[Thalo Labs]
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

Thalo Labs

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

Brooklyn, New York

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

Brian Zimmerly

Brief company or organization description <20 words

Thalo Labs builds emissions removal and reduction technology for the built environment paired with real-time measurement and verification.

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

[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.

Modular Direct Air Capture (DAC) Approach

Thalo Labs is proposing an alternate approach to direct air capture (DAC) by leveraging existing buildings and infrastructure to accelerate carbon removal efforts on a path to gigaton scale. Thalo has been developing a modular, DAC system for deployment in existing commercial, multifamily, and industrial buildings. Each Thalo DAC system is a standalone unit that plugs into an existing wall outlet and permanently sequesters CO2 from the ambient indoor air through direct mineralization. Our systems can be installed anywhere within a building and do not require integration with building HVAC systems. With current technology readiness, an average urban building with Thalo DAC can provide between 3-6 tons of nameplate carbon dioxide removal (CDR) per year with low upfront capital investment. Climate-relevant scale CDR is realized by aggregating and verifying the impact across many buildings using Thalo's proprietary onboard, real-time, and wireless communicating measurement, reporting, and verification (MRV) hardware.

In this initial removal project, Thalo will own and operate the DAC systems while the tenants and buildings benefit from better indoor air quality, lower HVAC ventilation costs, and participation in the decarbonization of their buildings and city. The cost of deploying and operating the DAC systems is covered by the sale of carbon credits. As costs decrease over time, Thalo plans to offer revenue share to participating buildings to further incentivize building participation and accelerate adoption. To-date, Thalo has established pilot relationships with about a dozen of the largest class A commercial building owners/operators, as well as two of the largest developers of LMI public and affordable housing, both of which unlock thousands of potential building sites. These partnerships are ready to move forward upon receiving a prepurchase agreement, establishing credibility of this approach to deploying modular DAC across many sites.

Catalytic investment at this stage will enable Thalo to demonstrate the operational viability of a modular approach while simultaneously accelerating improvements to our DAC system performance and calibrating the pathway to Gt CDR/year scale at $100/ton. As we look to accelerate drawdown, societal investment in diverse technological approaches to CDR is critical. Thalo's modular approach to CDR can unlock rapid innovation and cost reduction for DAC technology, similar to the impact that distributed solar had on the rapid improvement of the entire solar industry in the 2000s. Our solution is highly applicable to this year's priority innovation areas as we leverage existing infrastructure, have ultra-low energy demand, and drive impactful co-benefits and revenue generation opportunities. Unburdened by the large capital outlays, build times, and site selection constraints of centralized operations, Thalo's approach to CDR is poised to provide a faster path to high-quality, verifiable local carbon removals and become a key part of the global portfolio of climate solutions.

Direct Mineralization Permanent Sequestration Approach

Thalo's CDR approach takes place in three main steps, with transport in between each step.

Step 1: Generate sorbent: Thalo has developed a patent-pending technique to generate sorbent materials using a low-emissions technique.

Step 2: Capture CO2: The sorbent captures CO2 from ambient indoor air inside Thalo's novel reactor. The CO2 removed from the air is geologically permanently sequestered for >1,000 years through mineralization.

Step 3: Replace and reinsert: Once the sorbent is saturated, the used sorbent is easily removed and replaced with fresh sorbent. The saturated sorbent material is then reinserted into various supply chains, generating additional revenue sources.

Advantages and Differentiation

Speed to market through existing infrastructure: Thalo DAC systems are installed inside existing buildings, preferably in high occupancy areas, and do not require any connection to existing HVAC or building systems. Utilizing existing buildings as installation sites accelerates, by a factor of years, the time from contract signing to CO2 removal from the atmosphere. Thalo DAC systems are installed in a few hours and can start removing carbon immediately after installation. Project feasibility and timelines are de-risked by eliminating the need to acquire new land, obtain permits, and avoids environmental impacts from building new large centralized facilities.

Lower upfront capital cost: Smaller, modular systems require a fraction of the upfront capital investment compared to large centralized plants.

Rapid scalability: Incremental deployment means removal occurs as you scale and is only limited by the number of available buildings. Direct mineralization avoids any requirement of pipeline/well storage and therefore opens up new geographies for DAC sites. Short manufacturing lead times and minimal installation requirements enables near term rapid deployment of modular DAC systems.

Localized carbon removal: Locating DAC where emissions are generated increases capture efficiency due to elevated CO2 levels in the ambient indoor air. Co-benefits include improved building indoor air quality and lower HVAC costs from lower fresh air ventilation rates.

Accelerated technology innovation: Rapid iteration accelerates technology innovation by enabling continuous improvements and quicker feedback loops, which fosters faster problem-solving and adaptation to new challenges. This process leads to rapid cost reduction as inefficiencies are quickly identified and eliminated, production processes are optimized, and economies of scale are achieved more swiftly.

Leverage existing operational services: Thalo's modular approach leverages an already in-place workforce (i.e., building maintenance services), already scaled up operations (e.g., transportation logistics), and third-party service providers that already serve the buildings where DAC will be installed. With some training and enablement, these providers are uniquely positioned to manage sorbent cycling. Additionally, these services are already on a path to lower emissions, e.g., transportation's move to EVs, that will benefit Thalo's approach by increasing net CDR.

Built-in MRV: Each Thalo DAC system features proprietary best-in-class MRV hardware that uses scientifically rigorous and third-party verified methods to directly measure input and output air with the same accuracy and precision as utility continuous emissions monitoring systems (CEMS).

Permanent sequestration stored for > 1,000 years: Through the direct mineralization of CO2 onsite in the DAC system, our CDR is permanent and durable. CO2 will remain permanently adsorbed within calcium carbonate unless heated to the point of thermal decomposition at 900°C or exposed to acid. This method of storage is equivalent to geologic sequestration, permanently locking in carbon for at least 1,000 years.

Electrical grid optimization: In addition to emissions monitoring, Thalo closely monitors power consumption of both our sorbent generation process and capture process. This allows us to manage the operation of systems to participate in electrical grid optimization while also maximizing carbon efficiency.

Enhanced resilience: A modular network of DAC systems is less vulnerable to single points of failure, increasing overall system resilience and reliability.

Public awareness and engagement: Most CDR are distant and unrelated to a company's location, work, and community. Thalo's approach provides immediate, local impact that communities can see. Increased visibility of DAC systems in existing buildings will raise public awareness of their benefits, potentially leading to greater engagement and demand for DAC technology more broadly as people see its practical applications and positive environmental impact.

Job creation and local economic benefits: Locating DAC in existing buildings enables cities and their inhabitants to contribute and participate in the humanity-scale carbon removal effort in ways that are not possible with centralized DAC facilities.

Priority Innovation Areas Identified in the RFP

Overall

☑ Leverage existing assets to scale carbon removal quickly

☑ Lower prices through additional revenue sources

☑ Local environmental and economic co-benefits; improved IAQ and lower HVAC costs

Direct Air Capture (DAC)

☑ Ultra-low energy requirements

☑ Compelling plans to scale and reduce costs faster than existing players

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

Locations and Scale

Thalo Labs aims to build the world's lowest cost DAC "plant" through aggregation of many modular DAC systems installed in existing buildings. We aim to leverage short term operational effort to cut capital costs and deployment pain by orders of magnitude. Thalo's deployment for captured tons in this prepurchase project will come from existing commercial and large multifamily buildings in the New York City region, with an initial focus on low- and middle-income (LMI) multifamily buildings. Thalo is proposing a commitment of 550 tCO2 gross CDR at a prepurchase price of $900/tCO2 gross CDR.

Current cost breakdown

[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.

[Levelized upfront capital cost $71,600] + [Operational cost $324,400] = [Total cost $396,000]

Category	**Cost per gross tCO2**
Levelized capital cost	$130 / t CO2
Sorbent generation	$213 / t CO2
Sorbent transportation	$96 / t CO2
In-building sorbent management	$134 / t CO2
Energy cost	$145 / t CO2
Total	$719 / t CO2

Pathway to Deliver 0.5 Gt CDR/year at $100/ton

The pathway to gigaton removal at low costs depends on our ability to scale. Thalo's approach is an alternate way to accelerate the path to scale.

Capital costs: A key advantage of building a small-atomic unit modular DAC system is the ability to achieve economies of scale, significantly reducing manufacturing costs for both materials and labor. Additionally, rapid scaling and iterative design improvements will further enhance overall cost efficiencies in the hardware design.

Non-linear growth: Thalo's approach is designed to generate net negative CDR using power from the existing high emissions grid. As Thalo scales and the grid continues its transition to low cost, low emission power, net CDR will increase non-linearly.

Sorbent production: Sorbent production costs are a key focus area for Thalo. We plan to reduce these costs through improved process design and by locating our production facilities near low-cost, low-emission power plants to take advantage of low-cost electricity. As we are in the early stages of developing our process design, we anticipate substantial gains in efficiency and cost reduction.

Sorbent transportation: As the grid transitions to more low-cost low emissions sources, we'll be able to move sorbent production closer to the point of capture and reduce logistics cost and emissions.

In-building sorbent management: For this project, Thalo will independently conduct in-building sorbent replacements and servicing. Catalytic prepurchases, such as the Frontier project, enable Thalo to demonstrate to building owners and operators the ease of sorbent replacement in order to facilitate the transition of these services to the existing workforce. Costs to perform this work will be minimal or no additional cost, as these tasks closely align with their current responsibilities, and are quick to perform. Additionally, improved hardware design will further simplify in-building services and reduce costs.

Energy cost: Thalo is currently accounting for energy costs from on-site DAC in our cost breakdown. However, the low power requirements and operational benefits of on-site DAC systems are expected to drive this cost toward zero. Building owners and operators will pay for DAC power consumption on their existing bills, justified by the offset of the benefits from cleaner air and reduced HVAC ventilation costs. Additionally, as buildings transition to low emission and low-cost power sources, the on-site $/kWh will exert downward pressure on energy costs in general.

Technology: Thalo will need to execute on improving overall DAC performance, specifically in terms of time-to-full-saturation and reaction completeness. Based on current estimates, we see a clear path to 2-3x the tCO2 nameplate capacity and are expected to find more efficiencies and performance enhancement opportunities as we get more real-time performance data from an increasing number of deployments.

Market demand: An important lever on the pathway to gigaton scale and <$100/ton costs is a large and highly functional market for high quality verified carbon credits. Demand for carbon credits will accelerate investment and improve the cost of capital that will unlock many of the advancements necessary to realize climate-relevant scale for carbon removal.

Quantification Approach

All carbon dioxide removal and energy consumption is directly measured on-site. Each Thalo DAC system has integrated measurement, reporting, and verification (MRV) through our patented, real-time, third-party verified continuous emissions monitoring system (CEMS). Thalo's MRV hardware includes direct measurement of CO2 parts per million, temperature, humidity, and mass flux for both input and output air in order to perform real-time measurement of carbon dioxide removed. Systems are wirelessly connected to the cloud while also having onboard memory storage in cases of communication loss.

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

Technical

DAC system development: To date, Thalo has manufactured our pilot DAC systems in our Brooklyn facility at low volumes. Now that we have reached a level of maturity and design evolution, we have engaged with a contract manufacturer and begun the work to transition manufacturing over but have not yet demonstrated the ability to deliver DAC systems at the capacity required in this project. There is a risk that transitioning to third party contract manufacturing takes longer than expected and/or cannot be delivered for the expected price as modeled in the TEA. This risk will be mitigated by hiring additional staff internally to produce more units in our Brooklyn facility if contract manufacturing is delayed. The cost risk is mitigated by assuming the same manufacturing cost as today we have today at very low volumes and no economies of scale.

Project Execution

Servicing operation: During early-stage execution, Thalo will need to directly manage the operational personnel needed to complete sorbent swaps on the DAC systems installed in each building. As operations scale, existing building staff and third-party service providers will perform this task in the same way that they already carry out maintenance and waste removal duties. There is a risk that transitioning to existing staff and service providers cannot be negotiated at the expected operational costs and/or within the required timeframe to deliver systems at scale. This risk is mitigated by Thalo hiring and managing service staff and working directly with building owners on a transition plan to using building staff as operations reach a steady state. The costs of these tasks at Thalo's expected rates are included in the TEA and represent the cost of comparable existing building staff as reported on salary sites such as salary.com and payscale.com.

MRV

MRV: There is relatively low risk associated with this project as a DAC plus mineralized storage project given the high Verification Confidence Levels for this type of CDR. Established market-wide protocols have not been standardized by marketplaces, buyers, or governments. We are mitigating this risk by building MRV expertise in-house and currently have the ability to quickly develop state-of-the-art MRV hardware and software as needed. To-date, Thalo has installed over 50 MRV installations whose measurement and verification methodology have been third-party verified by a leading engineering firm.

Ecosystem

Sorbent availability: The availability of a sufficient supply chain for low-carbon sorbent material is existential to execution of carbon removal. This is a risk faced not only by Thalo, but numerous other CDR providers as well. Thalo has spent the last year mitigating this risk by verticalizing our supply chain, resulting in patents and a scalable method for generation. Additionally, Thalo is investigating long term, vertically integrated solutions that may be feasible as energetic conditions change.

Captured CO2 offtake: The carbon-to-value market is very nascent. Our process of direct mineralization is more resilient to the nascent market since it can feed into numerous supply chains, large and small, that already use this mineral in existing processes and products. However, there is a risk that partnerships between sectors take longer to form and supply chains take longer to establish than expected. To mitigate this risk, we have identified several offtake partners at different levels of supply chain needs, to enable offtake at different stages of scale.

Financial

Operational costs: A critical component of Thalo's modular approach is the ability to drive down operational costs. There is a risk that operational cost downs prove more difficult than expected and/or take too long such that it hinders scalability in the long run. For this project, Thalo is mitigating operational cost risks in two ways

- Our TEA conservatively models off-the-shelf non-optimized equipment power consumption for calcination and grinding during sorbent generation. As we begin to deploy and scale up these operations, Thalo expects to invest heavily in R&D to make meaningful improvements to unlock CDR at climate-relevant scale and costs.
- Similarly, we have modeled transportation costs using well known low volume trucking rates. At scale, Thalo expects to utilize lower cost, high volume freight transportation such as rail and barge.

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)*	550 tCO2 gross CDR
Delivery window *(at what point should Frontier consider your contract complete? Should match 2f)*	Q1 2025 - Q4 2027
Levelized cost (\$/ton CO_2) *(This is the cost per ton for the project tonnage described above, and should match 6d)*	\$719 / tCO2 gross CDR
Levelized price (\$/ton CO_2)[3] *(This is the price per ton of your offer to us for the tonnage described above)*	\$900 / tCO2 gross CDR

[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).