Terradot

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

Terradot Soil, Inc. & Terradot Ltda. (Brazilian Entity)

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

San Francisco, CA; São Paulo, Brazil

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

Connor Sendel, James Kanoff, Julia Sekula, Scott Fendorf

Brief company or organization description <20 words

Terradot is a science & technology company unlocking the existing global potential for gigaton scale carbon removal through Enhanced Rock Weathering.

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

Introduction to Terradot

[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.

Terradot is a science and technology company unlocking the potential for Enhanced Rock Weathering (ERW) to be a scalable, verifiable & impactful carbon dioxide removal (CDR) solution. Our mission is to regenerate Earth by permanently removing carbon from the atmosphere, enhancing agricultural ecosystems, and increasing food security.

We are currently establishing the foundation for nation-scale & regulatory compliant ERW in Brazil through our strategic alliance with Brazil's leading research agency EMBRAPA, innovative research pilots, novel funding mechanisms, and partnerships with large mining and agriculture players to enable scaled deployment. Our efforts aim to support Brazil's goal to become a leader in global ERW, leveraging an ideal climate for fast rock weathering, vast agricultural & silicate rock resources, and a low emission intensity grid. With our partners, we will showcase the results of this effort at COP30 in Belém, Brazil in 2025 with the goal of unlocking global governmental support for ERW–allowing the removal solution to scale beyond the voluntary carbon market.

How Terradot's Technology Removes CO_2 and Stores Carbon for >1,000 Years

Enhanced Rock Weathering (ERW) accelerates Earth's natural carbon removal process, transforming atmospheric CO_2 into stable bicarbonate to sequester carbon for 1,000+ years. ERW not only significantly reduces atmospheric CO_2 but also boosts soil health & crop yield, making it a scalable, impactful & governmentally attractive climate solution.

Earth's natural silicate rock cycle has provided gigaton scale CO_2 removal for >4.5 billion years. ERW is a CDR approach to accelerate this process by grinding the same rocks to increase their reactive surface area and spreading them on warm & wet cropland to achieve dissolution in years rather than centuries.

The silicate rock dust interacts with CO_2 in the soil water, releasing cations and other soil-health-boosting nutrients. The cations cause CO_2 to turn into bicarbonate, which eventually reach the ocean, where it is stored for thousands of years.

1 Rock Application

ERW speeds up the natural rock weathering process by grinding these same rocks, called silicates, and spreading them on farmland to achieve dissolution in years rather than centuries.

2 CO_2 Reaction

The dissolved rock dust interacts with CO2 in soil water, releasing charged particles called cations and other soil-health boosting nutrients.

3 Permanent Carbon Storage

These cations bond with the CO2 turning it into bicarbonates that eventually reach the ocean, where they durably remain for hundreds of thousands of years.

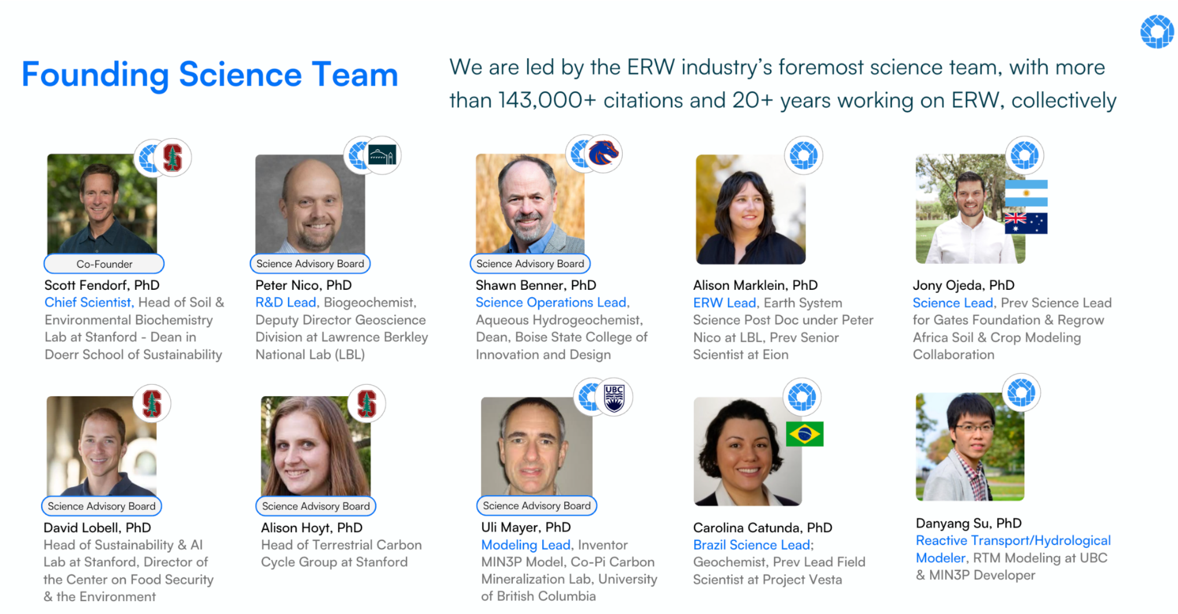
Figure 1. *Diagram showing ERW phases, including rock application, CO_2 reaction, and permanent carbon storage.*

<u>Why Terradot's System is Best-in-Class</u>

Terradot's approach to Enhanced Rock Weathering is differentiated by our scientific rigor, full project optimization and scalable deployment strategy.

Specifically, Terradot's industry-leading science team is developing the first foundational multiphase ERW scientific model and advancing ground MRV methods to capture the spatial and temporal heterogeneity of rock weathering. Building the model and our MRV in parallel enables Terradot to effectively quantify removal while generating high quality datasets. We deploy our model through our OpenERW project platform for full, end-to-end project optimization and for model-informed MRV to maximize project value and minimize project costs.

1. **Scientific Rigor to Build Trust**
    - **Scientific Team:** Terradot's team, originating from the Stanford Soil & Environmental Biogeochemistry Lab, leads global ERW scientific collaboration. Terradot actively collaborates with top academic and research institutions worldwide, continuously advancing the science of ERW. This ensures that our methodologies remain at the forefront of innovation and are adaptable to various global contexts.



- **MRV Approach:** Our Measurement, Reporting, and Verification (MRV) system advances multiple redundant methodologies to deliver full end-to-end quantification of ERW carbon removal. Our MRV is capable of accurately quantifying carbon removal and land benefits, validated by third-party reviewers.
- **Foundational Scientific Model:** We are developing and calibrating the first fully coupled ERW scientific model (coupled biogeochemical model APSIM + reactive transport model MIN3P) to optimize deployment strategies and reduce MRV costs over time.

2. **Full Project Optimization to and maximize value and reduce costs**
    - **Maximizing Value:** We leverage the predictive capabilities of our model to optimize for CDR and agronomic value. By tailoring deployment plans to specific soil and climate conditions, we enhance soil health and agricultural productivity to maximize value.
    - **Cost Reduction Strategies:** We focus on reducing removal costs through multiple avenues, including:
        - **Optimized Deployment Plans:** Model-enabled precision agriculture techniques help us develop deployment plans that minimize costs.
        - **Model-Informed Measurement:** Our MRV system innovates towards a model-informed approach that can reduce measurement costs by up to 90%.
        - **Investing in Scale:** We partner with existing scaled operations to take advantage of operational efficiencies and invest in improvements such as installing high-efficiency rock crushers to scale quarry capacity.
3. **Unlocking Scaled Deployment**
    - **Lighthouse Projects:** Terradot conducts our own large-scale ERW projects to rapidly advance the ERW market and best-practice ERW approaches. New developments are integrated into the OpenERW platform, ensuring continuous improvement market-wide. These projects serve as "Lighthouses" for the market, demonstrating the benefits of ERW at scale to encourage broader adoption.
    - **OpenERW Digital Project Platform:** Our OpenERW platform optimizes and manages ERW projects from start to finish, enabling rapid and efficient deployment. Unlike

other MRV licensing approaches, OpenERW acts as an operating system for large-scale ERW deployment, allowing existing feedstock suppliers and agriculture companies to enable large-scale ERW projects without becoming ERW developers themselves. This approach broadens the market and facilitates large-scale ERW adoption.

- **Partnerships for Scale:** We leverage existing infrastructure in mining and agriculture, starting in Brazil, to scale ERW rapidly. Our strategic alliance with EMBRAPA, Brazil's leading agronomic research agency, and partnerships with local mining companies and international financiers ensure operational efficiency and scalability.
- **Innovative Business Models:** Enabled by our platform and partnership-based approach, we are developing new financing mechanisms beyond traditional carbon markets, such as Article 6 transactions and development finance, to expand funding for ERW projects and maximize their impact.

Climate Equity

Enhanced Rock Weathering (ERW) offers significant co-benefits beyond CDR. By replenishing essential nutrients, improving soil structure, and increasing soil pH, ERW enhances land productivity and crop yields, especially in underutilized agricultural regions. This makes ERW a complementary farming practice, providing both CDR and agricultural productivity enhancements. In regions with intense land competition and food security issues, such as Brazil, this dual advantage is critical.

Deploying ERW in global tropics leverages climate finance for equitable development. In Brazil, for example, extreme weather has reduced crop yields and increased financial distress among farmers. Integrating ERW reduces input costs, improves soil health, alleviates financial strains, and enhances long-term climate resilience. This approach aligns with climate equity goals, using climate finance to support vulnerable farming communities, ensuring sustainable development and resilience against future climate impacts. Focusing on the global tropics, where rapid weathering and agricultural improvement potential is highest, ERW addresses climate and development challenges simultaneously.

Addressing Priority Innovation Areas

Terradot is addressing five priority innovation areas in this project:

1. **Furthering Understanding of ERW in Optimal Weathering Environments:** Terradot is developing ERW in Brazil, where hot and humid tropical conditions promote rapid weathering. This not only ensures faster CO_2 sequestration but also more rapidly provides valuable data and learning that can be applied to other regions globally, demonstrating the potential for gigaton-scale carbon removal.
2. **Deployment Models Generating Financial & Environmental Benefits at the Site:** Terradot uniquely quantifies and values the full set of compounding climate impacts associated with ERW. This comprehensive valuation approach allows us to unlock additional funding streams in the future, creating financial incentives for stakeholders and enhancing the economic viability of ERW projects. By integrating ERW with local agricultural practices, we also generate significant environmental co-benefits, such as improved soil health and increased crop yields, which further support sustainable development goals.
3. **Feedstock Strategy with Potential to Scale to >1 Gt:** Globally, there is potential for 4.9 Gt / yr of CDR by deploying Basalt feedstocks on cropland (Strefler et al. 2018). Terradot is building an operating model to activate the 5,000+ existing global Basalt quarries into scaled CDR facilities through our OpenERW platform to unlock this potential.

4. **Pioneering MRV Methods to Close the Gap on Key Uncertainties:** Terradot addresses key MRV uncertainties through advanced techniques:
    - **Time Lags of Soil Buffer Fields:** Sequential extractions for elemental analysis of soil samples from different depths.
    - **Deep Soil Carbon Pools:** Quantifying soil carbon fractions (organic and inorganic) to 1m depth and measuring soil CO_2 fluxes via chambers.
    - **Soil Respiration Changes:** Monitoring changes through chamber measurements
    - **Downstream Leakage:** Measuring groundwater and streamwater to account for potential carbon losses. These methods ensure robust and reliable MRV, providing high confidence in the reported durable carbon removal outcomes.
5. **Efficient Deployment & Logistics:** Instead of developing new capabilities, Terradot partners with existing feedstock suppliers and leverages their infrastructure and local logistics networks. This strategy allows us to deploy high volumes of feedstock efficiently, reduce costs, accelerate project timelines, and focus on optimizing the ERW process to scale.

Conclusion

Terradot's approach to Enhanced Rock Weathering is differentiated by our scientific rigor, full project optimization, and scalable deployment strategy. Our partnerships and strategic initiatives in Brazil - one of the world's highest-potential ERW markets (Strefler et al. 2018) - position us to lead the global ERW effort, demonstrating the potential for gigaton-scale carbon removal and significant agronomic benefits. As we move towards COP30, Terradot is committed to unlocking the full potential of ERW to address the climate crisis and Regenerate Earth.

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

What Terradot is Building

Terradot aims to build scalable and impactful Enhanced Rock Weathering (ERW) infrastructure, powered by our OpenERW platform, to achieve gigaton-scale carbon dioxide removal (CDR). We are executing lighthouse commercial projects that serve as pioneering examples to refine our methods and validate our models. These projects are instrumental in advancing our vision and laying the groundwork for large-scale deployment.

Our efforts are focused on Brazil, where we are establishing strategic alliances with research agencies like EMBRAPA, collaborating with universities like USP and ESALQ, and partnering with large mining and agriculture players that can bring these technologies to scale. By leveraging Brazil's ideal climate for fast rock weathering, we will showcase the results of this effort at COP30 in Belém, Brazil in 2025 to initiate a worldwide ERW movement.

[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.

Current Costs & Path to >0.5 Gt at <$100/ton

Current Cost Breakdown

Our costs today are primarily driven by feedstock cost, logistics costs, and MRV. Our current cost range is $250-300/ton, split roughly evenly between these cost drivers. The most immediate cost reduction opportunity for our ongoing projects in Brazil is transportation distance, as feedstock, rock application, and MRV costs remain relatively consistent across deployment areas.

Path to >0.5 Gt at <$100/ton

Our strategy for reducing costs and scaling to over 0.5 gigatons at less than $100 per ton involves several key levers. Our long-term, first-principles estimate of our portfolio average CDR cost is ~$85/ton. To reduce costs, we will use:

1. **Optimized Deployment:** Implementing full project optimization for carbon removal and agronomic benefit, including feedstock, logistics, and deployment planning.
2. **Investing in Scale:** Partnering with existing operations allows us to take advantage of operational efficiencies, and invest in further improvements such as installing high-efficiency rock crushers to scale quarry capacity.
3. **Model-Informed Measurement:** Our MRV system will leverage our foundational ERW scientific model to reduce measurement costs market-wide by up to 90%.

Reducing costs will support market growth but will not unlock Gigaton-scale ERW alone. To do so, Terradot is also working to scale both supply and demand for ERW. To scale ERW supply, we focus on leveraging existing mining and agricultural infrastructure and employing the OpenERW platform for comprehensive project management and optimization at scale.

To scale ERW demand, our focus is on quantifying the full range of ERW benefits (including soil health and crop yield improvements) to unlock new markets. We are specifically targeting supply-chain decarbonization, natural capital markets (e.g., biodiversity, adaptation, and water quality credits), and international regulatory markets.

Leveraging remote sensing and machine learning, we have identified over 5,000 high-potential sites for CDR deployment in the tropics, representing a 3-4 Gt/year opportunity. Powered by our OpenERW platform, we will transform these sites into scaled CDR facilities to unlock supply, leverage innovative business models to unlock demand, and move iteratively closer to our estimated first-principles cost of $85/ton in the process.

Frontier Pre-Purchase Project

Project Overview

This Frontier Pre-Purchase Project is designed to validate a novel approach to measuring weathering on soils derived from the same parent material as the feedstock, specifically basalt. This project utilizes our existing operational capabilities in Brazil.

Project Details

With this project, Terradot aims to address a critical scientific challenge: the reliability of existing weathering measurement techniques, when the rock and soil are chemically similar; for example, when the parent material is the same as the feedstock. Solving this issue is key to achieving

<$100/ton carbon removal for basalt-based ERW by enabling hyper-local deployment around feedstock suppliers.

Implementation

With our partner Grupo Siquiera, the second-largest basalt producer in Brazil, we have already deployed phase one of the project in Faxinal, Brazil, located ~150km from the mine. With the funding provided, we will complete the planned deployment on a second crop type (sugarcane) that is 40km from the mine. This will help derisk the offtake by diversifying parent material and crop type, gaining additional MRV learnings. We aim to deliver the first credits from this project by Q4 2024.

Expected Outcomes

Our first-principles techno-economic analysis suggests that for the 1,200+ active basalt quarry operations in Brazil, we can eventually achieve a <$100/ton removal within a 75km radius from the mine, covering over 100 million hectares and unlocking over 0.3 gigatons per year of removal potential in Brazil alone.

Current MRV Approach

Challenges in MRV for ERW

The challenges to comprehensive MRV for enhanced rock weathering are substantial due to the biogeochemical and hydrological complexity, operating over varying timescales and large geographical areas. Terradot is committed to developing a best-in-class MRV approach that addresses these challenges.

MRV Scientific Approach

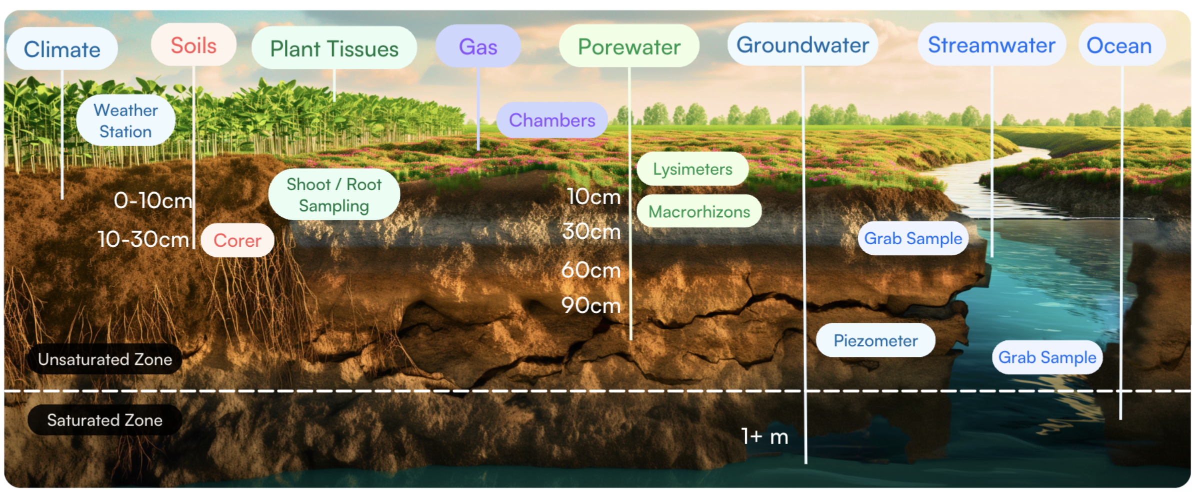


Figure 2. *In-field data collection description indicating type of measurements, devices, and soil depths.*

Our approach can be described in four steps:

1. **Measuring the Rate of Rock Weathering and Associated CO_2 Removed:**

- **Techniques:** We use multiple approaches, including mass loss assessment techniques, direct quantification of carbonate alkalinity generation, and integrative mass-balance modeling.
- **Measurements:** We collect solid and aqueous phase samples to analyze elemental concentrations, measure dissolved TIC (Total Inorganic Carbon), alkalinity and pH in soil pore water, and quantify hydrologic infiltration rates.

2. **Monitoring Bicarbonate Transport to the Ocean:**
   - **Monitoring Network:** Establishing a network from treatment fields through the hydrologic system (aquifers, rivers and streams) to the ocean, integrating existing infrastructure and datasets with new measurements.
   - **Key Measurements:** Monitoring pH, temperature, alkalinity, dissolved inorganic carbon, and ion species concentrations along the flowpath to identify and quantify losses of sequestered carbon.
3. **Measuring Changes to Agro-Ecosystem Health, GHG Emissions, and Crop Yield:**
   - **Soil Carbon Pools:** Quantifying changes to soil organic carbon pools via fractionation methods.
   - **Crop Yield and Biomass:** Evaluating crop yield and biomass through plant sampling and differential image analysis.
   - **Greenhouse gas (GHG) Emissions:** Monitoring soil emissions of CO_2, and potentially other GHGs like CH_4 and N_2O to assess the net GHG impact of ERW.
4. **Remote Monitoring and Modeling Network:**
   - **All-System Modeling Approach:** Developing a foundational ERW scientific model considering interactions between climate factors, soil properties, amendment composition and properties, and crop characteristics.
   - **Global Datasets Integration:** Populating the model with globally available datasets to reduce the need for extensive ground-based measurements over time.
   - **Optimization and Forecasting:** Enabling prediction and forecasting of CDR and crop yield prior to deployment, guiding optimization across ERW benefits.

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

<u>**Measurement, Reporting, and Verification (MRV) Risks**</u>

1. **Accounting for Uncertainties:**
   - **Uncertainty Tracking Approach:** We are developing an approach to quantify the level of uncertainty introduced at each step of the ERW process. Key uncertainties we must account for include:
     - **Quantifying Weathering in Soils, especially with the Same Parent Material as the Feedstock:**
       - **Uncertainty:** Existing methods are unreliable when the rock and soil are chemically similar, such as when the soil has the same parent material as the feedstock, posing a challenge for accurate measurement.
       - **Mitigation:** Developing multiple complementary approaches to measure weathering on similar parent materials including tracers,

isotopic ratios and innovating soil pore water sampling to measure functional outcomes of weathering.

- **Load Distribution in the Field:**
    - **Cause:** Heavy rain on sloped fields can lead to rock powder surface displacement (run-off), resulting in spatial heterogeneity in load.
    - **Solution:** Tilling immediately after deployment or assessing load distribution through geochemical analysis of post-deployment samples.
- **Spatial Intra-Field Heterogeneity:**
    - **Cause:** Fields have inherent spatial heterogeneity related to soil type, soil management, and crop rotation history.
    - **Solution:** Implementing a stratified sampling design and placing control plots based on topography and water flow paths ensures representative sampling.
- **Biological Respiration:**
    - **Cause:** Biological respiration in the soil profile produces CO_2, affecting pCO_2, weathering rates, and CO_2 efflux.
    - **Solution:** Quantifying autotrophic and heterotrophic respiration pools and accounting for interactions between crop type, soil tillage, and soil respiration through our coupled ERW-agroecosystem model.
- **Leakages (Post-Field - Downstream Modeling):**
    - **Cause:** Movement of bicarbonate through downstream waterways can affect TIC and CO_2, including mineral precipitation or degassing.
    - **Solution:** Developing reactive transport and ocean biogeochemical models to track the transport and fate of bicarbonate. Monitoring groundwater and stream chemistry regularly for parameterization and validation, along with existing datasets.

<u>**Project Execution Risks**</u>

1. **Timely Delivery and Spreading:**
    - **Risk:** Delays in spreading rock powder could impact project timelines and effectiveness.
    - **Mitigation:** We organize and plan delivery and spreading in advance, leveraging existing operational locations and partnerships to ensure timely execution.

<u>**Ecosystem Risks**</u>

1. **Potential for Heavy Metals and Contamination:**
    - **Risk:** Certain feedstocks might introduce heavy metals or other contaminants into the soil.
    - **Mitigation:** Use low-risk feedstocks such as basalt. Conduct thorough analysis and pre-deployment testing of feedstocks for contaminants and continuously monitor soil quality and composition post-deployment to ensure no harmful accumulation.
2. **Potential for Expanded Mining:**
    - **Risk:** Scaling ERW could lead to increased mining activities.
    - **Mitigation:** Prioritize the use of existing quarries and promote sustainable mining practices. Work with partners to ensure environmental regulations and sustainable practices are adhered to.

<u>**Financial Risks**</u>

1. **Inability to Secure Project Finance:**
    - **Risk:** Difficulty in attracting project finance without securitized assets.
    - **Mitigation:** Develop robust business models and financial structures to attract investment. Leverage strategic partnerships with financial institutions and government bodies to secure funding.
2. **Insufficient Demand for Further Scaling:**
    - **Risk:** Market demand may not grow sufficiently to support scaling efforts.
    - **Mitigation:** Create new markets for ERW through international collaborations and policy support. Engage in nation-level campaigns and co-deployments to unlock additional funding sources and drive demand.

Other Risks

1. **Public Perception:**
    - **Risk:** Working with mining and agricultural companies not typically known for sustainability could negatively impact public perception.
    - **Mitigation:** Maintain transparency and engage in public education efforts to highlight the sustainability benefits of ERW. Showcase successful case studies and collaborate with reputable environmental organizations to build trust and credibility.

Conclusion

Terradot's proactive approach to risk management ensures that we address potential challenges across project execution, MRV, ecosystem, financial, and public perception areas. By implementing robust mitigation strategies, we are confident in our ability to advance ERW as a scalable and sustainable solution for carbon dioxide removal and climate resilience.

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)*	1,880 tons
Delivery window *(at what point should Frontier consider your contract complete? Should match 2f)*	2024-2026
Levelized cost ($/ton CO_2) *(This is the cost per ton for the project tonnage described above, and should match 6d)*	$232 / ton
Levelized price ($/ton CO_2)[3] *(This is the price per ton of your offer to us for the tonnage described above)*	$266 / ton

[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).