AirMyne Inc.
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

AirMyne Inc.

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

United States of America

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

Mark Cyffka

Brief company or organization description <20 words

AirMyne is scaling high-quality carbon removal through our patented low-temperature, solvent-based Direct Air Capture (DAC) process.

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.

AirMyne is developing an affordable DAC technology to permanently remove CO2 from air at 0.5 billion tons-per-year scale and beyond. We do this by engineering our solution around the following design criteria:

- **Low-temperature thermal desorption** for integration with abundant, low-cost energy;
- **Liquid-phase capture** for a proven absorption mechanism & convenient material handling;
- **Continuous (e.g. non-batch) process** for most economical plant utilization;
- **Low-cost commodity material inputs** for predictable scaling via global supply chains;
- **Straightforward plant concept** using equipment familiar to the chemical industry; and
- **Minimal fire risk & toxicity** for lower costs and complexity of engineered controls.

Since launching in Q2 2022, we have demonstrated and scaled this approach in over 36 prototypes and reached 15 kg-per-day capacity while spending less than $3.5M. In Q1 2024, we hit a commercial milestone by delivering canisters of captured atmospheric CO2 to our partners CarbonBuilt and Rubi Technologies. AirMyne's DAC system is now protected by 5 granted patents and has been selected for support by 2 Department of Energy DAC Hub grants.

AirMyne's proprietary technology will be the first DAC deployment powered by next-generation geothermal technologies leveraging knowledge and techniques from the oil and gas industries. In doing so, AirMyne will help bring geothermal solutions down their cost curves and help Frontier achieve its programmatic goals of promoting DAC innovation, industrial integration, and delivering environmental/economic co-benefits.

Technology
In the first step of our process, fans pull atmospheric air into air-liquid contactors where CO2 is absorbed into a liquid capture agent composed of water, inorganic salts, promoters, and phase transfer catalysts. In the second step, the CO2-rich capture agent is heated to release CO2 gas and regenerate the capture agent for the next capture cycle. After the released CO2 is dehydrated of water vapor, it is ready for multi-stage compression and transport to permanent geological sequestration. The process is visually represented below in Figure 1.1.

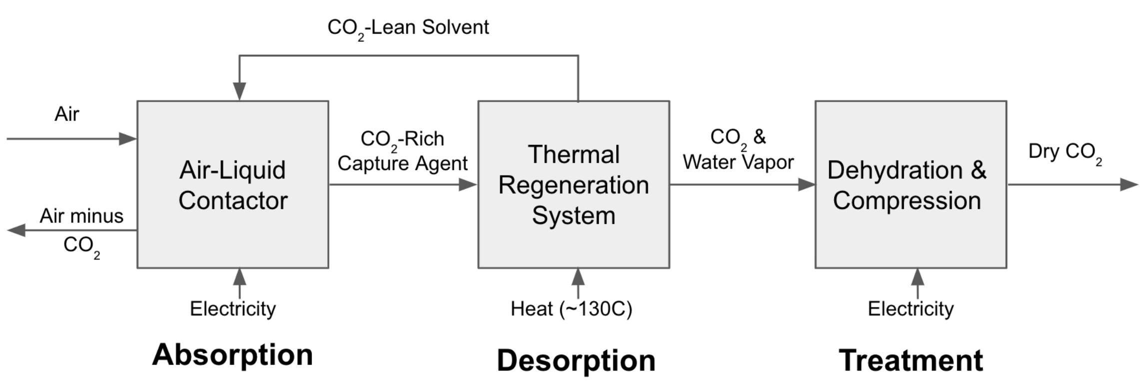

FIGURE 1.1. Flow diagram of AirMyne's Direct Air Capture (DAC) Process.

Team
AirMyne brings an industrial perspective to DAC with a diverse team of technical and commercial experts. AirMyne is, to our knowledge, the only DAC company founded & led by chemical industry veterans with experience inventing and scaling industrial products and processes to over $1B in annual revenue. AirMyne has since grown to a multidisciplinary team of 20, with domain expertise

spanning reaction engineering, mechanical engineering, automation, sensing, chemistry, commercial scaling, and project management.

AirMyne's engineering team prioritizes quick iteration on physical prototypes, utilizing materials from hardware retailers to create simple, practical, low-cost solutions. Examples of builds led by the engineering team include DAC prototypes, environmental chambers for simulating geographical climate conditions, and equipment for in-house, high-throughput production of self-designed air-liquid contactors. Our deployment team brings expertise in project management, risk assessment, construction, civil engineering, pipeline characterization & regulation, and well characterization, allowing us to evaluate and risk-assess energy, transport, and sequestration partners from an informed perspective. We are further supported by professors of fluid dynamics, aerodynamics, and phase transfer catalysis (UC Berkeley and Hebrew University), as well as IP strategy consultants (ex-Honeywell General Counsel), process safety consultants, and founders of industrial companies with multiple successful exits.

Innovation

Liquid DAC approaches with low-temperature thermal desorption processes combine the proven performance of absorption capture processes with the low cost & abundance of low-temperature heat. Despite having the potential to overcome scaling barriers faced by incumbent and competing DAC approaches, liquid low-temperature thermal DAC (LTT-DAC) remains nascent and mostly unexplored, with existing efforts focused on amino-acid capture pathways and processes designed to flexibly accommodate electrolytic desorption for the co-production of hydrogen. AirMyne sees a need and an opportunity to advance the state-of-the-art in LTT-DAC by using our industrial backgrounds and systems engineering mindset to develop an integrated and scalable LTT-DAC concept for which global supply chains can rapidly support every design element.
AirMyne is accomplishing this goal by prototyping and optimizing low-cost DAC systems designed to maximize our learning rates and system output. Our innovation strategy is balanced across the various system inputs needed to deliver a cost-effective integrated solution; specific examples of our innovation approach are presented below.

- Our **air-liquid contactors are designed, tested, and manufactured in-house**, using low-cost, off-the-shelf materials and conventional manufacturing processes for easier future transfer to toll manufacturers.
- Our **liquid capture agents are formulated, tested, and manufactured in-house** for <$1/kg costs at scale, comprising only **ingredients with existing global supply chains**.
- Our liquid capture agent is primarily inorganic in composition, offering **improved resistance to oxidative and thermal degradation** compared to approaches requiring higher proportions of organic ingredients for an **improved solvent lifetime.**
- The **low human and ecological toxicity** of the chemical inputs ensures the **lowest possible health, environmental, and financial costs** for waste disposal, safety engineering, and remediation response.
- A **proprietary blend of phase transfer catalysts and promoters** unique to AirMyne maximizes system performance and volumetric efficiency.

Designing & manufacturing our own air-liquid contactors and formulating our own liquid capture agents have led to faster compounding system improvements than could be achieved by focusing primarily on one element of the design. Further research into the LTT-DAC approach, and specifically AirMyne's innovative implementation, will be catalytic to unlocking DAC at scale in a way that is practical and cost-effective.

Geothermal Energy Strategy

Implementing DAC at 0.5 billion ton-per-year scale will require dedicated power sources that are abundant, low-cost, and low carbon. In parallel to our LTT-DAC innovation efforts, AirMyne has developed a differentiated, understudied, and impactful geothermal energy strategy to power DAC with next-generation geothermal technologies including sedimentary geothermal and enhanced geothermal systems (EGS).

While renewable electricity from solar and wind are being deployed at unprecedented levels, they may be unfit to power DAC at large scale due to their land use, intermittency, and cost when implemented with on-site energy storage. In contrast, geothermal heat is a firm, renewable energy resource with global abundance, low costs today, and a minimal surface footprint.

Previous DAC-geothermal deployments and concepts have relied on conventional techniques like “dry steam” and “flashed brine” geothermal. These techniques tap into the hottest, shallowest geothermal reservoirs found in volcanic regions which are geographically scarce and poorly distributed. Moreover, the subsurface geology in volcanic regions typically limits sequestration to *in situ* mineralization, which lacks regulatory approval in many jurisdictions and has not yet been safely demonstrated at the same scale as CO_2 storage in saline aquifers.

Sedimentary geothermal and EGS are next-generation geothermal technologies that leverage knowledge and techniques from the oil and gas industry to extract clean, firm energy from geological formations distributed widely around the world. Sedimentary geothermal extracts heat from brines that circulate naturally through sedimentary basins, including abandoned or uneconomical oil and gas formations depleted of hydrocarbons. EGS, on the other hand, extracts heat from a working fluid, typically water, that is flushed through artificially-induced fractures in a low-permeability rock. While each technology uses a different mechanism to extract heat, each taps into an abundant, renewable thermal resource not currently used for other purposes. Each technique can be deployed in rock formations which are ubiquitous around the world, and can often be located in close proximity to geology favorable for saline aquifer sequestration. As the costs of these techniques come down, they may become the most abundant and cost-effective sources of firm, low-carbon heat in most parts of the world.

Our geothermal strategy was developed after hundreds of hours of staff research and over two years of discussion and collaboration with leading geothermal companies, research groups, government agencies, and regulators. Evidence of our growing in-house geothermal expertise includes our selection as the anchor DAC technology partner of the only Department of Energy Regional DAC Hub project focusing on geothermal-DAC integration.

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

AirMyne plans to build the first demonstration of DAC powered by EGS or sedimentary geothermal heat in the world and the first geothermal-DAC project in the United States. This project will be the initial deployment in AirMyne’s plan to develop multi-kiloton-per-year and eventually multi-megaton-per-year DAC facilities powered by geothermal heat and coupled with geological sequestration.

Step 1: Site Evaluation (Q2 2024 - Q4 2024)

[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.

After conducting a year-long international siting study, AirMyne identified Texas and the broader Gulf of Mexico region as possessing a number of promising attributes including:

- Sedimentary geothermal heat accessible throughout Texas, Louisiana, Mississippi, and Alabama at conventional drilling depths and, in several cases, via existing oil and gas wells
- A growing EGS partner ecosystem and extensive geology suitable for EGS deployment
- Multiple Class VI geological sequestration projects under review by the EPA or, in the case of Louisiana, the Louisiana Office of Conservation
- Climate and weather conditions ideal for AirMyne's liquid DAC process
- Project partners active in the region with experience in geothermal, CO2 transport, and sequestration, as well as permitting, regulatory, and construction

While we continue to evaluate other project sites in consultation with our partners, our focus is narrowing to one of three specific sites of interest in South Texas, Southeast Texas, and South Alabama. In Q2 2024, AirMyne staff visited Houston, Texas to meet with two of these potential project partners and discuss project timelines and requirements in detail. After additional site visits and negotiations, AirMyne expects to make a final site selection decision in early Q4 2024.

Step 2: Deployment (Q1 2025 - Q1 2026)
Following site selection, we will install and commission a DAC system powered primarily by geothermal heat and able to capture CO2 from air at a 150 ton-per-year scale.

In the first phase of a two-phase deployment, a 25 ton-per-year integrated DAC system will be built and tested near our headquarters in Berkeley, California by Q1 2025. The system will be mounted to a skid for transport by truck to the chosen geothermal project site. There, brine would be sourced from a repurposed oil and gas well (sedimentary geothermal configuration) or a slipstream from an existing geothermal well (EGS configuration) and routed to a heat exchanger in the desorption system prior to re-injection. Electricity will be sourced from grid power, and process water will be sourced from municipal water supply or existing on-site water wells. The 25 ton-per-year system will undergo field testing with troubleshooting and process optimization performed on-site by AirMyne staff. Data and learnings from field testing, especially with respect to the system's robustness and sensitivity to varying weather conditions, will be used to optimize the design and operating parameters of future systems. No removals are currently planned for this 25 ton-per-year system.

After field testing is complete and after securing all necessary permits, AirMyne will expand the project to a 150 tons-per-year scale by Q1 2026 by installing additional air contactors and, optionally, a distillation column tuned to the thermal output of the geothermal heat source at the site. Electrical energy will transition to sourced or installed solar in order to meet our net-negativity targets. Upon commissioning and initial troubleshooting of the expanded facility, the project would then transition to a credit delivery phase.

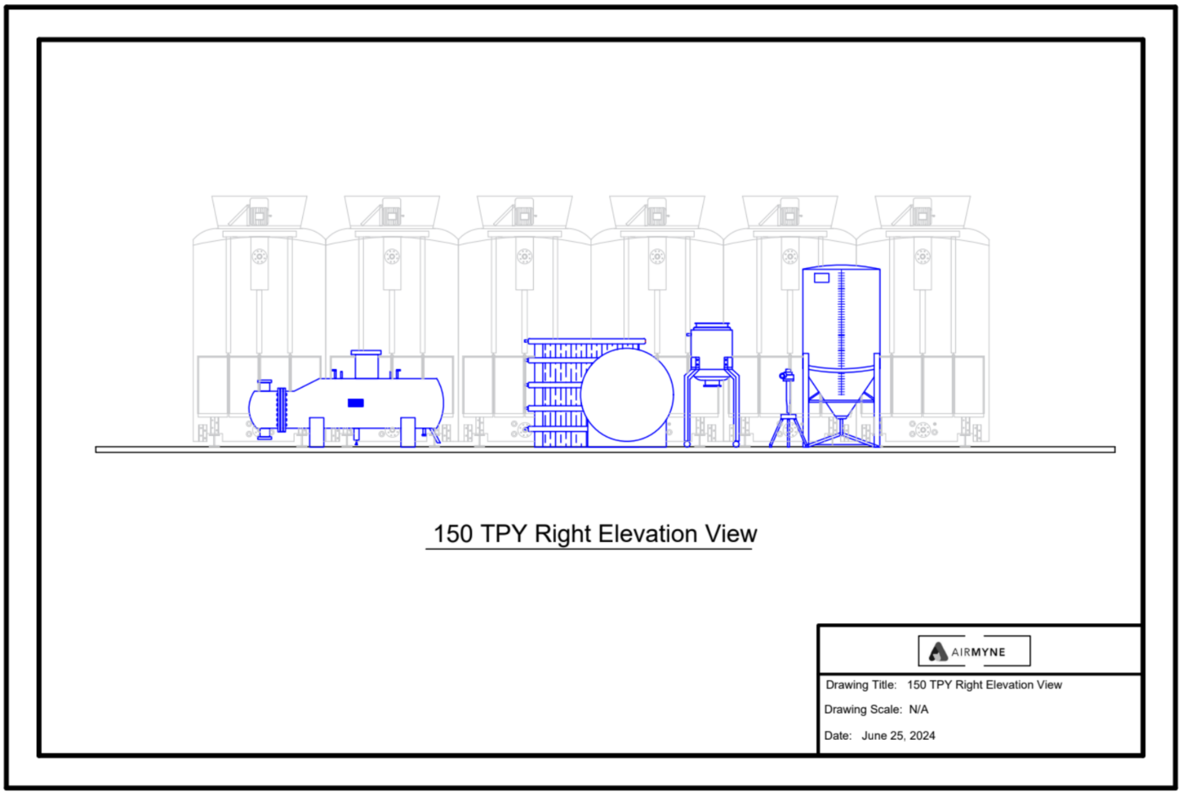

FIGURE 1.2. CAD diagram of the planned 150 ton-per-year DAC system.

Step 3: Delivery (Q2 2026 - Q4 2028)
In the Delivery phase, we will operate our 150 ton-per-year DAC system in a continuous manner, with any downtime solely for the purposes of maintenance, repairs, or upgrades. Data will be recorded and regularly shared with project partners.

All captured CO2 will be quantified via flow meter and stored in on-site vessels until it can be trucked to a regional sequestration partner with a sequestration method compatible with our methodology & registry. We are in discussions with four geological sequestration project developers to evaluate which of their projects could be most suitable for project success, and reaching out to others. Because trucking CO2 is emissions intensive, all efforts will be made to minimize trucking distance or identify alternate, lower-emissions options for transport to a suitable sequestration partner.

After delivery of all contracted carbon removal credits, AirMyne will continue operating the 150 ton-per-year DAC facility until its 10 year planned lifetime is reached. In parallel, we will seek all available pathways to expand the project to kiloton-per-year scale.

Cost Projections
Project costs can be broken down into Capex, referring to all the equipment used in the project and their associated financing costs, & Opex, referring to the variable costs associated with each additional ton of removal. Opex can be further broken down into Fixed Operating Expenses (e.g. overhead such as labor, permits, insurance, etc.), Energy costs (e.g. the energy used per delivered ton of carbon removal), and Non-energy variable costs (e.g. CO2 transport, sequestration, MRV, etc.).

For this project, we expect the cost breakdown as follows:

Cost Category	**% of total project cost**

	(rounded)
Capex	53%
Fixed Opex	39%
Energy	3%
Non-Energy Variable	5%

At scale, we expect Capex and associated financing costs to dominate our cost profile, with fixed Opex costs decreasing relative to other categories as economies of scale are realized.

Bringing our process to 0.5 billion-ton-per-year scale at <$100 ton will require continued innovation across the dimensions below:

1) **Minimizing CapEx.** The capital cost of air-liquid contactors is the biggest cost driver of our approach. Improving the volumetric efficiency of our air-liquid contactors is therefore critical to our success. Our air-liquid contactors have significant room for innovation, specifically in our interfacial packing material (e.g. for improved wetting properties, liquid hold-up, durability, & material cost) and our liquid capture agent (e.g. improved diffusion kinetics, molar conversion of reacted product). We will continue our rapid prototyping and iteration with the fastest possible learning rates.
2) **Minimizing electricity use.** We expect sourcing low-carbon electricity at the costs and volumes necessary to support large-scale DAC will be a challenge for decades to come. It is therefore critical to minimize electricity requirements in order to reach 0.5 billion-ton-per-year scale. With most of our electrical requirements going towards fans and pumps, we continue to pursue process optimizations that decrease electricity usage and improve efficiency, such as the use of pulsed flow for liquid distribution in the air-liquid contactor.
3) **Maximizing plant lifetime.** Chemical production plants and power plants are designed for decades of sustained operation to maximize their economic return. Similarly, DAC systems designed for easy maintenance and longevity will improve the net removal efficiency and economic return on invested capital.
4) **Accelerating geothermal deployment.** Geothermal energy offers myriad benefits, but deployment remains limited due to the financing and substantial up-front costs required to drill and commission a geothermal resource. Helping to bring geothermal along its cost curve, and working to develop DAC offtake contracts with durations matching the planned lifetime of a geothermal resource, will unlock geothermal heat as the best-in-class energy source for land use, cost, and emissions profile suitable for powering million-ton-per-year DAC plants.

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

Project Execution Risks:
We see three primary execution risks relating to geothermal well operations, sequestration, and weather.

The first risk concerns unplanned rework or integration costs from repurposing oil and gas wells for geothermal pilot studies or establishing slipstream lines from existing geothermal wells. Using repurposed oil and gas wells to extract geothermal heat has been demonstrated (See Gradient Geothermal, DOE Wells of Opportunity) and may offer the fastest, lowest-cost way to explore the integration of next-generation geothermal technologies with DAC in a pilot-scale context. However, unplanned rework, whether at the wellhead or downhole, could add substantial unplanned project costs. AirMyne is evaluating a variety of wells with help from our partner network to leverage their expertise to select the best possible project site for a successful outcome.

The second execution risk concerns sequestration. As of 6/20/2024, 35 sequestration projects and 107 wells are being evaluated for Class VI permits in the Gulf of Mexico region of our initial project focus. While Class VI permits are expected to be granted in the project timeline, it is still uncertain which of these projects will achieve an affirmative Final Investment Decision (FID). AirMyne has built relationships with CO2 utilization partners active in the region, but more planning is needed to ensure that CO2 captured from this project is used to generate removal credits through sequestration.

A third execution risk concerns extreme weather events. The coastal Gulf of Mexico region where we have narrowed our site evaluation efforts is susceptible to hurricanes, tornadoes, flooding, and other extreme weather events. Resulting system damage and power outages could introduce downtime that delays the delivery of credits. We will seek to insure our project and weatherize our systems to withstand inclement conditions up to 100-year weather events.

Environmental risks:
AirMyne is taking a number of steps to minimize our environmental and ecosystem risks. For example, our liquid capture agent is composed of nonvolatile chemical inputs with low environmental toxicity, and our air-liquid contactors include drift eliminators engineered to keep drift to acceptable levels. The largest environmental risk we can identify is if our system is destroyed in a catastrophic weather event e.g. hurricane or flood, and unplanned release of solvent occurs. All possible steps will be taken to plan & implement spill-prevention systems in anticipated operating conditions.

Technical Risks:
AirMyne has not yet demonstrated our process in a continuous, integrated system integrated with geothermal heat. As such we expect to encounter a range of as-yet-unknown challenges requiring troubleshooting, optimization, and engineering. These could be small (e.g. pumps burning out, corrosion damage of sensitive components, etc.) or large (e.g. scaling or corrosion within the geothermal heat exchanger exceeds our projections, etc.). We are using a FMEA framework to anticipate risks prior to their occurrence.

Financial Risks:
While Frontier's support will cover many direct expenses tied to the project, AirMyne will require additional funding to cover staffing, R&D, and other ongoing business operations critical to the company's short and long-term success. AirMyne has a track record of securing funding from investors and grant-making organizations, and will continue to take all possible steps to secure any necessary funding needed from dilutive & non-dilutive sources.

MRV Risks:
Delivery of credits will depend on AirMyne being able to ensure the CO2 injected via Class VI wells is covered by an MRV plan considered acceptable by our chosen methodology and registry. While we cannot control the MRV plans used by project partners such as sequestration project developers, we have developed internal processes to perform risk assessments, e.g. for well integrity and pipeline integrity, allowing us to evaluate sequestration partners and select those with a lower risk MRV profile.

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)*	185
Delivery window *(at what point should Frontier consider your contract complete? Should match 2f)*	EOY 2028
Levelized cost ($/ton CO_2) *(This is the cost per ton for the project tonnage described above, and should match 6d)*	$7134

Levelized price ($/ton CO_2)[3] *(This is the price per ton of your offer to us for the tonnage described above)*	$2703 ($500k/185 tons)

[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).