# [Auxilium]
## 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

Auxilium

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

Tucson, AZ

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

Abraham Jalbout

Brief company or organization description <20 words

Auxilium is a technology company, focused on developing innovative regenerative solutions for tailings valorization.

## 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

The proposed Carbon Dioxide Removal (CDR) technology harnesses the unique properties of processed mine tailings to capture and store atmospheric CO2 in the form of stable mineral carbonates. This process not only mitigates the impact of CO2 emissions but also repurposes mining

[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.

waste into valuable construction material. This innovative approach ensures the carbon is sequestered for over 1,000 years.

**Mechanism of CO2 Removal and Storage:**

Tailings Processing

The mine tailings undergo a processing phase to remove sulfides and other harmful substances in order to make them environmentally safe and suitable for Geofoam production. This involves several steps, including flotation, filtration, and sieving to achieve the ideal particle size. The treated tailings are then submitted for assay to ensure they meet stringent safety standards, making them safe for use in construction applications. This pre-treatment process not only guarantees the safety and integrity of the final Geofoam product but also ensures that it can be widely adopted without posing any health or environmental risks.

Capture and Carbonation Process

The Geofoam reaction employs processed fine tailings, treated with specific reagents to enhance their reactivity with CO2. The core of the process is the carbonation reaction, where CO2 from the atmosphere reacts with calcium hydroxide in lime water to form calcium carbonate ($CaCO_3$) and calcium bicarbonate ($Ca(HCO_3)_2$). This process not only captures CO2 but also converts it into stable mineral forms that are naturally occurring and environmentally benign.

Storage Stability

The carbonates formed during the carbonation process are highly stable and resistant to decomposition. Calcium carbonate, in particular, is a prevalent mineral in natural settings, known for its durability and longevity. Carbonates can remain stable for millions of years under typical environmental conditions.

**Differentiating Factors:**

Innovative Use of Mine Tailings

Unlike other CDR technologies that rely solely on direct air capture or biological methods, our approach integrates mine tailings, converting a waste product into a valuable resource. In addition, our process takes place on-site, reducing any additional CO2 emissions from transportation. The dual benefit of waste reduction and carbon sequestration as well as our on-site approach sets our technology apart from other similar methods.

Stability and Longevity

By converting CO2 into carbonate minerals, Geofoam effectively locks carbon in a stable, long-term form, reducing atmospheric CO2 levels. Our process uniquely removes sulfides from tailings before mineralizing CO2 into calcium carbonate. The presence of sulfides can lower the surrounding pH which can cause calcium carbonate to decompose back into atmospheric CO2. Other technologies may face challenges with the permanence of storage, but our mineralization process guarantees stability for thousands to millions of years.

Versatile Applications

Geofoam produced from our process has multiple applications in construction and environmental engineering. A few applications include use as an insulator due to its high thermal resistance, as a synthetic aggregate due to its high durability, and as backfill for pit mining operations. Each of these add economic value and promote sustainability.

*R*esource Efficiency

By utilizing existing mining waste, the technology reduces the need for new material extraction, conserving natural resources and minimizing environmental impact. Due to the on-site nature of our process, their is minimal need for material transport, reducing additional CO2 emissions. This efficient use of resources enhances the overall sustainability of the system.

**Priority Innovation Areas:**

Durability

Our carbon sequestration process ensures the storage of carbon for thousands to millions of years by converting $CO_2$ into stable mineral carbonates that are resistant to environmental changes. For our process we first remove any sulfides from mine tailings before mineralizing $CO_2$ into calcium carbonate. This process prevents the decomposition of calcium carbonate back into $CO_2$. The final Geofoam product is a durable and lightweight material with insulative properties and high structural stability.

Physical Footprint

By utilizing mine tailings, this technology repurposes existing industrial byproducts, thus avoiding the need for additional raw materials and land use. This approach reduces the overall environmental footprint and helps to conserve natural resources.

Cost

The integration of mine tailings provides a scalable and cost-effective solution. The abundant availability of tailings ensures a steady supply of raw materials, while the simplicity of the carbonation process keeps operational costs low. This has the potential to make the technology affordable at scale, targeting $90 per ton of $CO_2$ removed.

Capacity

The system is designed for scalable deployment, capable of capturing substantial amounts of $CO_2$. It aims to become a significant component of the global carbon removal portfolio, with a target of sequestering over 0.5 gigatons of $CO_2$ annually. By leveraging existing industrial byproducts and optimizing the carbonation process, this technology has the potential to make a meaningful impact on global carbon reduction efforts, contributing to climate goals and sustainable development initiatives.

Net Negativity

By maximizing the net removal of atmospheric carbon dioxide, the technology ensures that more $CO_2$ is removed from the atmosphere than is emitted during the process, contributing to a net-negative impact on greenhouse gas concentrations.

Additionality

The use of mine tailings ensures that the removal of $CO_2$ is additional, meaning it results in net new carbon removal rather than taking credit for removal that was already going to occur. This is achieved by utilizing waste materials that would otherwise remain as environmental burdens.

Verifiability

The technology employs scientifically rigorous and transparent methods for monitoring and verification, ensuring that the amount of $CO_2$ captured and stored is accurately measured and reported. This includes regular audits and independent verification.

Safety and Legality

The system is engineered to adhere to the highest standards of safety, regulatory compliance, and local environmental sustainability. It proactively mitigates risks and minimizes negative environmental impacts and other externalities continuously, ensuring that the technology remains within legal and ethical boundaries.

**Conclusion:**

Auxilium’s CDR technology offers a robust and sustainable solution for atmospheric $CO_2$ removal. By leveraging the unique properties of processed mine tailings and stabilizing agents, our technology ensures long-term carbon storage in the form of mineral carbonates. Our approach not only addresses carbon emissions but also repurposes mining waste, contributing to a circular economy.

The innovative design, scalability, and multiple co-benefits position this technology as a leading solution in the field of carbon capture and storage.

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

Our objective is to develop a scalable and cost-effective Carbon Dioxide Removal (CDR) system that utilizes processed mine tailings to capture and store atmospheric CO2 in stable mineral carbonates. This innovative approach not only mitigates CO2 emissions but also repurposes mining waste into valuable construction material, thus promoting a circular economy.

The project will initially be piloted at an existing mining operation using legacy tailings. This pilot phase will focus on optimizing the pre-treatment and carbonation process and scaling up production to produce significant amounts of Geofoam. Once carbonate formation and cost-effectiveness are validated, the technology will be deployed at multiple mine sites worldwide, particularly in regions with abundant mine tailings.

The pre-treatment process includes a concentration process to remove all the sulfides, this prevents leaching and outgassing of CO2 once it is sequestered. The resulting slurry is filtered to remove all liquid, allowing it to be sieved to smaller particle sizes. The small particle size allows the Geofoam to form a matrix with supplemented foam microbubbles. Reagents added to improve cohesion of the particles, and form carbonate molecules which increase the strength of the overall Geofoam. The formation of these carbonate molecules requires CO2 as an input, allowing carbon to be safely sequestered from the atmosphere during the Geofoam curing process.

The target is to establish multiple facilities capable of collectively sequestering over 0.5 gigatons of CO2 annually. Each facility will be designed to handle the specific types of mine tailings available locally, ensuring adaptability and efficiency. Each type of tailings used will be carefully sampled and analyzed to determine initial carbonate contents and characterization of other minerals/chemicals. Small initial Geofoam cubes are made in lab to be XRD analyzed for carbonate composition, leach tests are also completed to verify the stability of the carbonate minerals.

**Current Cost Breakdown:**

Reagents: $0.12/t

*Reagents are used to remove sulfides from initial tailings and facilitate carbonate formation during Geofoam creation.*

Power: $1.45/t

*Power output to ensure tailings processing and geofoam production remain operational.*

Labor $0.5/t

*Laboratory technicians will be responsible for operating the tailings processing facilities and Geofoam production.*

Supplies and Services: $0.3/t

*Equipment required for tailings processing and Geofoam production.*

Maintenance: $1.6/t

[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.

*Regular maintenance will be completed on all equipment to ensure the accuracy of all data acquisition and the consistency in final products.*

**Total: $3.97/t**

**To approach Frontier's cost and scale criteria, the following steps are necessary:**

Process Optimization

Our process takes steps to enhance the efficiency of the carbonation process by assessing the mineral composition of treated mine tailings, thus reducing energy consumption and increasing CO2 capture rates. Continued research and development using a variety of tailings samples is crucial to the continued optimization of the Geofoam production process. This research will involve different combinations of reagents and tailings to reach the ideal ratio for Geofoam curing with maximum CO2 sequestration.

Economies of Scale

Expand production capacity and standardize operations across multiple facilities to lower per-unit costs. Multiple mine sites with multiple tailings storage facilities will allow for a consistently large supply of input material. Localized production and use of Geofoam is ideal for the reduction in transportation costs and emissions. Replication of successful pilot plants and standardization across all facilities will allow for increased efficiency, consistency, and cost-savings.

**Quantifying Carbon Removed:**

To accurately quantify the net removal of carbon, it is essential to conduct detailed analyses of Geofoam samples at a small scale for each new pilot facility. This initial step involves producing multiple Geofoam samples and evaluating their carbonate content, which directly correlates with the amount of CO2 sequestered. X-ray diffraction (XRD) analysis is a reliable method for quantifying the carbonate content within the samples. By consistently sampling and analyzing these Geofoam blocks, we can establish a baseline for CO2 capture efficiency.

The results from XRD analysis will provide precise measurements of the calcium carbonate ($CaCO_3$) and calcium bicarbonate ($Ca(HCO_3)_2$) present in the samples. Since the formation of these carbonates is a direct result of CO2 reacting with calcium hydroxide, higher levels of $CaCO_3$ and $Ca(HCO_3)_2$ indicate a greater amount of CO2 sequestered. This means that by measuring the carbonate content, we can infer the amount of CO2 captured during the carbonation process.

To ensure the reliability and accuracy of our data, we will perform XRD analyses on a statistically significant number of samples from each pilot facility. These analyses will be conducted at regular intervals to monitor the consistency of CO2 capture over time. The data obtained from these samples will be averaged to provide a comprehensive understanding of the carbonation efficiency at small scales.

Once the baseline data from the pilot facilities are established, we can extrapolate these results to predict the performance of larger-scale operations. This scaling-up process involves applying the averaged carbonate content data to the increased production volumes at full-scale facilities. By doing so, we can estimate the total amount of CO2 sequestered in a larger operation based on the initial small-scale analyses.

This approach also allows for continuous optimization of the carbonation process. By identifying variations in carbonate content, we can adjust the initial process parameters to enhance CO2 capture efficiency. This iterative process of sampling, analysis, and optimization ensures that each new pilot facility operates at peak efficiency, contributing to the overall scalability and effectiveness of the CDR technology.

In summary, the systematic analysis of Geofoam samples using XRD at small scales is crucial for quantifying the net removal of carbon. Consistent sampling and thorough analysis provide a reliable foundation for scaling up the process and ensuring that the technology meets its carbon sequestration targets. This methodical approach not only validates the efficiency of CO2 capture but also facilitates ongoing improvements, making our Geofoam a robust and scalable solution for mitigating atmospheric CO2.

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

**Risk: Inconsistent CO2 Capture Efficiency**

Description: Variability in the carbonation process could result in inconsistent CO2 capture rates, reducing the overall effectiveness of the technology. Factors such as fluctuations in temperature, pressure, and the concentration of reactants can impact the efficiency of CO2 uptake.

Mitigation: Implement rigorous quality control and monitoring throughout the carbonation process. Sample Geofoam at regular intervals for analysis, ensuring consistency in the resulting carbonate formation.

**Risk: Variability in Mine Tailings Composition**

Description: The composition of mine tailings can vary significantly depending on the source, potentially affecting the consistency and efficiency of the carbonation process. Variations in mineral content and particle size could impact the reaction with CO2.

Mitigation: Conduct thorough characterization of mine tailings before use to understand their chemical and physical properties. Pre-treatment protocols are standardized to ensure uniformity in tailings quality. Sampling protocols are standardized to ensure accurate data acquisition that can be scaled to larger volumes. Collaboration with multiple mining sites is ongoing to diversify the source of tailings, thus reducing the impact of variability.

**Risk: Scaling Up Production**

Description: Transitioning from pilot-scale to full-scale production involves significant challenges, including ensuring process consistency, managing increased resource demands, and maintaining quality control.

Mitigation: Begin with a smaller pilot project as a minimum viable product to refine processes and identify potential challenges before scaling up. Gradually increase production capacity while closely monitoring performance and making necessary adjustments. Work closely with mine sites to ensure efficient tailings processing and Geofoam implementation.

**Risk: Inaccurate Carbon Sequestration Data**

Description: Inaccurate measurement of the amount of CO2 sequestered could undermine the credibility of the project and result in non-compliance with regulatory or contractual obligations.

Mitigation: Employ advanced and reliable measurement techniques, such as XRD analysis, to quantify carbonate content accurately. Establish a rigorous sampling protocol to ensure representative data. Engage third-party auditors for independent verification of carbon sequestration metrics.

**Risk: Environmental Impact of Tailings Processing**

Description: The processing of mine tailings could have adverse environmental impacts, such as soil and water contamination, if not managed properly.

Mitigation: Pre-treatment processes are environmentally friendly and remove harmful substances from mine tailings. We will conduct thorough environmental impact assessments before full-scale project initiation. By following best practices for waste management and pollution control, we can minimize negative effects on the local ecosystem.

**Risk: Operational Cost Overruns**

Description: Unanticipated operational expenses could exceed budget projections, affecting the project's financial viability.

Mitigation: Conduct thorough cost-benefit analyses during the planning phase. Establish clear financial controls and monitoring systems. Implement efficiency improvements and continuous optimization to reduce operational costs. Work closely with stakeholders to ensure a continuous

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| availability of raw materials and funding.<br><br>**Risk: Regulatory Compliance**<br><br>Description: Failure to comply with local, national, or international regulations could result in legal penalties, project delays, or shutdowns.<br><br>Mitigation: Maintain open communication with regulatory authorities and promptly address any compliance issues. Maintain open communication with mine sites to ensure all regulations and standards are followed. |

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.

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| **Proposed CDR** over the project lifetime (tons) *(should be net volume after taking into account the uncertainty discount proposed in 5c)* | Delivery of up to 16M tons of CO2 |
| **Delivery window** *(at what point should Frontier consider your contract complete? Should match 2f)* | This will take place over the course of 25 years at a rate of around 500k tCO2/year |
| **Levelized cost** ($/ton $CO_2$) *(This is the cost per ton for the project tonnage described above, and should match 6d)* | At a cost (industrial scale) of around $93/t which can be significantly reduced to below $80/t CO2 |
| **Levelized price** ($/ton $CO_2$)[3] *(This is the price per ton of your offer to us for the tonnage described above)* | Purchase price of ~$100/t |

[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).