TAKACHAR

Carbon Dioxide Removal Purchase Application

Fall 2022

General Application - Prepurchase

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

Company or organization name

Takachar Limited

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

New Delhi, India

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

Kevin Kung, Ph.D.

Brief company or organization description

We turn crop/forest residues (biomass) into higher-value, carbon-based materials (such as biochar) through small-scale, decentralized, and community-customizable processing.

1. Project Overview[1]

a. Describe how the proposed technology removes CO_2 from the atmosphere, including as many details as possible. Discuss location(s) and scale. Please include figures and system schematics. Tell us why your system is best-in-class, and how you're differentiated from any other organization working on a similar technology.

<1500 words

<u>Current challenges:</u> Most existing biochar companies have not scaled cost-effectively for two reasons. Firstly, many are large-scale and capital-intensive: while they work well co-located with large biomass point sources (e.g. mills), distributing this biochar to farmers is cost-prohibitive. Secondly, biochar

[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.

technologies are often restrictive in input-output characteristics, which is incompatible with highly variable agricultural contexts: what works well for one crop may not replicate to another.

Our solution: We use MIT-developed technology to build a decentralized internet-of-things-enabled reactor network to rapidly and profitably scale biochar deployment. Our low-cost, portable hardware and control systems (see Fig. 1) enable village-based production of customizable biochar-based fertilizer blends (branded as Safi Sarvi) using locally available crop residues/labor in resource-constrained settings, without access to electricity, heat, water, chemical inputs. Unlike some of the other biochar technologies, our technology allows us to intentionally design/engineer the permanence of our biochar as per end user requirements, including for 1,000-plus-year durability.

Figure 1: A model of our decentralized, portable prototype.

CDR mechanism: CO_2 is captured from the air by growing crops. During harvest, normally the crop residues in these communities are burned in open air, releasing the CO_2 (plus particulates, black/brown clouds). Through our process, the low-energy, hydrogen- and oxygen-based volatile molecules in the residues, thermochemically, are driven out and oxidized as heat to run the internal reaction, which requires no external energy or heat input (as shown in our process diagram). What remains is a carbon-rich, recalcitrant biochar that after blending with nutrient components are applied as a standalone fertilizer to farmers' soil. This high-purity carbon stays inert in the soil for at least a thousand years. Through our process, only about 50% of the carbon from the plant goes back into the atmosphere. The remaining carbon is sequestered into the soil. When the same crops are replanted, they absorb more carbon from the atmosphere, leading to a net sequestration.

An initial pilot project: Currently we are already operating/scaling up a project in Mwea, Kirinyaga, Kenya that has sequestered around 1,100 tonnes of CO_2 in 2022. It will exceed 3,000 tonnes/year in capacity in 2023, reaching full-scale. Then we will scale to other communities. We sell the biochar-nutrient blend to 7,000 farmers as standalone fertilizer to replace the imported chemical fertilizers farmers currently use. The project pays farmers $26/tonne CO_2-removed for their post-harvest crop residues which are otherwise burned in open-air (creating air pollution). These residues are brought to our project from a 5-km radius by donkey carts. Then we convert the residues to biochar on-site, and then electrically mix the residues with nutrients (using the same chemical fertilizers that farmers would otherwise use, but at a reduced application rate per hectare). We then package the blend and sell it to farmers in 50 kg bags at the same price per hectare as what the farmers would otherwise pay for their imported chemical fertilizers. The bags are distributed to farmers on motorbikes through existing middlemen, the same way they are done with business-as-usual chemical fertilizers. Farmers take pictures of biochar-nutrient blend applied to their soils and send these to us to verify long-term sequestration.

This project: In this proposal, we plan on expanding our initial pilot to full scale (3,500 tonnes/year capacity), and building out additional community-based production units both in Kenya (Nakuru), as well as with other prospective partners (World Food Programme in India, four Tribal Nations in remote Canada, etc.). The goal is to initially own and operate a fleet of smart, self-coordinating reactors in the field capable of learning from each other based on the overall internal/external data collected in the specific communities, and to iterate the technology/process with co-leadership from the local communities based on their own needs. The plan is that at the end of three years, we will have delivered 14,300 tonnes of carbon credits as part of the prepurchase, which will comprise of a fraction of the 1.1 million tonnes of carbon credits that this constellation of projects will deliver over the next 10 years. At the end of the 3-year prepurchase period, our technology/process will also be sufficiently mature to be owned/operated by our scaling partners for more rapid expansion worldwide.

Best-in-class: Our differentiation comes from a new business model enabled by new technology. Most existing biomass-to-value companies are large-scale (100+ tons/day) and take advantage of the economy of scale. As such, they generally seek out large point-source of biomass, usually the byproducts from an agriculture/forestry mill. These companies start as technology providers, but invariably pivot to project developers, where they orchestrate the entire project from financing to technology. We understand that Frontier has various valid concerns about this approach, such as the hefty biomass logistics.

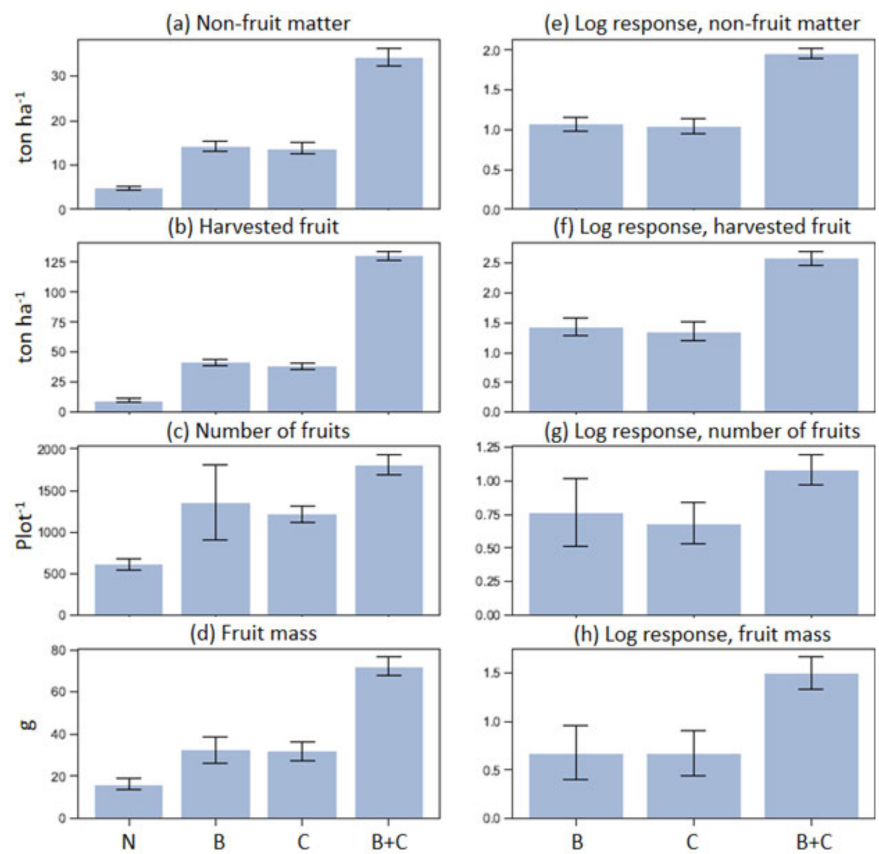
In our case, in contrast, we make our biomass technology small-scale, portable, and flexible in terms of biomass and output bioproducts. We intentionally forgo economy of scale, allowing us unique access to rural, decentralized, small pockets of biomass for localized utilization that larger technologies cannot reach. Our hardware systems are affordable enough for most landowners to own; thus, we do not need to become project developers. First, we license our technology cheaply to agricultural/forestry OEMs as a complementary product to their existing clienteles to distribute/maintain via their existing dealership network. We then remotely coordinate our fleet of reactors, using machine learning to adjusting reaction conditions in real-time to variable input feedstock. This results in products matched and optimized to real-time market demand. This Uber-like market matchmaking/arbitrage model affords us to become a software service provider, where we can charge a per-tonne fee for using our equipment fleet and administering the carbon credits.

Agronomic benefits to farmers: From the perspective of farmers, traditionally, chemical fertilizers are produced in large-scale, centralized locations and then imported. Due to the long-distance logistics, rural farmers often pay 2-5 times the world price for their fertilizers. This problem has only exacerbated as the global supply chain has been disrupted by the pandemic and geopolitics. In many cases, this has led to fertilizer price hikes (from Kenya to Canada), leading farmers worldwide to stop planting, and in many instances plunging rural communities into food insecurity.

We produce not just the pure biochar (which lacks nutrient), but rather customizes the thermochemical treatment conditions and the nutrient blends in response to farm-specific soil test results, thereby delivering an optimized, standalone, government-certified biochar-fertilizer blend that helps farmers improve their net income by 50% at the same cost that they currently pay for chemical fertilizers (see Figure 2). To verify these agronomic benefits, we have teamed up with Prof. Johannes Lehmann from Cornell University to conduct a longitudinal, randomized controlled field trial in Kenya. Figure 3 summarizes the initial outcomes from such a trial, where the Safi Sarvi blend (B+C) almost doubles farmers' harvest yields in comparison with the business-as-usual baseline (chemical fertilizers). Meet Mrs. Wacecilia, a smallholder farmer tilling acidified, degraded soil. After switching to our product, she has seen an immediate increase in harvest yield by 27% and net income by 50% compared to chemical fertilizers. She chooses to sell the extra harvest to the market, making enough additional income to send her children to school and become financially independent from her husband. "After switching to this new product, I never worry about putting enough food on the table for my family," she testified. See additional testimonials here: https://youtu.be/0aUNLPwiaos

Figure 2: Photographs of our Safi Sarvi biochar-nutrient blend which is customizable

Figure 3: Randomized controlled trial conducted by Cornell University on our biochar-based blends (B+C) in comparison with our biochar only (B), chemical fertilizer only (C), and no intervention (N).



Additionality: Currently we work with 7,000 farmers who already use significant quantities of chemical fertilizers in their soils, in that our biochar-based fertilizer blend alternative can help them save on the rising costs of chemical fertilizer inputs. This implies that these farmers are sufficiently wealthy to afford such use. However, not all farmers fit into this mold, and there are many smaller, more marginalized farmers who cannot afford the same. A carbon credit paid to the farmers effectively expands our service to other farmers who may otherwise not be in a position to afford our product, and where CDR would otherwise not be economically feasible, by providing them with a carbon subsidy for the carbon removal that they provide on their lands. Therefore, through carbon financing, we are able to deliver the CDR and agronomic benefits to a much wider selection of farmers, thereby achieving climate justice for the poorest farmers. Understanding Frontier's strict criteria for additionality, we are working closely with the local communities in devising a way to segment the farmers appropriately, in terms of those who can afford to pay, versus those who would not be using biochar without Frontier. We would be happy to brainstorm with Frontier some of our ideas here offline.

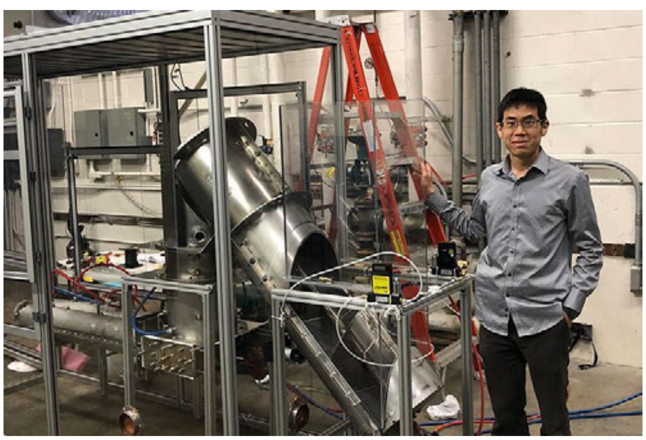
b. What is the current technology readiness level (TRL)? Please include performance and stability data that you've already generated (including at what scale) to substantiate the status of your tech.

<500 words

We have achieved a TRL level of 5, by having built and successfully tested laboratory-scale and field-scale hardware prototypes as well as the control strategy, as detailed below.

In terms of the hardware, we have already demonstrated, in laboratory, that our prototype can stably process a diverse range of input feedstock, ranging from wood chips, pine shavings, rice husks, hay straws, to walnut shells, and even coconut shells, under various moisture contents (Figure 4).

Figure 4: Our initial laboratory-scale prototype, and the diverse biomass feedstock types converted into customizable biochar samples



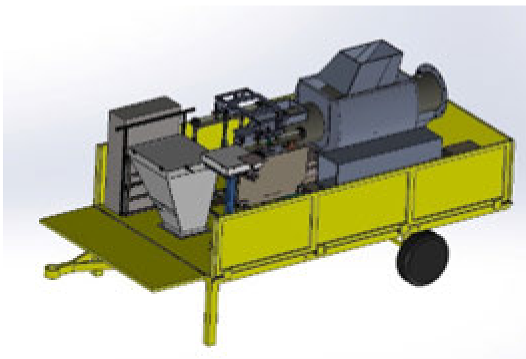
In terms of developing the software, machine-learning-based control strategy, we have demonstrated that, by adjusting the air-to-biomass ratio, we can control the steady-state temperature; and by adjusting the output removal rate, we can control the solid residence time. We have filed the appropriate patent application on this control strategy. This control strategy allows the reactor prototype to be operated, with minimal human intervention, to consistently produce specific feedstock characteristics (fixed carbon content, ash content, combustion temperature, etc.), from fluctuating input biomass (including higher moisture contents). Currently, we are working with researchers from the University of British Columbia on applying machine learning techniques to automate a real-time, cloud-based control strategy for coordinating a fleet of reactors deploying in the field, similar to a Uber model.

We were able to submit the various flavors of biochar we produced (under different reaction conditions and input feedstocks) for laboratory analysis at University of California and Eurofins (an accredited laboratory for European Biochar Certificate). As shown in a third-party verification letter in the confidential section, we demonstrated that our biochar samples can meet not only the EBC biochar standards, but also the 1,000-plus-year durability requirement according to the best scientific knowledge.

Based on our work, we implemented a preliminary version of the technology in Mwea, Kenya and started selling biochar-based fertilizer. We grew the customer base to 7,000 recurrently paying farmers, who purchase our biochar-nutrient blend for improved agronomic outcomes. Subsequently we scaled up to a pre-commercial prototype and demonstrated it in the field in the following additional contexts:

- A public forest as well as a large electric utility conducting vegetation management along their power lines in California;
- Three First Nations communities in rural British Columbia;
- Cooperatives of farmers in Haryana and Tamil Nadu, India.

Figure 5: A model and a photo of our decentralized, portable prototype.



Please find a letter from an authoritative third-party validating our technology/process in the confidential material section.

c. What are the key performance parameters that differentiate your technology (e.g. energy intensity, reaction kinetics, cycle time, volume per X, quality of Y output)? What is your current measured value and what value are you assuming in your nth-of-a-kind (NOAK) TEA?

Key performance parameter	Current observed value (units)	Value assumed in NOAK TEA (units)	Why is it feasible to reach the NOAK value?
Carbon yield	50% (inferred based on mass yield and chemical composition)	60%	The carbon yield of the system can be further optimized by further fine-tuning the underlying reaction conditions/kinetics.
Aperture of compatible biomass types	Successfully tested with wood chips, pine shavings, hay straws, coconut shells, rice husks, walnut shells, and almond shells	Successfully tested with at least 50 additional types of biomass in field-like conditions	The same process which we have used to test and validate a new type of feedstock previously can be indefinitely applied to new biomass feedstock types.
O/C_{org} ratio (a	0.09-0.14	<0.20 (Puro.Earth	The NOAK value has already been

proxy of durability)	(produced under different setpoints)	definition for 1,000+ year durability)	achieved successfully. We can uniquely adjust our reactor setpoints to engineer for the desired O/C_{org} ratio.
H/C_{org} ratio (a proxy of durability)	0.04-0.06 (produced under different setpoints)	<0.20 (Puro.Earth definition for "hardly degradable")	The NOAK value has already been achieved successfully. We can uniquely adjust our reactor setpoints to engineer for the desired H/C_{org} ratio.
Physical hardware footprint	Compatible with dimensions of a standard 5' x 8' trailer	Compatible with dimensions of a standard 5' x 8' trailer	The NOAK value has already been achieved successfully. See Figure 3 above.

d. Who are the key people at your company who will be working on this? What experience do they have with relevant technology and project development? What skills do you not yet have on the team today that you are most urgently looking to recruit?

We combine the intimate, lived experience of our customers with the cutting-edge technical prowess from MIT.

Vidyut Mohan graduated from the Technical University of Delft with a master's thesis focusing on decentralized biomass systems, conducting detailed fieldwork in the rural biomass supply chain. He worked with Simpa Energy, focusing on small-scale rural solar deployment. His expertise is on understanding customer needs and developing service offerings in a user-centric manner. Prior to this company, Vidyut founded Pirool Energy, which turns unused pine needles into a low-cost biofuel.

Kevin Kung, Ph.D. completed his PhD thesis on decentralized biomass/biochar production at Massachusetts Institute of Technology (MIT). Kevin has 10 years of experience with engineering design and entrepreneurship in rural, resource-constrained communities in Africa and India. Kevin co-founded a previous company that sold over one million low-toxin mosquito coils (SafiCoils).

Joyce Kamande grew up in a poor farming family in rural Kenya. She oversees the marketing team, makes regular visits to local farmers and partners, and builds the Safi Sarvi biochar fertilizer brand. She holds an MSc in Procurement and Logistics Management from Jomo Kenyatta University of Agriculture and Technology.

Samuel Rigu grew up in a poor farming family in rural Kenya and witnessed first-hand the fertilizer access issues that his grandmother faced. He studied Agribusiness at University of Nairobi. He then served as the Manager of Turning Point Trust Farm, where he turned a loss-making business into profitability in 6 months by implementing organic farming practices.

Our scientific advisor, Professor Johannes Lehmann, of Cornell University, has research interests in soil biogeochemistry and fertilizer management with a focus on carbon sequestration, nutrient recycling from wastes, biochar systems, and sustainable agriculture in the tropics.

As we scale, we're actively looking for talents on operations and corporate partnerships.

e. Are there other organizations you're partnering with on this project (or need to partner with in order to be successful)? If so, list who they are, what their role in the project is, and their level of commitment (e.g., confirmed project partner, discussing potential collaboration, yet to be approached, etc.).

Partner	Role in the Project	Level of Commitment
Safi Organics	Local implementation partner	Confirmed
Cornell University	Agronomic and soil carbon measurement	Confirmed
University of British Columbia	Laboratory analysis	Confirmed

f. What is the total timeline of your proposal from start of development to end of CDR delivery? If you're building a facility that will be decommissioned, when will that happen?

> Delivery of CDR can occur immediately in 2023. The production facility is expected to operate for at least 10 years. We anticipate fulfilling the prepurchase amount in 3 years.

g. When will CDR occur (start and end dates)? If CDR does not occur uniformly over that time period, describe the distribution of CDR over time. Please include the academic publications, field trial data, or other materials you use to substantiate this distribution.

> <100 words
>
> CDR is already occurring and will continue to expand at our growing network of projects. Please see table under Question 1h for projected CDR capability. Each of our community-based, decentralized project is expected to achieve 3500 tonnes/year capacity, normally within two years of commissioning, based on our prior experience operating a pilot project ourselves. Usually, within each project, production/application is highest leading up to the planting season, which occurs twice a year in our geography. However, there are many agricultural applications we serve where planting occurs year-round, leading to a pretty consistent baseline CDR.

h. Please estimate your gross CDR capacity over the coming years (your total capacity, not just for this proposal).

Year	Estimated gross CDR capacity (tonnes)
2023	3000
2024	7000
2025	10000

2026	20000
2027	60000
2028	110000
2029	240000
2030	650000

i. List and describe at least three key milestones for this project (including prior to when CDR starts), that are needed to achieve the amount of CDR over the proposed timeline.

	Milestone description	**Target completion date** (eg Q4 2024)
1	Become certified with at least one mainstream registry (European Biochar Certification / C-Sink)	Q3 2023
2	Set up a second production site in Nakuru	Q3 2023
3	Finalize an agreement with a strategic scaling partner	Q2 2024

j. What is your IP strategy? Please link to relevant patents, pending or granted, that are available publicly (if applicable).

<200 words Our core intellectual property comprises of a combination of patents and trade secrets. Two PCT patent applications, covering the reactor network architecture (PCT/US20/60011) and hardware system configurations (US63/030861), have both been assigned to Takachar Limited. In addition to patent-based IP, the company also retains significant trade secrets, in knowing how to map diverse input biomass types and characteristics into quality-controlled biochar and other carbon-based bioproducts specified by different end users depending on their agricultural contexts, using machine learning. Finally, while counter-intuitive, open-sourcing is also a part of our IP strategy, in ensuring that certain key parts of the knowledge and processes are retained and available for rural, underserved communities to use, thereby reducing the barrier to entry, rather than excluding them prematurely from early-stage, small-scale feasibility studies.

k. How are you going to finance this project?

<300 words Firstly, the certification, development and integration of carbon credit payment program into our automated control system in the field is being funded by the Elon Musk Foundation through the XPRIZE Carbon Removal Milestone Award as a non-dilutive grant (US$1.25 million), as well as the proposed Frontier prepurchase. This component is critical for us to be able to administer carbon

credits.

Secondly, the initial low-volume manufacturing and design-for-manufacturability process for our hardware is being funded by the Royal Foundation through Prince William's inaugural Earthshot Prize as a non-dilutive grant (GBP 1 million).

Thirdly, we are setting up an initial network of decentralized, community-based biochar production sites to deliver the aggregate CDR volume for this project. This is being done in Kenya (Schmidt Family Foundation), India (World Food Programme and Breakthrough Energy Fellowship), California (California Energy Commission and the U.S. Department of Energy), and British Columbia (Agriculture and Agri-Food Canada and the Government of British Columbia). These parallel pilots will confer us the experience of operating and coordinating a fleet of smart, self-interacting biomass reactors in the field, each adapting to the local community needs and contexts. This is expected to greatly strengthen our technology/process design, ensuring that it is scalable globally for various biomass/agriculture contexts.

l. Do you have other CDR buyers for this project? If so, please describe the anticipated purchase volume and level of commitment (e.g., contract signed, in active discussions, to be approached, etc.).

<200 words

We are in active discussion with a few potential CDR buyers who have proactively approached us. Their identities are governed under confidentiality agreements.

m. What other revenue streams are you expecting from this project (if applicable)? Include the source of revenue and anticipated amount. Examples could include tax credits and co-products.

<200 words

Biochar is blended with key nutrients to make a government-certified, standalone fertilizer that improves farmers' yields on average by 27%, at the same fertilizer selling price (actual pricing data available upon request) per hectare-season. Many farmers we work with face food insecurity associated with soil degradation and the disrupted supply chain of chemical fertilizers due to the pandemic and the situation in Ukraine. "After switching to Safi Sarvi, I never worry about putting enough food on the table for my family," said one farmer. "What's more, I sell the excess harvest and use the extra income to send my children to school." Currently we have 7,000+ farmers as recurrently paying customers. As our pilot production shows, there are certain specific agricultural applications where the sales of biochar-based fertilizer blend is sufficient to cover the production costs plus profit, without depending on carbon credits.

Given this project's carbon credit is additional, we only offer Frontier offsets from the most marginalized farmers (subsistence such as rice), where biochar-based fertilizer could otherwise not be afforded/applied without a carbon credit. However, this selling price will drastically reduce the actual cost of carbon removal from the cost computed in our technoeconomic worksheet.

n. Identify risks for this project and how you will mitigate them. Include technical, project execution, ecosystem, financial, and any other risks.

Risk	Mitigation Strategy
COVID-related travel and work restrictions	The international team is accustomed to working remotely since 2018. Travel of key personnel will be minimized by relying on local prototype operation teams. Workers will adhere to strict COVID-19 safety measures.
Overall system cannot perform as per requirements	Rigorous testing of individual components will precede a system-wide testing to isolate any potential problems before fully assembly
Delay in the permitting process with certain host sites	We also have secured back-up sites where we have the necessary permits secured. Testing can proceed until the permit is fully permitted.
Long component lead time due to disrupted supply chains	We will competitively source from at least three vendors. For mission-critical components less than $500, we will have a back-up copy for quick replacement in case of failures or malfunction.
Communication and coordination issues with collaborators and partners	As requirements can change quickly in an R&D project, having frequently (twice-a-week) Zoom-based communication as well as more frequent text-based communication is key in staying in sync with each other. We will also set up a regular channel of communication with the relevant funders (including Frontier, if funded) to update any changes.
Project fails to obtain one or more of funding sources to scale up	The aggregate amount of grants and investments sought exceeds the overall project budget by at least a 20% margin in case one or more are not approved, and is designed to give the company reasonable runway beyond the end of the project.

2. Durability

a. Describe how your approach results in permanent CDR (> 1,000 years). Include citations to scientific/technical literature supporting your argument. What are the upper and lower bounds on your durability estimate?

< 300 words, including number/range of durability estimate

While we do not have the capability/time in the short term to actually measure the changes in carbon stock in the soil over thousands of years, we do our best to infer the durability based on existing literature. Based on our best understanding in the literature (see the Spokas study as an example), one proxy for biochar durability is the elemental ratios (e.g. H/C_{org}, O/C_{org}). A molar O/C_{org} ratio of less than 0.2, for example, is commonly assumed to have a halflife of more than 1,000 years, with a range of between 1,000-5,000 years.

Unlike some of the other biochar technologies, our technology allows us to intentionally design/engineer the permanence of our biochar as per end user requirements. By modifying the reaction temperature (air-biomass ratio) and reaction residence time (solid removal rate), we fine-tune

our reaction to product low H/C_{org} and O/C_{org} ratios that satisfy such permanence criteria defined by mainstream methodologies such as Verra and Puro.Earth. We include, in the confidential information section, select biochar analysis data independently validated by a credible third party, demonstrating that our biochar satisfies the proxy measurements stated above. In order to verify this durable removal experimentally, we are performing a longitudinal study of soil carbon stock on at least 25 randomized controlled farm plots with Prof. Johannes Lehmann at Cornell University under a Department of Energy SBIR grant. We can then make some extrapolation based on these soil carbon measurements. If further updated studies found out that, the biochar that we produce does not indeed have a durability of 1,000+ years, then it is entirely possible for us to redesign the biochar based on the updated criteria for durability.

b. What durability risks does your project face? Are there physical risks (e.g. leakage, decomposition and decay, damage, etc.)? Are there socioeconomic risks (e.g. mismanagement of storage, decision to consume or combust derived products, etc.)? What fundamental uncertainties exist about the underlying technological or biological process?

<200 words Biochar can emit volatile carbon from the soil, leading to loss of durability. To minimize this, we will minimize the volatile components, which is done by carrying out the thermochemical treatment at a high temperature to reduce the H/C_{org} and O/C_{org} ratios as per the guidelines in existing methodologies and academic literature. In addition to the LCA, we will actually measure soil carbon longitudinally with Cornell University to provide another validation data for durable CDR. Furthermore, biochar in bulk is flammable. Under certain conditions (e.g. wildfires), it can burn and release the stored carbon back into the atmosphere. This fire risk exists mainly when the biochar is being stored in a facility waiting to be distributed to the farm (which less applicable in our case as the case of conventional large-scale biochar production), rather than the low percentage of biochar intermingled within the soil. Finally, the biochar produced in Kenya could equally be used as a domestic cooking fuel (i.e. charcoal). One potential risk is that farmers will purchase the biochar from us to burn it rather than putting it into the soil, thereby negating durable removal. Mitigation measures are discussed in Section 3.

3. Gross Removal & Life Cycle Analysis (LCA)

a. How much GROSS CDR will occur over this project's timeline? All tonnage should be described in **metric tonnes** of CO_2 here and throughout the application. Tell us how you calculated this value (i.e., show your work). If you have uncertainties in the amount of gross CDR, tell us where they come from.

Gross tonnes of CDR over project lifetime	1.1 million
Describe how you calculated	The project can be considered ongoing and expanding after being

that value	set up. The tonnage above is based on summing the anticipated cumulative offsets generated between 2023 and 2032 (see 1h). We assume that a fraction of this (around 30,000 tonnes) will be earmarked towards Frontier's prepurchase program. The remaining will be sold elsewhere.

b. How many tonnes of CO_2 have you captured and stored to date? If relevant to your technology (e.g., DAC), please list captured and stored tons separately.

1,500 tonnes

c. If applicable, list any avoided emissions that result from your project. For carbon mineralization in concrete production, for example, removal would be the CO_2 utilized in concrete production and avoided emissions would be the emissions reductions associated with traditional concrete production. Do not include this number in your gross or net CDR calculations; it's just to help us understand potential co-benefits of your approach.

Our project also has avoided emissions coming from two sources: (1) avoided long-distance chemical fertilizer production and transport, and (2) avoided biomass burning.

(1) Avoided long-distance chemical fertilizer production and transport

Currently, most chemical fertilizers are produced in large-scale, centralized, and energy-/carbon-intensive processes and then shipped to rural areas. Not only do these rural communities pay 2-5 times the world price for their fertilizers, but this act of long-distance transportation and importation also contributes to significant carbon emissions. The irony is that a significant portion of the applied chemical fertilizers are often not available to the plants, but rather leached out from the soils, leading to water pollution. This is the baseline case.

In our work with rural farmers, applying biochar on their soils that retains moisture/nutrients more effectively and reduces leaching, has resulted in the reduction of application rates of chemical fertilizers without negatively affecting the crop/plant performance, sometimes by as much as 40%. Therefore, in contrast with the baseline case described above, by switching to our biochar-based blend, the farmers can effectively reduce the rate of chemical fertilizers applied in their fields over the baseline. Therefore, technically, there is a net carbon avoidance through our intervention. According to our lifecycle assessment, the most rural, underserved communities (with poor transportation links) can see a net avoidance of up to 2.8 tonnes CO2-e per tonne of biochar applied.

(2) Avoided biomass burning

We specifically work with non-merchantable biomass residues. In the baseline, the most common fate for crop residues such as stubbles, or forestry residues such as slash piles from vegetation management operations on wood killed by mountain beetle located in wildfire-prone areas, are frequently burned in open air without generating any bioenergy. As per Verra methodology, such baseline can be assumed to be net zero *if the combustion were complete*. However, in addition to that, the uncontrolled, non-stoichiometric combustion process means that, in addition to CO2, a small fraction of the carbon (up to 5%) from the biomass is often being released as methane (as reported by

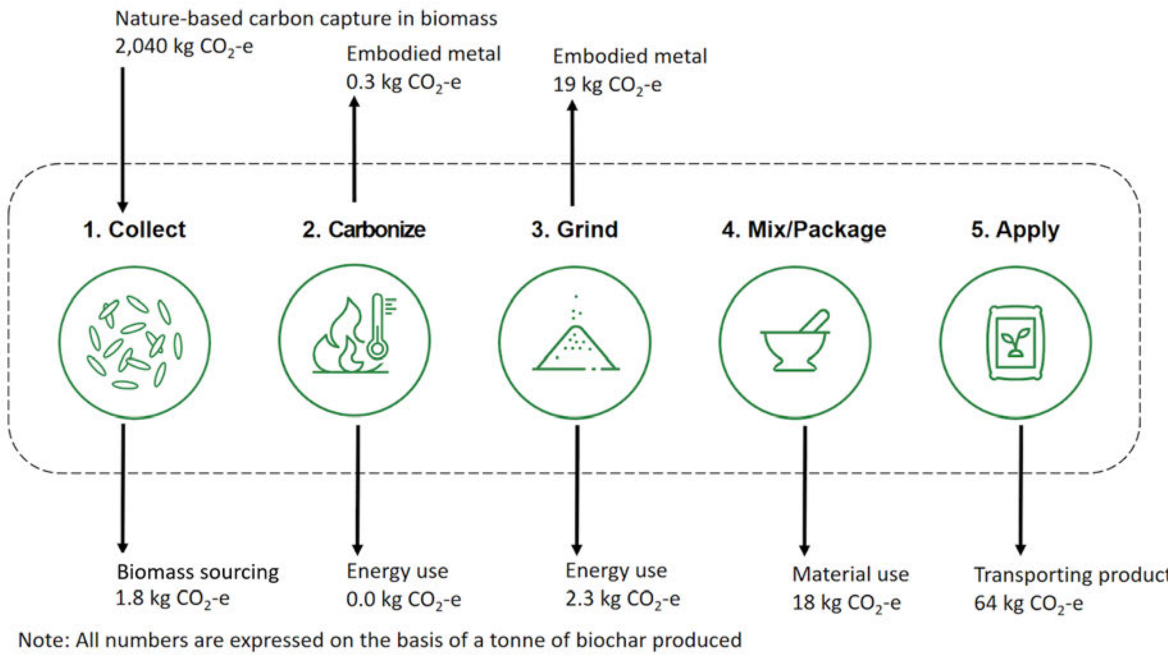
Ithaka Institute), a much more potent greenhouse gas (around 84 times the CO2 warming potential over a period of 20 years). This can easily double the total equivalent greenhouse gas emissions from such operations, such that the process is now net greenhouse gas positive. In other similar cases, the residues are left to decompose on-site, which anaerobically generates even a larger fraction of methane (see Thengane et al., 2021). In other cases, we have heard of landowners unable to conduct open-air burning in slash piles transporting high-hazard, non-merchantable residues off-site to be landfilled. This occurs more rarely and is not at this stage incorporated into our baseline, as it includes additional variable factors such as distance from the closest landfill, and the methane gas capture technologies in use at such landfill. In all of the above-mentioned scenarios, by utilizing the non-merchantable residues and avoiding biomass burning, there is likely an additional net avoidance.

d. How many GROSS EMISSIONS will occur over the project lifetime? Divide that value by the gross CDR to get the emissions / removal ratio. Subtract it from the gross CDR to get the net CDR for this project.

Gross project emissions over the project timeline *(should correspond to the boundary conditions described below this table)*	57,000 tonnes
Emissions / removal ratio *(gross project emissions / gross CDR–must be less than one for net-negative CDR systems)*	0.05
Net CDR over the project timeline *(gross CDR - gross project emissions)*	1.0 million tonnes

e. Provide a process flow diagram (PFD) for your CDR solution, visualizing the project emissions numbers above. This diagram provides the basis for your life cycle analysis (LCA). Some notes:

- The LCA scope should be cradle-to-grave
- For each step in the PFD, include all Scope 1-3 greenhouse gas emissions on a CO_2 equivalent basis
- Do not include CDR claimed by another entity (no double counting)
- For assistance, please:
  - Review the diagram below from the CDR Primer, Charm's application from 2020 for a simple example, or CarbonCure's for a more complex example
  - See University of Michigan's Global CO_2 Initiative resource guide
- If you've had a third-party LCA performed, please link to it.



f. Please articulate and justify the boundary conditions you assumed above: why do your calculations and diagram include or exclude different components of your system?

The boundary begins with procuring biomass residues, and includes all production steps (drying, thermochemical conversion, milling, blending, packaging, transportation). Furthermore, we accounted for the emissions embodied in materials/equipment (e.g. metals, packaging bags). We then “depreciated” these embodied emissions over the expected lifetime of these materials/equipment. Another consideration is how our intervention affects the baseline agricultural practice (i.e. demand for synthetic chemical fertilizers). In most cases, using our biochar reduces the application rate/demand for chemical fertilizers, resulting in net carbon avoidance. As we’re more interested in removal than avoidance, we exclude this avoidance from our boundary.

g. Please justify all numbers used to assign emissions to each process step depicted in your diagram above. Are they solely modeled or have you measured them directly? Have they been independently measured? Your answers can include references to peer-reviewed publications, e.g. [Climeworks’ LCA paper](#).

All numbers below have been independently verified by a third-party expert in LCA. Furthermore, as the packaging/sales of the biochar as an ingredient of our Safi Sarvi agricultural fertilizer blend in our project is inextricably linked to the CDR process, there really is not a good way to feasibly segregate the two activities when conducting our LCA. Therefore in the emissions calculations, we accounted for all emissions associated with CDR as well as the selling of biochar as a fertilizer blend. Hence, the emissions calculations below likely over-estimates the actual emissions incurred solely by the act of CDR, when the act of fertilizer-selling is excluded.

Process Step	CO_2(eq) emissions over	Describe how you calculated that number. Include

	the project lifetime (metric tonnes)	references where appropriate.
Biomass sourcing	970	According to some methodologies (e.g. Verra), this step should not be included. However, we include it here for the sake of completeness. In general, instead of bringing the biomass to us, we bring the equipment on-site. In either case, normally a donkey cart is used for this. For the donkey transportation calculation, it was assumed that a donkey emits 10.9 kg of methane per year (Song *et al.*, 2015). Per tonne of biochar produced, on average, we make use of a two-hour donkey trip daily. This estimate is based on assumption that the only factor that significantly effects emissions is number of animals being used.
Energy use during thermochemical conversion	0	Our process requires no external energy, heat, or fuel sources to power itself. All energy required is drawn from the intrinsic heating value of the biomass. Therefore, this energy use is already factored into the overall system's carbon yield, as the more energy we use, the less biochar we get.
Embodied metal for making the thermochemical reactor unit	160	The conversion reactor is created using a series of thin recycled steel cylinders, weighing in at an estimated 60 kg, that last about 45 months before they need to be replaced. For this calculation, it was assumed that the steel emitted 2.7 kg of CO_2e per kg of metal from cradle-to-grave (World Steel Association). Lifetime emissions for each drum is given by multiplying the weight in kg by the CO_2e emissions per kg; this comes out to 30 kg CO_2e. We divided this number by the number of work days in the lifetime of the drum.
Postprocessing energy use	1,200	The electricity used was calculated by multiplying the horsepower of the hammermill motor (5) by the number of hours a day the hammermill was run (4). Then, the horsepower-hours was multiplied by the number of kilowatts per horsepower-hour (0.7475). Given that our initial project scale-up will occur in Kenya, multiply this number by Kenya's estimated carbon intensity in 2016 (116 grams of CO_2 per kilowatt hour) (Laconde, 2018). The actual number will vary from country to country depending on the carbon intensity of the grid.
Postprocessing embodied metal	10,000	The cradle-to-grave carbon footprint of the hammermill was determined by combining a) the estimated CO_2e from the LCA of the motor and b) the estimated CO_2e from the LCA of the iron creating the hammermill's body. The motor's lifetime CO_2e emissions due to operations were assumed to be 9,400 kg CO_2e (Torrent *et al.*,

		2011). We conservatively assume that the hammermill lasts about 2.5 years. We then divided the lifetime emissions by the lifetime in years and then divided that number by the approximate work days in a year (~260). The lifetime embodied CO_2e emissions were assumed to be 1.5 kg CO_2e/ kg of iron (Nuss and Eckelman). The hammermill shell weighs about 30 kg, and by multiplying the emissions per kg by the amount of iron in kg the lifetime emissions comes out to 45 kg CO_2e. Repeating the last step from the motor equation, we divided the lifetime emissions by the lifetime in years and then divided that number by the approximate work days in a year (260). Combining these two numbers gives the total emissions associated with this step.
Postprocessing material use	9,700	The gunny bags used for packaging are made from polypropylene (PP). One ton (~910 kg) of the of PP woven sacks emit about 3,900 kg of CO_2e (MoEFCC, 2018). Furthermore, each woven bag weighs about 0.12 kg. By dividing the number of kilograms in a ton by the weight of each gunny bag, we can find the number of bags made when emitting 3,900 kg of CO_2e. By dividing the total emissions by the number of bags, we find the amount of emissions per bag: 0.51 kg CO_2e. Based on actual pilot operations, generally, these bags are reused on average 25 times.
Field application	35,000	While the biochar is produced close to the field already, it needs to be transported to be evenly distributed on the field, during which sometimes diesel-burning heavy equipment is often deployed. Various frameworks exist for this calculation. We used the equations and numbers presented in Durango-Cohen *et al.*, 2013.

4. Measurement, Reporting, and Verification (MRV)

Section 3 above captures a project's lifecycle emissions, which is one of a number of MRV considerations. In this section, we are looking for additional details on your MRV approach, with a particular focus on the ongoing quantification of carbon removal outcomes and associated uncertainties.

a. Describe your ongoing approach to quantifying the CDR of your project, including methodology, what data is measured vs modeled, monitoring frequency, and key assumptions. If you plan to use an existing protocol, please link to it. Please see [Charm's bio-oil sequestration protocol]() for reference, though note we do not expect proposals to have a protocol at this depth at the prepurchase stage.

<300 words

Currently, the most compatible methodology is European Biochar Certification's C-Sink. However, we also extensively borrow the best practices from Verra and Puro.Earth.

Within our production, we minimize the risk of stock loss by depriving oxygen in biochar under storage, and cooling as needed. The same technique to minimize volatile carbon by conducting the thermochemical conversion at a higher temperature also works, as it discourages biochar from flammable off-gassing. Our production process is fully instrumented to measure mass losses. However, given that our carbon credits are counted/sold only when the biochar is applied in the field, production-stage losses at an earlier step technically will not affect the actual carbon credits.

Regarding the risk that biochar is burned as a fuel, we can mitigate with two measures. Firstly, farmers upload photos of themselves applying the biochar (whose packaging is tagged with a unique QR code) to the field to verify that biochar is indeed sequestered. This serves as evidence to pass the carbon credit payments to farmers. Secondly, the initial biochar produced in our pilot is from rice hulls, which is a high-ash biomass. While ash can be good as a fertilizer blend as it contains minerals for plants, it is terrible when used as a cooking fuel as it limits the heat output. For example, we failed to bring a pot of water to boil with our biochar tested as a solid fuel. Therefore, if farmers should try to burn our biochar as a fuel, then the effort will likely not be successful. For subsequent biomass types, even if the ash content turns out much lower than rice hulls, from our experience, the unit economics of biochar-based fertilizer tends to work out much more favorably than that of solid fuel, thereby inhibiting efforts at the latter.

b. How will you quantify the durability of the carbon sequestered by your project discussed in 2(b)? If direct measurement is difficult or impossible, how will you rely on models or assumptions, and how will you validate those assumptions? *(E.g. monitoring of injection sites, tracking biomass state and location, estimating decay rates, etc.)*

<200 words

In terms of durability quantification, we go beyond the mainstream methodologies such as Puro.Earth and Verra which mainly rely on proxy correlations in the literature. In order to experimentally verify durable removal, we are performing a longitudinal study of soil carbon stock on select randomized controlled farm plots (no intervention, biochar only, biochar+status quo, and status quo) with Prof. Johannes Lehmann at Cornell University under a Department of Energy grant. Currently, we are tracking soil carbon from various biochar application sites in India, Kenya, the U.S., and Canada in different agricultural contexts.

Furthermore, as a secondary effect, the act of biomass utilization can also affect the carbon stock of the growing plant in the same land over which biochar is applied. This is an area that is highly complex, and much is unknown in the literature. In an effort to elucidate some of these effects, we are working with Prof. Kevin Fingerman's group at the Schatz Energy Research Center, in the context of California at least, in applying their California Biomass Residues Emissions Characterization (C-BREC) model to our work. This will account for additional factors such as location-specific decay (avoided emissions), and changes in wildfire behaviors.

c. This tool diagrams components that we anticipate should be measured or modeled to quantify CDR and durability outcomes, along with high-level characterizations of the uncertainty type and magnitude for each element. We are asking the net CDR volume to be discounted in order to account for uncertainty and reflect the actual net CDR as accurately as possible. Please complete the table below. Some notes:

- In the first column, list the quantification components from the Quantification Tool relevant to your project (e.g., risk of secondary mineral formation for enhanced weathering, uncertainty in the mass of kelp grown, variability in air-sea gas exchange efficiency for ocean alkalinity enhancement, etc.).
- In the second column, please discuss the magnitude of this uncertainty related to your project and what percentage of the net CDR should be discounted to appropriately reflect these uncertainties. Your estimates should be based on field measurements, modeling, or scientific literature. The magnitude for some of these factors relies on your operational choices (i.e., methodology, deployment site), while others stem from broader field questions, and in some cases, may not be well constrained. We are not looking for precise figures at this stage, but rather to understand how your project is thinking about these questions.
- See this post for details on Frontier's MRV approach and a sample uncertainty discount calculation and this Supplier Measurement & Verification Q&A document for additional guidance.

Quantification component Include each component from the Quantification Tool relevant to your project	**Discuss the uncertainty impact related to your project** Estimate the impact of this component as a percentage of net CDR. Include assumptions and scientific references if possible.
Ex: storage leakage	*Ex: Based on historical monitoring data from well operator*
Storage	Minimal (<1%): Precise output/input can be easily tracked and corroborated over different sources (e.g. photos, mass data, volumetric data, laboratory analysis of chemical composition).
Leakage	Low (1-5%): After application to the field, leakage of volatile carbon from the soil can be indirectly measured such as using soil carbon, though authoritative measurement requires specific technical expertise (e.g. Cornell University). Direct measurement of changes in the soil GHG fluxes is way harder and more costly to implement over large land areas.
Feedstock storage counterfactual	Minimal (<1%): In this project, we specifically identify and work with feedstock whose counterfactual fate is open-air burning. However, as we scale up, we may encounter other types of feedstock storage counterfactuals, such as slow decay (over decades) in forest floor. In a limited study involving California, we are currently working with the Schatz Energy Research Center to apply its California Biomass Residues Emissions Characterization (C-BREC) model to address such counterfactuals in a site-specific way throughout the state. If successful, such model can be expanded to other regions.
Indirect land use change	Low (1-5%): Any benefits that the biomass suppliers (e.g. farmers with residues, forested landowners) gain from biomass utilization could also indirectly change their agricultural or forestry practices, in either net-positive or

	net-negative way depending on the context. While C-BREC modeling may address a part of this, this needs to be verified via larger-scale technoeconomic analyses, potentially supplemented with satellite imagery or other data.
Materials	Minimal (<1%): While we already account for embodied emissions in material consumption in our LCA calculations above through a cradle-to-grave analysis (above and beyond what current biochar methodologies may ask for), the standard methodologies do not specify a consistent way to do so. The best we can do so far is be transparent in our approach, clearly state the key assumptions, and be prepared to change in light of better practices. However, based on our sensitivity analysis, embodied emissions is not a key sensitivity in our LCA.
Energy	Minimal (<1%): Energy use in our overall process factors minimally into the overall emissions figures. Despite possible uncertainties, it is not a key sensitivity in our LCA.
Storage monitoring and maintenance	Minimal (<1%): While the soil is an open system, and there is no guarantee that biochar will remain within a bounded land area after a period of time (for example being washed away by flood or rain), according to standard methodologies such as Verra, this does not usually change the solid form of biochar and the fact that the solid form is still durably sequestering carbon, even if it ends up elsewhere (e.g. in rivers or lakes).

d. Based on your responses to 4(c), what percentage of the net CDR do you think should be discounted for each of these factors above and in aggregate to appropriately reflect these uncertainties?

<50 words The category-specific percentages are already listed above. A highly conservative estimate would sum up the upper bound of all the uncertainty ranges given above, resulting in a 15% maximum uncertainty. This is the percentage we propose should be discounted.

e. Will this project help advance quantification approaches or reduce uncertainty for this CDR pathway? If yes, describe what new tools, models or approaches you are developing, what new data will be generated, etc.?

<200 words One main challenge with biochar as a CDR pathway is that it is very context-dependent. Change the feedstock, the end use application, and the reaction conditions, for example, and the LCA numbers could change. It is infeasible to recertify every time a new biochar project is implemented in a new community/context. Our position is that much can be learned based on detailed process data and external environmental data. As we deploy a fleet of our reactors in different contexts in India, Kenya, the U.S., and Canada, we are simultaneously collecting high-quality internal and external data (e.g.

weather, satellite imagery, carbon prices, etc.) for machine learning. The goal is to develop a cloud-based, internet-of-things-based controls approach that not only adjusts the operations of the fleet of reactors in response to real-time market demands, but also updates the localized/customized LCAs accordingly, generating the suitable QR code for individualized verification in different communities. This controls approach is being developed in collaboration with the University of British Columbia, and we will publish the general approaches and datasets in peer-reviewed journals. If successfully implemented, it can also apply to other types of small-scale, decentralized chemical engineering and carbon removal pathways.

f. Describe your intended plan and partners for verifying delivery and registering credits, if known. If a protocol doesn't yet exist for your technology, who will develop it? Will there be a third party auditor to verify delivery against that protocol or the protocol discussed in 4(a)?

<200 words

Biochar is a relatively well defined removal pathway, with various mainstream protocols already published (e.g. Puro.Earth, Verra, European Biochar Certification C-Sink). Currently, given our geography, C-Sink is the most compatible pathway. We are already in the EBC certification process, and have received a letter of intent (LOI) from Carbonfuture. However, we are still very early on in investigating the suitable platform/marketplace to host the carbon credits.

While we will initially start with an EBC implementation (potentially on the Carbonfuture or similar platform, as needed), we recognize that there are ways where existing biochar methodologies can be reshaped/improved to better address small-scale, decentralized biochar production, and in doing so, provide better access/linkage to rural, underserved communities, thereby advancing climate justice. We are happy to discuss with the Frontier team what these preliminary plans may be, and will advocate for these changes.

5. Cost

We are open to purchasing high-cost CDR today with the expectation the cost per tonne will rapidly decline over time. The questions below are meant to capture some of the key numbers and assumptions that you are entering into the separate techno-economic analysis (TEA) spreadsheet (see step 4 in Applicant Instructions). There are no right or wrong answers, but we would prefer high and conservative estimates to low and optimistic. If we select you for purchase, we'll work with you to understand your milestones and their verification in more depth.

a. What is the levelized price per net metric tonne of CO_2 removed for the project you're proposing Frontier purchase from? 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), but we will be using the data in that spreadsheet to consider your offer. Please specify whether the price per tonne below includes the uncertainty discount in the net removal volume proposed in response to question 4(d).

$105/tonne CO_2

b. Please break out the components of this levelized price per metric tonne.

Component	Levelized price of net CDR for this project ($/tonne)
Capex	3
Opex (excluding measurement)	108
Quantification of net removal (field measurements, modeling, etc.)[2]	8
Third party verification and registry fees (if applicable)	10
Pro rata selling price of fertilizer	-24
Total	105

c. Describe the parameters that have the greatest sensitivity to cost (e.g., manufacturing efficiencies, material cost, material lifetime, etc.). For each parameter you identify, tell us what the current value is, and what value you are assuming for your NOAK commercial-scale TEA. If this includes parameters you already identified in 1(c), please repeat them here (if applicable). Broadly, what would need to be true for your approach to achieve a cost of $100/tonne?

Parameter with high impact on cost	Current value (units)	Value assumed in NOAK TEA (units)	Why is it feasible to reach the NOAK value?
Input biomass feedstock cost (incl. sourcing-related transportation)	$26/tonne	$26/tonne	NOAK value already achieved successfully in our pilot.
Carbon yield	50%	60%	Conversion yield can be optimized by changing the reaction conditions (e.g. reaction temperature, residence time) in a way that maximizes carbon yield
Capacity factor	50%	70%	The figure is based on capacity factors of other similar biomass gasifiers and combustors in the NOAK (product) stage.

d. What aspects of your cost analysis are you least confident in?

<100 words We are least confident in the capital cost associated with the thermochemical reactor unit, as it is based only on prospective quotes and approximate technology scaling factors, in contrast to the

[2] This and the following line item is not included in the TEA spreadsheet because we want to consider MRV and registry costs separately from traditional capex and opex.

operating costs, which have already been validated and iterated once with actual in-the-field operations. Fortunately, the capital cost represents a very minor part of the levelized cost of CDR, and thus is not a key sensitivity.

e. How do the CDR costs calculated in the TEA spreadsheet compare with your own models? If there are large differences, please describe why that might be (e.g., you're assuming different learning rates, different multipliers to get from Bare Erected Cost to Total Overnight Cost, favorable contract terms, etc.).

<200 words

A full financial model accounts for not just the CDR portion of our work, but also the biochar-based product ("fertilizer business"). While we tried to segregate the costs into a "CDR cost pool" and "fertilizer cost pool", and excluded the "fertilizer cost pool" from the TEA spreadsheet, in reality, all the costs listed in the TEA worksheet are inseparable between the two pools: The entire capital equipment, production, packaging, and field application serve the dual function of CDR and production of an agronomic product.

Likewise, it is unclear how the selling price of the fertilizer product should be allocated. In determining the offer price for 5a, we split our business into two: the "CDR business" and the "fertilizer business". We then apportioned the selling price into the two businesses based on the relative sizes of the "inseparable cost pool" (presented in the TEA worksheet) and the "fertilizer cost pool" (excluded from the worksheet). Given that carbon credits mainly belong to the farmers who purchase our biochar blends and apply these on their lands, we assessed a carbon price (our Frontier proposal) on a cost recovery basis (i.e. we should not make a loss while administering credits on farmers' behalf).

f. What is one thing that doesn't exist today that would make it easier for you to commercialize your technology? (e.g., improved sensing technologies, increased access to X, etc.)

<50 words

Given the different "flavors" of biomass/biochar, and given our unique input-output customizability, our dream is a thoroughly annotated database of the different input feedstocks, biochar characteristics, and crop response in diverse conditions. While such data already exist in pieces/patches in the literature, synthesizing them takes lots of work.

6. Public Engagement

In alignment with Frontier's Safety & Legality criteria, Frontier requires projects to consider and address potential social, political, and ecosystem risks associated with their deployments. Projects with effective public engagement tend to:

- Identify key stakeholders in the area they'll be deploying
- Have mechanisms in place to engage and gather opinions from those stakeholders, take those opinions seriously, and develop active partnerships, iterating the project as necessary

The following questions help us gain an understanding of your public engagement strategy and how your project is working to follow best practices for responsible CDR project development. We recognize that, for early projects, this work may be quite nascent, but we are looking to understand your early approach.

a. Who have you identified as relevant external stakeholders, where are they located, and what process did you use to identify them? Please include discussion of the communities potentially engaging in or impacted by your project's deployment.

<300 words

The main beneficiaries of our project are two-sided: (1) the biomass suppliers (in our case farmers and occasionally vegetation managers producing the non-merchantable residues), and (2) output biochar offtakers (in many cases the same farmers applying biochar to their soil to improve agronomic outcomes), both of whom located within the rural, underserved communities. In order to access these groups, we work with agricultural input distributors (known locally as "agrovets") to distribute our biochar-based blends, as well as agricultural input-output companies which sometimes directly supply seeds/fertilizers to farmers in exchange for buying back the produce. In working with new communities, it is crucial to obtain high-level blessing from the local authorities. This could range from a village elder in Kenya to a Council of Elders in a Native American tribe. Finally, in order to market the carbon credits, we interface with a diverse set of buyers, third-party certifiers, and agents. We have two goals: (1) to undertake meaningful engagement, and (2) to invite the communities to co-design the CDR process with us.

In undertaking meaningful public engagement/co-design, firstly, we need to acknowledge/describe the diversity amongst farmers/other stakeholders. In particular, CDR/climate justice may have different meanings/values attached for the different groups. In addition to incorporating relevant governmental statistics in understanding group representation/composition, we are identifying local organizations working specifically on behalf of these subgroups, such as Aboriginal Tribal Councils or co-operatives of female farmers. This has helped us design the best ways to identify and engage any subgroups. During the engagement process, we also continually ask questions such as "Is there anyone else we should speak to?" in order to identify anyone who is missing at the table.

b. If applicable, how have you engaged with these stakeholders and communities? Has this work been performed in-house, with external consultants, or with independent advisors? If you do have any reports on public engagement that your team has prepared, please provide. *See Project Vesta's community engagement and governance approach as an example and Arnestein's Ladder of Citizen Participation for a framework on community input.*

<300 words

We have engaged these stakeholders/communities in-house through the C-suite leadership. To do so in a meaningful/inclusive way, we are implementing Gender-Based Analysis Plus (GBA+) techniques. Not only do we reach out to the different subgroups through their preferred channel, we have also designed engagement sessions in ways convenient for them. For example, in addition to holding general townhalls where everyone is present, we also hold specific subgroup meetings, and conduct in-person visits to individual farms while respecting the different scheduling needs of the different sub-populations (e.g. caring for dependents, working night shifts). Then, our interview designs are intended to be initially open-ended, with many "why" questions, in order to solicit differences in perspectives that may be ignored. We expect that different sub-populations may generate different insights into the potential use and desired characteristics of our CDR process to be implemented in the field, as well as the baseline for impact assessment. Finally, once we understand/appreciate the broad trends and differences in the perspectives, we devise a way, informed by the principal component analysis, to disaggregate our data by the most prominent metrics, such as gender, age, Indigeneity, as well as other potentially relevant factors. This then also allows us to establish the baseline scenarios for the subgroups appropriately, in order to assess the impact that our intervention may have differentially on their yield, livelihood, and other beneficial factors important to the different subgroups. We expect, therefore, that the human-centered aspects of our research to be a highly iterative process, requiring significant trial-and-error as well as community feedback. Ultimately, the purpose of this engagement is to put us in the shoes of the communities, and furthermore, to include them in a co-design process with us on how CDR/climate justice looks like for their families/communities.

c. If applicable, what have you learned from these engagements? What modifications have you already made to your project based on this feedback, if any?

<100 words

By immersing ourselves in agricultural/forestry operations alongside these communities, we have learned how to operate some of the heavy equipment from John Deere/Caterpillar, and how our reactor/process can be designed to be in line with the process/safety requirements of such existing equipment. We also learned that different communities have different priorities–some are worried about water stress, while others, soil acidification. By working with them to conduct soil tests, often for the first time, we unraveled the key deficiencies on their lands not only for our production process to optimize for, but also for their own insights.

d. Going forward, do you have changes to your processes for (a) and (b) planned that you have not yet implemented? How do you envision your public engagement strategy at the megaton or gigaton scale?

<100 words

While we have developed a community/stakeholder engagement strategy, it is our wish to go a step further: We would like to invite the communities to play a leading role co-designing a robust and scalable CDR process with us. For example, we have hosted public demonstrations in Canada, U.S., and India where communities interact and suggest improvements to our working prototypes and controls interface to be more integrated in line with their other agricultural/forestry equipment/operations. As we scale, our user-centric techniques described in 6a will be automated into our control system interface co-designed by these same communities.

7. Environmental Justice[3]

As a part of Frontier's Safety & Legality criteria, Frontier seeks projects that proactively integrate environmental and social justice considerations into their deployment strategy and decision-making on an ongoing basis.

a. What are the potential environmental justice considerations, if any, that you have identified associated with your project? Who are the key stakeholders? Consider supply chain impacts, worker compensation and safety, plant siting, distribution of impacts, restorative justice/activities, job creation in marginalized communities, etc.

> <200 words
>
> Our decentralized, low-cost, portable solution overwhelmingly benefits/caters to rural, underserved communities most affected by climate change (e.g. wildfires), thereby building local resilience. Our process retains 90% of the labor/economic value within local communities, also applying the agronomic benefits of biochar locally, thereby reducing communities' dependence on centralized production of chemicals (e.g. fertilizers) that is not only costly and carbon-intensive, but also vulnerable to supply chain disruptions (e.g. COVID, geopolitics). As these carbon-negative activities are generated in rural communities, they also get to access the carbon credits aggregated/verified through our internet-of-things and cloud-based control system.
>
> Our initial project occurs around Mwea Town, Kirinyaga, Kenya. We chose this location as our core team members Samuel and Joyce grew up near here and experienced the challenges of poor, smallholder farmers first-hand, and they are intimately connected with the local farming communities. In this region, 87% of the population is involved in agriculture, tilling 54% of the county's land. Of this, >80% of the growers are smallholder farmers, with maize-beans, horticulture, coffee, rice, and banana as common crops. The local soil is highly weathered, and soil fertility degradation is very common. Around 50% of the population is food-insecure.

b. How do you intend to address any identified environmental justice concerns and / or take advantage of opportunities for positive impact?

> <300 words
>
> Purchasing credits from us means much more than CDR, as each tonne of Takachar CDR is inextricably linked with other social/environmental impacts that overwhelmingly benefits rural, underserved communities. This is the unique selling point of our carbon credits in contrast to many other centralized, capital-intensive CDR/cleantech projects. Instead of educating/convincing a community to accept our project, we do the opposite by immersing our work within these communities and have them co-lead our projects and core technology development by allowing the communities a floor to articulate their deepest desires. Indeed, our current 7,000 customers range from the poorest smallholder farmers in Kenya and India to the most remote First Nations in Canada.
>
> In terms of unintended harm, our process requires no external energy sources/chemicals/water except room-temperature air. Its electricity requirements (minimal and non-disruptive to the community in the first project) can be fulfilled by the reaction process internally at the NOAK phase. Given that

[3] For helpful content regarding environmental justice and CDR, please see these resources: C180 and XPRIZE's Environmental Justice Reading Materials, AirMiners Environmental and Social Justice Resource Repository, and the Foundation for Climate Restoration's Resource Database

respiratory illnesses from crop/forest residue burning is a leading health burden in many of these rural communities, in collaboration with Colorado State University, we're ensuring that the exhaust from our process adheres to the emission requirements set by the most stringent regulating bodies.

Finally, we see this environmental justice angle also as an opportunity for us to intentionally train/shape a cleantech workforce adept in considering/addressing such issues. At the heart of our company, we serve the underdogs, and this is enshrined in our company's core culture/values. From day one, in developing our product, our salespeople/engineers, from VP to entry-level, are required to embed themselves in underserved communities, and take a use-centric customer discovery/co-design process. We certainly hope our employees, if they ever choose to leave Takachar, will carry these skillsets/mindsets to other companies.

8. Legal and Regulatory Compliance

a. What legal opinions, if any, have you received regarding deployment of your solution?

<100 words

Various types of biochar projects have already been implemented in many jurisdictions worldwide, and have faced no legal hurdles beyond compliance with local environmental, health, and safety regulations. We also have no reasons to believe otherwise for our projects, beyond the customary legal/safety precautions that need to be taken.

b. What permits or other forms of formal permission do you require, if any, to engage in the research or deployment of your project? What else might be required in the future as you scale? Please clearly differentiate between what you have already obtained, what you are currently in the process of obtaining, and what you know you'll need to obtain in the future but have not yet begun the process to do so.

<100 words

Currently, for internal R&D, we operate under a research equipment exemption. In our initial pilots with the communities, we generally operate under our host communities' existing permission, such as a First Nation organization's timber harvest license. The additional activities generated by our process are so minimal that they have only involved minor revisions to their existing licenses. As we scale up, we will seek licenses associated with portable equipment, similar to the agricultural/forestry equipment being used in the field, where landowners or end users generally need not take out another site-specific license in order to operate the equipment.

c. Is your solution potentially subject to regulation under any international legal regimes? If yes, please specify. Have you engaged with these regimes to date?

<100 words

The transportation of charcoal (especially as a fuel rather than for soil application) may be subject to certain international standards, regulations, and restrictions. Our activities mainly involve localized production and application of biochar-based fertilizer blends, and we do not anticipate being involved in this international trade in the foreseeable future.

d. In what areas are you uncertain about the legal or regulatory frameworks you'll need to comply with? This could include anything from local governance to international treaties. For some types of projects, we recognize that clear regulatory guidance may not yet exist.

<100 words Biochar standards are still continuously being defined and revised. For example, the European Biochar Certificate publishes at least four classes of standards, for animal feed, for organic agriculture, for non-organic agriculture, and for incorporation into materials. In general we need to comply with these standards. These standards may change

e. Do you intend to receive any tax credits during the proposed delivery window for Frontier's purchase? If so, please explain how you will avoid double counting.

<50 words Not applicable.

9. Offer to Frontier

This table constitutes your **offer to Frontier**, and will form the basis of contract discussions if you are selected for purchase.

Proposed CDR over the project lifetime (tonnes) *(should be net volume after taking into account the uncertainty discount proposed in 4(c))*	4,760 tonnes (based on initial prepurchase), with option to another 9,520 tonnes, which represent a small fraction of the total CDR generated in project's lifetime
Delivery window *(at what point should Frontier consider your contract complete? Should match 1(f))*	3 years
Levelized Price ($/metric tonne CO_2) *(This is the price per tonne of your offer to us for the tonnage described above)*	$105

Application Supplement: Biomass

Feedstock and Physical Footprint

1. What type(s) of biomass does your project rely on?

<100 words

Our initial project in Kenya relies on rice husks which otherwise are burned in open air. In principle, our technology is compatible with a much wider aperture of crop and forest residues such as straws, shells, and wood chips. In subsequent replication of our project in other areas, we will incorporate these other types of biomass. The common ground is that all these biomass types are non-merchantable in nature, where the counterfactual is being burned in open air, landfilled, or piled to decompose over time.

2. How is the biomass grown (e.g., kelp) or sourced (e.g., waste corn stover)? Do you have supply agreements established?

<200 words

The biomass is sourced from the non-merchantable components of agricultural and forestry operations. In our initial project, the rice husks are purchased from farmers upon harvest, thereby enabling them additional income to a waste stream that they would otherwise have set on fire. We already have established supply transactions with around 7,000 farmers in the field. Generally, farmers sell the residues as a commodity; therefore, we do not execute a long-term offtake agreement. However, that is something we can consider in the future.

3. Describe the logistics of collecting your waste biomass, including transport. How much carbon emissions are associated with these logistics, and how much does it cost? How do you envision this to evolve with scale?

<200 words

In general, due to the decentralized nature of our conversion, biomass collection is minimal. For some crop types, it is necessary to centralize residues at the field level. Based on real market data in cases where similar biomass types have other economic use, the associated collection cost is ~$20-30/tonne of biomass. This also closely corresponds to the average cost we arrived at during our field pilot, which is listed in the TEA (adjusted to a-per-tonne-CO2-e basis). Additionally, there is a cost and carbon footprint for bringing the portable equipment to the field. The cost, as experienced in our field pilot, is minimal. The combined carbon footprint of biomass collection and the transportation of portable equipment, shown in the “biomass sourcing” step of the LCA above, comprises less than 2% of the total emissions, and less than 0.1% of the total carbon removed. As we scale up, generally, biomass sourcing will scale proportionately. As we deploy a fleet of self-coordinating reactors into the field, such coordination, like a Uber model for biochar production, can improve the logistical cost and reduce

the carbon intensity somewhat, by optimizing the route and the time the reactor spends in transit (i.e. downtime).

4. Please fill out the table below regarding your feedstock's physical footprint. If you don't know (e.g. you procure your biomass from a seller who doesn't communicate their land use), indicate that in the table.

	Area of land or sea (km^2) in 2022	**Competing/existing project area use (if applicable)**
Feedstock cultivation	E.g. 1 km^2 (floating kelp array) OR N/A (procuring waste biomass)	Non-merchantable residues are sourced over ~2,500 ha (7,000 farmers) for a single community-based project
Processing	E.g. 0.1 km^2 (boat yard, manufacturing facility) OR 0.5 km^2 (manufacturing facility for mobile biochar plants)	Our production facility measures roughly 20 m by 20 m
Long-term Storage	E.g. N/A (uncertainty in final state of kelp) OR 2 km^2 (ag fields in which biochar is deployed)	Over ~2,500 ha for a single community-based project

Capacity

5. How much CDR is feasible globally per year using the biomass you identified in question 1 above? Please include a reference to support this potential capacity.

<100 words

It is difficult to estimate the total biomass residues available to be harvested/converted. The first place to start is the "Billion-Ton Report", which is updated regularly by the U.S. Department of Energy on the distribution of biomass resources within the U.S. Of this, depending on the exact operations, we estimate that at least 30%-50% comprises of non-merchantable residues, based on prior interviews with farmers and vegetation managers. This is corroborated by WBA report estimating world biomass residue availability to be between 4.3-9.4 billion tons (wet)/year, equaling ~1.4-3.3 gigatons/year of CDR.

Additionality and Ecosystem Impacts

6. What are applications/sectors your biomass feedstock could be used for other than CDR? (i.e., what is the counterfactual fate of the biomass feedstock)

<100 words

In our work, we specifically focus on non-merchantable biomass residues, that is, biomass that otherwise would be burned in open air, landfilled, or left to decompose. We appreciate the diverse range of counterfactuals where biomass is used for other purposes, such as mulching, pulping, animal feed, biofuel (sometimes with carbon capture and storage), construction materials, or bedding. In general, if such biomass is already utilized, we ask the question of whether such baselines are more attractive in terms of CDR and technoeconomics when compared to our method. If they are, then our intervention would not be suitable for these baselines.

7. There are many potential uses for waste biomass, including avoiding emissions and various other approaches to CDR. What are the merits and advantages of your proposed approach in comparison to the alternatives?

<200 words

Our position is that biomass utilization is highly context-dependent, and there is no universal, one-size-fits-all solution that works for all communities. As indicated in Question 6, in many communities, certain streams of biomass residues are already being utilized (for example, coconut shells for activated carbon production, pine shavings for chicken bedding, or rice husks for bioenergy), often by the serendipitous virtue of the communities' location to suitable offtake markets or mills. In such cases, we take these existing uses as the baseline, and ask the question of whether our intervention is superior in terms of CDR and technoeconomics compared to the baseline. In general, we only recommend implementing our process when it is the best available option for utilizing the biomass residues at hand.

This means that in many communities, we will first identify and exclude any high-value biomass utilization pathways from our processing. Then we work with the community to identify all other biomass residues that cannot be economically utilized. Given the wide aperture of input feedstock characteristics our process can accept, and the various customizable carbon-based bioproducts that we can produce, our solution then becomes the unique catch-all of all residues where other alternatives failed to gain traction.

8. We recognize that both biomass production (i.e., growing kelp) and biomass storage (i.e., sinking in the ocean) can have complex interactions with ecological, social, and economic systems. What are the specific, potential negative impacts (or important unknowns) you have identified, and what are your specific plans for mitigating those impacts (or resolving the unknowns)?

<300 words

The biochar produced could be used as a cooking fuel (i.e. charcoal) in many communities. One risk is that farmers will purchase the biochar to burn it rather than putting it into the soil, thereby negating CDR. We mitigate this risk with two measures. Firstly, farmers upload photos of themselves applying the biochar (whose packaging is tagged with a QR code) to the field as a way of verifying that biochar is indeed applied to the soil. Secondly, the initial biochar produced in our project is from rice hulls, which is a high-ash biomass. While ash can be good as a fertilizer blend as it contains plant minerals, it is terrible when used as a cooking fuel as it limits the heat output. For example, we failed to bring a pot of water to boil with our biochar tested as a solid fuel. Therefore, if farmers try to burn our biochar as a fuel, then the effort will likely not be successful. For subsequent biomass types, even if the ash content is lower, from our experience, the unit economics of biochar-based fertilizer with CDR tends to work out much more favorably than that of solid fuel, thereby inhibiting efforts at the latter.

Furthermore, at scale, one concern is that rural communities will grow dedicated “carbon crops” to make biochar while displacing food production. This scenario is unlikely, because the total agricultural and carbon value of biochar is only a fraction of the value of the food grown.

Finally, applying biochar has secondary effects in altering the soil biogenic GHG fluxes. Little research has been done on this subject (Song *et al.*, 2016), and much additional measurement is needed in different contexts. However, the comfort is that these changes tend to be small (<1%) compared to the net CDR amount.