices impact on carbonate durability*: Field management practices, such as nitrogen fertilizer application, pose a potential risk of re-emission of $CO_2$ from carbonate minerals. | 1. Andes applies its microbes on fields with a near-neutral to alkaline pH and high buffering capacity, conditions under which have a high likelihood of long-term durability (Gandois et al., 2011)<br>2. Andes has observed CCE build up across different crop types and geographical locations on 25k acres in 2022. As part of the Andes Carbon program, farmers provide Andes detailed information of the management practices for every single field enrolled in the program. To date, Andes has not observed a correlation between the buildup of CCE and any of the management practices recorded. Nevertheless, Andes will continue to monitor for more subtle correlations between field management practices and CCE as we collect more data from fields in the coming years.<br>3. Andes will conduct laboratory column studies, looking at the effects of different inputs (e.g. nitrogen fertilizers) on CCE buildup and stability. |
| Gandois, L , Perrin, A -S , & Probst, A (2011) Impact of nitrogenous fertiliser-induced proton release on cultivated soils with contrasting carbonate contents: A column experiment *Geochimica et Cosmochimica Acta*, 75(5), 1185-1198 https://doi org/10 1016/j gca 2010 11 025 | |

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)<br>*(should be net volume after taking into account the uncertainty discount proposed in 5c)* | 1,666.67 |
| **Delivery window**<br>*(at what point should Frontier consider your contract complete? Should match 2f)* | April 2025 |

| | |
|---|---|
| **Levelized Price** ($/ton $CO_2$)* *(This is the price per ton of your offer to us for the tonnage described above)* | $300 |

** 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).*

[redacted]

[redacted]

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