Octavia Carbon

Carbon dioxide removal prepurchase application

Summer 2023

General Application

(The General Application applies to everyone; all applicants should complete this)

Public section

The content in this section (answers to questions 1(a) - (d)) will be made public on the [Frontier GitHub repository](https://github.com) after the conclusion of the 2023 summer purchase cycle. Include as much detail as possible but omit sensitive proprietary information.

Company or organization name

Octavia Carbon

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

Nairobi, Kenya

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

Martin Freimüller

Brief company or organization description <20 words

Octavia Carbon builds low temperature-pressure swing Direct Air Capture (DAC) technology that uniquely leverages Kenya's geothermal energy and competitive talent.

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

[1] We use "project" throughout this template, but note that term is not intended to denote a single facility. The "project" being proposed to Frontier could include multiple facilities/locations or potentially all the CDR activities of your company.

project addresses any of the priority innovation areas identified in the RFP, tell us how. Please include figures and system schematics and be specific, but concise. Aim for 1000-1500 words.

Octavia Carbon designs and builds machines that directly capture CO_2 from the atmosphere using Direct Air Capture (DAC) technology at a low cost in Kenya, a highly favorable location for DAC. As we will explain below, the combination of our unique technology and strategy constitutes a new DAC approach for lower cost (in both CAPEX & OPEX), one of Frontier's priority innovation areas.

At the core of our DAC technology is a proprietary amine-based solid sorbent that facilitates the selective capturing of CO_2 from atmospheric air. Our patent-pending sorbent technology allows desorption to occur at ~60°C, the lowest sorbent regeneration temperatures recorded in the DAC industry. This ultra-low desorption temperature allows us to utilize a uniquely wide range of waste heat sources, from data centers to geothermal waste heat, to supply ~85% of our energy requirements. Specifically, our approach allows us to leverage Kenya's geothermal waste heat for desorption uniquely well, which is available up to million-ton scale of CDR at least. That is a crucial edge over most amine-based solid sorbent approaches, who would struggle to tie into waste heat at the temperatures and pressures typical for Kenya's geothermal sector. That low desorption temperature is the result of countless iterative innovations by our 25-strong Kenyan team, most notably our unique guillotine damper system and a sorbent structuring approach that is optimized for our local context.

The capture of CO_2 (adsorption) begins with the opening of our machine's damper plates, which exposes the sorbent chamber. The solid sorbent is packed in a bed constellation inside the sorbent chamber to maximize surface area exposed to the atmospheric air. Once the damper plates are opened, fans draw atmospheric air into the sorbent chamber from four sides. The sorbent selectively captures the CO_2 while allowing other atmospheric gases to pass through the machine's top plate. Once the sorbent is fully saturated, the damper plates close and create an airtight seal within the plenum area housing the sorbent chamber.

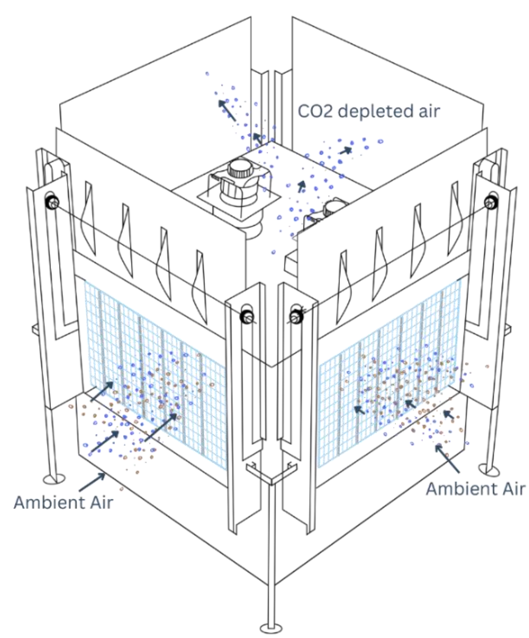

Figure 1 : Adsorption phase

The closing of the damper plates initiates the CO_2 release (desorption) phase, which begins with the evacuation of the plenum by a vacuum pump. The evacuation process creates the optimal vacuum pressures for our desorption approach, of <200mbar. Upon achieving the required vacuum pressures in the plenum, the sorbent is indirectly heated at temperatures of ~60°C using steam contained in pipes. The heating process releases the adsorbed CO_2, which is then compressed and directed to an air receiver for purification. The process utilizes steam derived from geothermal waste heat, available locally at the low cost of <$0.005/kWh. This heat energy for the desorption process accounts for ~85% of our overall energy requirements, meaning we use a mere ~400kWh/tCO_2 in electricity for our process, mostly to power our fans. Therefore, integrating geothermal waste heat into the desorption phase steeply reduces our operational cost.

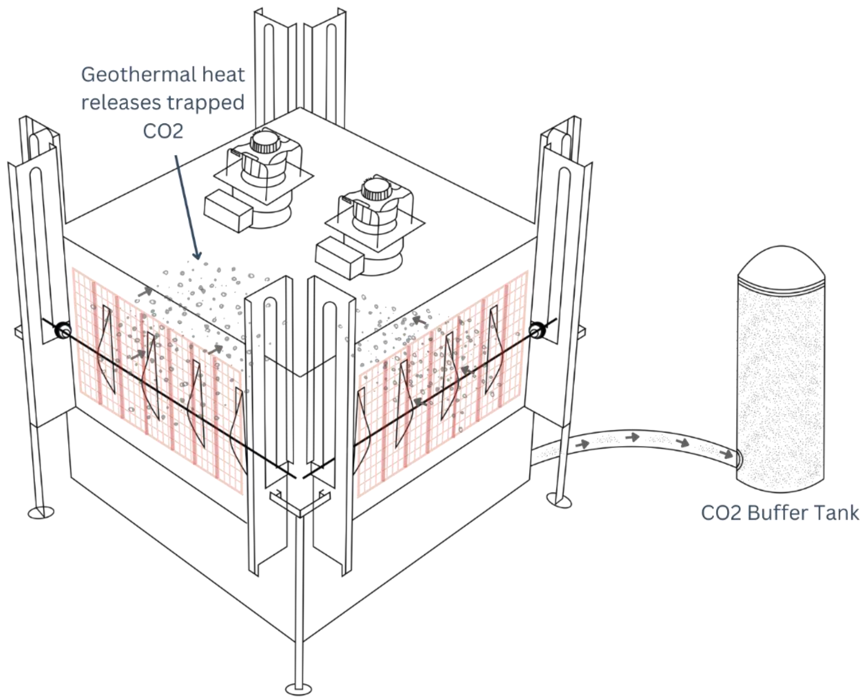

Figure 2 : Desorption phase

The adsorption and desorption processes operate in cycles, with each adsorption phase lasting approximately three hours, followed by a desorption phase lasting approximately one hour. To maximize the sorbent's life cycle, estimated at 5,000-10,000 cycles, the sorbent is cooled to temperatures below 40°C before the next adsorption phase begins.

Following the DAC process, we have partnered with Cella Mineral Storage ('Cella') – an in-situ carbon mineralization company operating in Kenya, to provide CO_2 storage. Cella – part of Frontier's Winter '22 cohort – will host a commercial CO_2 storage well, where the captured CO_2 will be injected into basaltic rock underground. Cella's injection process involves in-situ injection of CO_2 and water, allowing for mineralization to occur rapidly and completely. The Kenyan Rift Valley is rich in porous basaltic rocks, which are well suited for secure and permanent CO_2 storage. Mineralization ensures that CO_2 is durably stored as carbonate minerals and persists within basaltic rocks for millions of years.

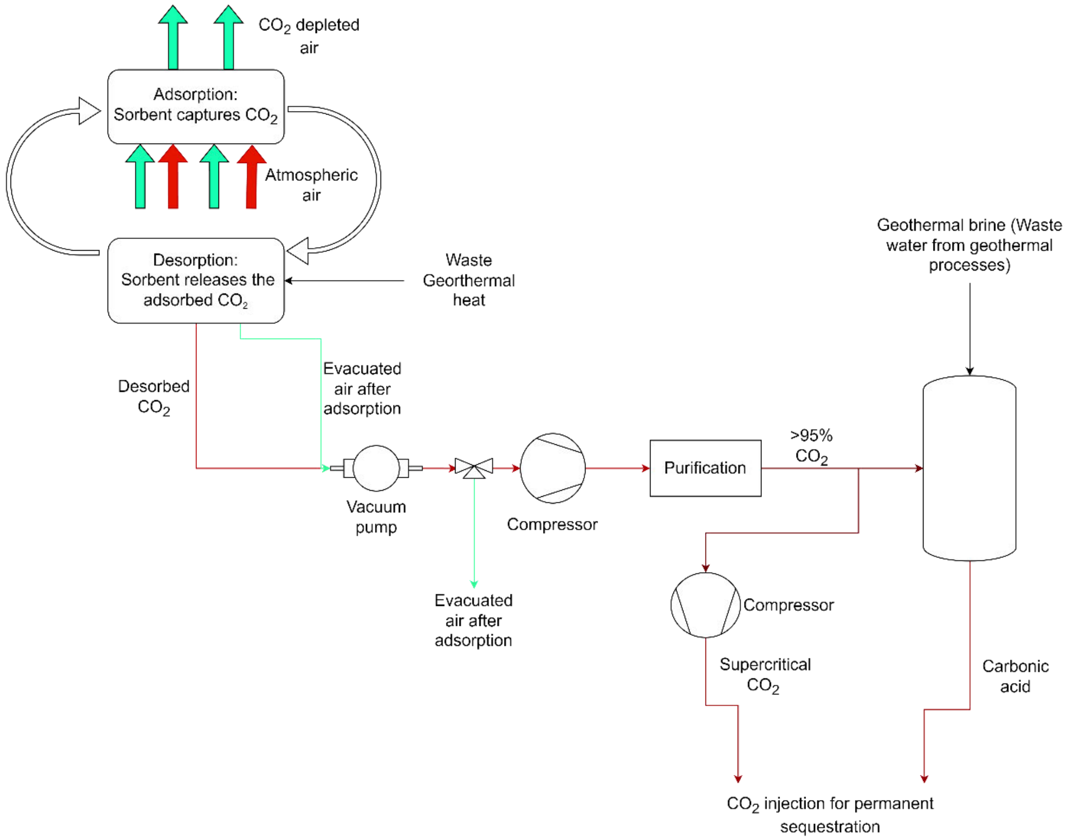

Figure 3: System schematics

We build our machines in a standardized and highly modular design allowing for fast iteration. In 13 months of operating as a company, we have built four at-scale DAC models, incl. 2 of the 100 modular >10 tCO_2/yr units that will constitute the DAC+Storage pilot described below. Over these at-scale iterations we have optimized our design for mass manufacture and long-term machine life, reducing points of potential failure and lowering the number and complexity of manufactured parts.

Figure 4: Lenana Model

Our strategic location in Kenya differentiates us from other DAC companies. We firmly believe Kenya is the world's best place to build and deploy DAC given its renewable energy, geology, and talent.

Kenya's electricity grid is 93% renewable (Kavilu, 2021), with credible plans to scale this to 100% by 2030. Kenya is the world's 8th largest geothermal producer (e.g., ahead of Iceland), with 863 MW of installed geothermal power, ~75% of which was added over the past decade. Kenya plans to increase this to 3 GW by 2030, though a lack of bankable industrial demand for geothermal electricity is increasingly constraining this build-out. Per day around 1,000 MWh of Kenya's geothermal electricity capacity is curtailed for lack of demand. That currently wasted baseload electricity alone and the concurrent waste heat from geothermal power generation, can power our DAC process to million-ton scale. Geothermal electricity also supplies us with 24/7 renewable energy at comparatively low cost of ~$0.10 / kWh. As electricity accounts for most of our OPEX, the ~400 kWh/tCO_2 needed for our process thus translates to ultra-low (DAC-related) OPEX of ~$66.2/t$CO_2$.

The presence of basaltic rocks around these geothermal sites also endows the Kenyan Rift Valley with ideal preconditions for permanent CO_2 storage. This further optimizes our operational costs, eliminating the need to acquire capital-intensive infrastructure for CO_2 transportation to storage sites. It also minimizes our project's environmental impact and makes it more sustainable and easier to execute. What is more, Kenya's decades-long geothermal expertise allows our CO_2 storage partners Cella to tap into unique capabilities to build out geological CO_2 storage capacity quickly.

Kenya also boasts a well-educated talent pool capable of advancing, building and deploying DAC technology at massive scale. This talent pool has been instrumental in developing our DAC technology, with >25,000 R&D hours invested in our tech within our first 13 months of operations alone. A key advantage is the lower cost of living in Kenya, which allows us to provide our staff with a decent lifestyle at a 1/10th the cost of our peers in the Global North. That, coupled with a Global South focused supply chain strategy for input chemicals and electricals, gives us uniquely low CAPEX. At machine-level, our current DAC design has CAPEX of <$232/t$CO_2$. While we will only have full visibility on plant-level CAPEX once our pilot plant is online in mid-2024, a conservative estimate suggests plant-level CAPEX of ~$67/t$CO_2$, suggesting a highly competitive ~$300/t$CO_2$ in total CAPEX (excl. financing costs).

Kenya's cost-competitive talent also allows us to scale our operations faster, and to have a much higher learning rate. Within 13 months as a company and on a relative shoestring budget, we have built a team of 25 people, projected to grow to >100 people by EOY-2023 as we transition to mass manufacturing our DAC machines. At a base level, we believe that learning rates in the DAC industry will be a function of how many brains are devoted to tackling the many technological challenges involved. It is the reason why the Global South was instrumental in bringing every other mainstream climate technology down the cost curve, and ultimately it is what allows us to progress at the urgency of the climate crisis.

While we believe that Kenya is the world's best place for low-cost DAC deployment, that is only true for companies that develop their technology in alignment with Kenya's natural and demographic endowments. Our patent-pending sorbent structure requires a low-temperature swing for desorption, allowing us to uniquely leverage Kenya's abundant geothermal waste heat for desorption. Additionally, our 10tCO_2/yr standalone DAC machines also give us the DAC industry's most modular DAC design produced at scale. That level of modularity is highly labor-intensive and would be cost-prohibitive in the Global North, but also enables us to very quickly create in-house manufacturing & EPC expertise that will be crucial to quickly scaling DAC.

Beyond cost reduction, our integration into Kenya's geothermal sector also brings significant co-benefits to our deployment. By utilizing waste geothermal capacity, heat, and infrastructure, we contribute to reducing geothermal electricity costs for end consumers. This will help drive Kenya's green industrialization and can cross-subsidize electricity access for both rural and urban communities. This key factor has attracted enthusiastic support from Kenyan policymakers and local communities, including influential figures like Dr. Ali Mohammed, Kenya's climate change envoy, who is an advisor to Octavia. Beyond the tangible impacts on energy access and job creation, we also take immense pride in leading the charge of globally competitive climate tech innovation in Kenya, instilling a deep sense of purpose and pride in our 25 employees.

b. **Project objectives:** What are you trying to build? Discuss location(s) and scale. What is the current cost breakdown, and what needs to happen for your CDR solution to approach Frontier's $100/t and 0.5Gt targets? What is your approach to quantifying the carbon removed? Please include figures and system schematics and be specific, but concise. Aim for 1000-1500 words.

We are building a >1,000tCO_2/yr DAC + Storage plant, Wangari 1 (*see Fig 5),* named in honor of Prof. Wangari Maathai, the first African woman to win the Nobel Peace Prize for her endless efforts in environmental conservation. Wangari 1 will be located around Naivasha, a town in the Kenyan Rift Valley.

Figure 5: A concept rendering of our 1,000 tCO_2/yr pilot project, Wangari 1

This project will be co-located with the operations of our geologic storage partner, Cella, who will store our air-captured CO_2 through in-situ mineralization in subsurface basalt formations. As referenced above, the Kenyan Rift Valley is rich in porous basalt formations and abundant geothermal energy, which makes it highly suitable for deploying our technology in the region.

Wangari 1 will house 100 of our 10tCO_2/yr modules arrayed in an installation that will be integrated with a geothermal source of heat and electricity, a processing plant, and a CO_2 storage well.

We estimate the CO_2 capture cost (without financing) to be ~\$530/tCO_2. With a 6% finance cost, we estimate the CO_2 capture cost to increase to ~\$642/tCO_2.

Table 1: Cost Breakdown

Item	Breakdown	Cost (\$/tCO_2)
CAPEX	DAC Level	231.40
	Plant Level	66.80
OPEX	Energy	66.20
	CO2 Storage	40.00
Other	Maintenance	43.60
	Insurance	32.70
	Contingency	27.30
SUBTOTAL		508.00
Removal Efficiency compensation		21.17
	TOTAL	529.17

Having already built two of the 100 DAC units we intend to deploy at site, we have a clear understanding of the machine-level costs. However, we lack as much visibility on the plant-level CAPEX as we have yet to build the pilot. That is an uncertainty we are factoring into our pricing strategy. As a result, we plan to pre-sell the credits generated by Wangari 1 at a higher price, accounting for the potential risks and uncertainties associated with plant-level CAPEX and other cost components.

Requirements for CDR:

To permanently remove CO_2 from the air, we need access to renewable electricity, waste heat, and a storage well. Renewable electricity serves as the power source for the electrical components within our machines, including fans, compressors, vacuum pumps, and more. Our preferred source of electricity is geothermal, which in Kenya has remarkably low lifecycle emissions even by the standards of other renewables deployed globally, at 16.7g CO_2-eq/kWh (Mutia, 2012). The waste heat generated during the geothermal process plays a crucial role in regenerating our sorbent. This waste heat is derived from either the geothermal brine or the exhaust steam produced during the electricity generation process. By utilizing this waste heat, we can meet ~85% of our total energy requirements, enabling us to maintain very low OPEX of <\$70/tCO_2 (at the currently proposed \$0.10/kWh of electricity).

The storage well and storage processes will be provided and handled by our storage partner – Cella.

The high modularity of our technology offers a significant advantage as it enables cost-effective mass production in Kenya. This scalability is key to advancing DAC. Our roadmap for 2023 entails building 100 units of the 10tCO_2/yr model while incorporating iterative improvements into each build. Simultaneously, we are making substantial investments in our R&D to enhance the capacity of each module. Our upcoming second-generation design will capture 100tCO_2/ while occupying the same physical footprint as our 10tCO_2/yr model. By the end of 2023, we aim to produce a prototype of this advanced unit, which will serve as the cornerstone of our scaling efforts.

Table 2 shows our scale-up trajectory towards $100/t$CO_2$ captured:

Table 2: Scale-up plans

Approximate timeline for cost milestone (year)	Annual production volume (tCO_2/yr.)	Target Cost ($/t$CO_2$-captured, ***excl. storage***)
2024-25	50K	400
2025-26	250K	200
2026-28	1M	100

In 2027-30 and beyond, we will scale our costs to below $100/t$CO_2$ net captured and stored, factoring in expected cost savings by our CO_2 storage partner Cella.

Quantification of CO_2 removed:

The measurement of CO_2 captured is done using a combination of sensors and flowmeters.

Within our machines, we have strategically placed 2 ambient CO_2 sensors: one upstream and one downstream of our sorbent. These sensors enable us to measure the extent of CO_2 adsorption that occurs within the system. By monitoring the differential readings between these sensors, our control system precisely calculates the amount of CO_2 that has been adsorbed in real-time. As the adsorption phase progresses, the control system continuously analyzes the differential readings, and when the average of subsequent values falls below a threshold of 10%, it signifies the completion of the adsorption phase. Subsequently, the desorption phase commences, allowing for the release of the captured CO_2.

The desorption phase takes place at elevated temperatures in a partial vacuum. To measure the amount of CO_2 desorbed, we use a combination of a pressure sensor, volumetric CO_2 sensor, and temperature sensors. All sensors are calibrated to operate effectively within vacuum conditions. As desorption occurs, the pressure within the machine increases. All the sensor readings are relayed to the control system. It is programmed to use the partial pressure of CO_2, derived from the concentration readings, along with the gas equations, to calculate the mass of CO_2 being desorbed by the sorbent.

At plant level, we will monitor the CO_2 at 2 key strategic points. The CO_2 desorbed from the machines is pumped into high pressure air receivers that are used for buffer storage. At this point, the same technique used during desorption is used to compute the mass of CO_2 stored in the air receiver. As the CO_2 leaves the air receiver into the downstream liquefaction plant, it passes through a flowmeter. Upstream of the flowmeter, we will sample the gas and feed it to a gas analyzer that feeds its readings directly to the flowmeter. The flowmeter is designed to self-calibrate in real time using the readings from the gas analyzer. This will give us an accurate measurement of the amount of CO_2 being fed into the liquefaction plant.

The liquefaction plant purifies the CO_2 to >95% and will feed it into the injection well where it will be mixed with water. We will take samples of CO_2 downstream of the liquefaction plant to determine the CO_2 concentration. A liquid flowmeter will be installed just upstream of the injection well to determine the exact amount of CO_2 being injected underground. This gives us a highly accurate understanding of the gross CO_2 removed.

For a detailed description of how our storage partner Cella will quantify CDR post-injection, we refer the reader to Cella's Frontier application to the 2022 Winter cohort.

To get the net CO_2 removed, we have had a rigorous 3rd party LCA done by Carbon Based Consulting in accordance with ISO 14040 and ISO 14044. This LCA has taken the emissions across our entire supply chain into account. The gross removal is then discounted against our removal efficiency to account for our own emissions and sell the net removal as credits. Currently, our removal efficiency is 96%. We expect to update this figure as we build out the plant.

c. **Risks:** What are the biggest risks and how will you mitigate those? Include technical, project execution, measurement, reporting and verification (MRV), ecosystem, financial, and any other risks. Aim for 500-1000 words.

Technological Risks:
We have built four at-scale DAC machines and are currently iterating our latest 10 tCO_2/yr ('Lenana') model. Our track record demonstrates our ability to iterate quickly and overcome technological challenges, ensuring the efficiency of our machines.

One challenge we face in large-scale DAC units is maintaining low vacuum pressures during desorption. The use of inconsistent welding procedures by different contractors has caused steel sheets to warp, compromising the tight seal in the plenum. We have taken proactive steps to standardize our welding processes by bringing them in-house.

In our commitment to cost-effectiveness, we have been determined to source input chemicals from low-cost suppliers. This has occasionally resulted in variable sorbent quality, as we produce the sorbent in batches of >100 kilograms. However, we are establishing robust supply chains to ensure consistent and high-quality sorbent production.

To account for uncertain performance risks, our Lenana models have been designed with a 50% higher actual capacity (15tCO_2/yr), compared to their nameplate capacity (10tCO_2/yr). This design considers the potential risk of sorbent degradation, which is estimated to occur after approximately 5,000 cycles or 2 years of operation. To mitigate against sorbent degradation, we are implementing an innovative solution of cooling the sorbent before each subsequent adsorption cycle. This measure ensures that our machines maintain optimal capture capacities throughout their operational lifespan.

Project Execution Risks:

Scaling up the manufacturing of our DAC machines is pivotal to meeting our project execution timelines. Our goal is to manufacture 100 Lenana models by the end of Q4-23. We are leveraging Kenya's excellent manufacturing capabilities by sourcing experienced managers from manufacturers with a long-standing legacy of manufacturing in Kenya, such as Isuzu. Kenya's abundant pool of skilled talent and our ability to pay top-of-market salaries enables us to hire skilled professionals such as welders and electricians within 3-5 business days. This enhances our operational efficiency as we can rapidly add staff capacity in alignment with our ambitious scale-up targets. We have already secured ~20,000 ft^2 of manufacturing space at a highly competitive rate of \$0.2/ft^2.

For full control of our costs and timelines, we have decided to handle the EPC of our pilot plant in-house. In full awareness that this requires a steep learning curve, we are implementing some strategies to mitigate associated risks. We are actively engaging external consultants on topics such as steam distribution and distributed industrial control, while also looking to hire highly experienced EPC managers to ensure we have the required skillsets.

DAC is energy intensive and requires a reliable energy supply. We will work with a private geothermal concession holder, giving us access to geothermal electricity and heat. It also gives us the flexibility to negotiate lower than market rates for industrial electricity with the concession holder. Cella has led the conversations with the concession holder and are now at contracting stage.

Regulatory Risks:

The potential delay in obtaining national regulatory permits for the deployment of our plant could impact the timelines of our project. Aware of this, we started engaging the Kenyan government in Q1 this year. We gained assurance of the government's support in our deployment through our advisor, Dr. Ali Mohammed – Kenya's climate change envoy and advisor to the president. We require an Environmental Impact Assessment (EIA) form from Kenya's National Environmental Management Agency (NEMA) before commencing our deployment. We will initiate discussions with NEMA regarding this impact assessment in Q3 of 2023 and have had several assurances that this will not become a roadblock to our project timeline.

Measurement, Reporting and Verification Risks:

We recognize the importance of accurate MRV standards in ensuring the transparency and credibility of our DAC operations. In this regard, we consider Puro.earth the best in class regarding DAC + in-situ mineralization MRV. We are now listed on Puro's registry and expect to be the first DAC company to get fully validated via their Geologically Stored Carbon standard, and hence the first-ever DAC company validated under an ICROA-approved standard.

Additionally, we are actively contributing towards the CCS+ Initiative and anticipate the release of their DAC and in-situ mineralization standards. Once their standards become available, we will strongly consider getting certified against these standards. We believe that external MRV protocols are crucial in advancing our DAC industry, therefore, we do not intend to develop an entirely in-house MRV protocol.

Ecosystem Risks:

A key advantage of DAC technology is that it requires a minimal land footprint and offers a closed-loop system, minimizing the risk of ecosystem leakage. We do not anticipate any significant ecosystem risk with Wangari 1. We acknowledge the potential for noise emissions from our operations. However, the noise emissions would be similar to what is typical for the geothermal plant present in our deployment area. We have accounted for potential ecosystem risks at our project's decommissioning, which includes proper sorbent disposal upon its end-of-life.

We are taking proactive steps to address any potential ecosystem risks by engaging local environmental regulatory bodies. This will ensure appropriate measures are implemented within our deployment area by identifying and mitigating unanticipated risks.

Financing Risks:

As an organization, we are at a crucial stage, transitioning from the development stage to scaling our operations. This transition poses a challenge as we need substantial capital to expand our in-house manufacturing capacity.

To achieve our scaling objectives, we have devised a strategic financing plan focused on two primary factors: seeking equity financing and generating revenue through preselling carbon credits.

We are raising a seed round for equity financing to facilitate the timely deployment of Wangari 1. This poses some challenges as deep climate tech companies outside US & Europe have limited equity financing options, even for post-revenue startups like us. Additionally, Africa-focused VCs are

often limited to funding climate adaptation, with carbon removal often being outside their scope. However, we are in active discussions with some interested parties. We plan to generate substantial revenue from carbon credit pre-sales to complement our narrow scope of equity financing. Substantial revenue generation will enable us to meet about >80% of our working capital requirements for Wangari 1. We have good customer interest and have had first pre-sales of ~$300k but will still need to increase the scale of actual booked revenue substantially.

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)*	714 tons
Delivery window *(at what point should Frontier consider your contract complete? Should match 2f)*	2024 – 2027. The plant will begin CO_2 removal in Q3 2024 and deliveries to Frontier will be made over a 3-year period from our pilot plant's capacity.
Levelized Price ($/ton CO_2)* *(This is the price per ton of your offer to us for the tonnage described above)*	$700. This price factors in a profit margin and the certification price we will pay to Puro.earth (7% of top-line revenue).

** 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).*

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