Frontier

Climate Robotics

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

Climate Robotics Inc.

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

Houston, TX

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

Jason Aramburu, Morgan Williams PhD, Daniel Mulqueen PhD

Brief company or organization description

Mobile pyrolysis systems for production of high pH, durable biochar from waste biomass

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.

Climate Robotics is a developer of mobile, modular, biochar production systems from agricultural and wood waste. Climate Robotics' reactors are self-powered, tractor-mounted systems that operate directly in the field where corn stover and other agricultural/wood residues exist. Climate Robotics' systems are capable of stationary operation at the edge of field or continuous, in-field operation similar

[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.

to a combine harvester. Our deployment approach eliminates the need to transport bulky material (feedstock, biochar, etc) over long distances. Our pyrolyzer design allows for precise control over pyrolysis reaction conditions including temperature (700-1,000C) and residence time. A photo of our TRL-6 system is included in the confidential addendum.

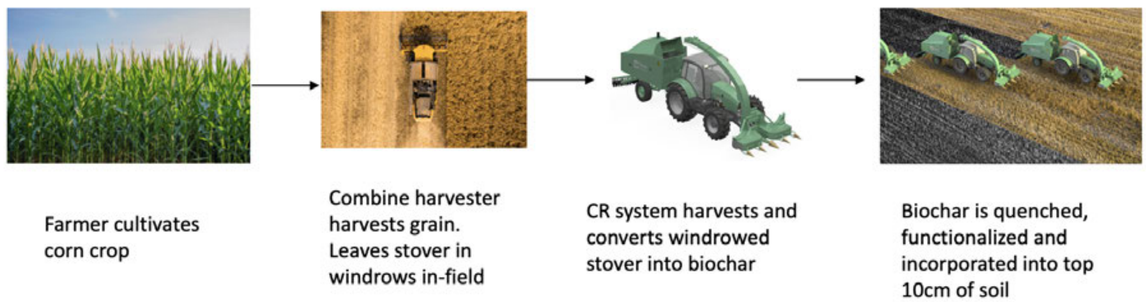


Figure 1: Overview of CR Process

The focus of the proposed pre-purchase project is on the production of high pH (10+), durable (1,000 year+) biochar from corn stover, and development of an appropriate MRV protocol. These agricultural residues are abundant on commercial row crop farms and have few, if any, commercial uses. However, their distributed nature (2-6 metric tons of residue per acre) and low bulk density creates material harvesting, transportation and conveyance challenges. As a result, virtually all competing biochar companies focus on the use of high bulk density, point-source feedstocks such as wood chips, pellets or nut shells/pits. However, these woody feedstocks already have other profitable, competing applications, such as biomass energy and heat generation. Furthermore, annual production of these feedstocks is 1-2 orders of magnitude lower than that of agricultural waste. For example, the US produced approximately 8.7MM tons of wood pellets in 2020 (https://www.mdpi.com/1999-4907/13/5/786/pdf), compared to over 120MM tons of corn stover (https://www.agmrc.org/commodities-products/biomass/corn-stover#:~:text=Corn%20stover%20is%20the%20largest,biomass%20residue%20is%20available%20annually). To achieve gigaton scale carbon annual sequestration with any biochar system, 300-500MM metric tons of biomass feedstock are likely required each year. This demand cannot be satisfied with woody feedstocks alone.

Climate Robotics' pyrolysis system is designed to meet the unique challenges of harvesting, transporting, and conversion of bulk agricultural waste such as corn stover into biochar via a continuous process. Most pyrolysis systems that focus on conversion of agricultural wastes into biochar are batch processes, requiring significant labor and time to load and unload. Our mobile, tractor-mounted reactors can be towed to the edge of the field and continuously fed with baled or windrowed material. The systems can also be fitted with an off the shelf forage harvesting implement to harvest waste continuously, in-situ, similar to a combine harvester. This unique approach enables the efficient bulk collection of agricultural waste feedstocks at scale. CR's technology is purpose-built for addressing the unique materials handling and conveyance challenges associated with agricultural waste. Low bulk density feedstocks are notorious for clogging and bridging equipment. CR has designed a proprietary system of shaftless, ribbon and paddle augers that efficiently chop, homogenize and convey bulk agricultural waste feedstocks through the system without clogging.

Our reactor is likewise unique in its ability to operate at elevated pyrolysis temperatures, in excess of 700-1,000C. Competing mobile pyrolysis systems operate within a much lower temperature range, typically 300-500C, and require significant inputs of thermal or fossil fuel energy to dry feedstock and maintain reaction temperature. CR's system is able to achieve high temperatures through the efficient combustion of the pyrolysis gas in an external flare stack. This heated exhaust gas is then used to both dry incoming feedstock, and achieve pyrolysis temperatures in excess of 700-1,000C.

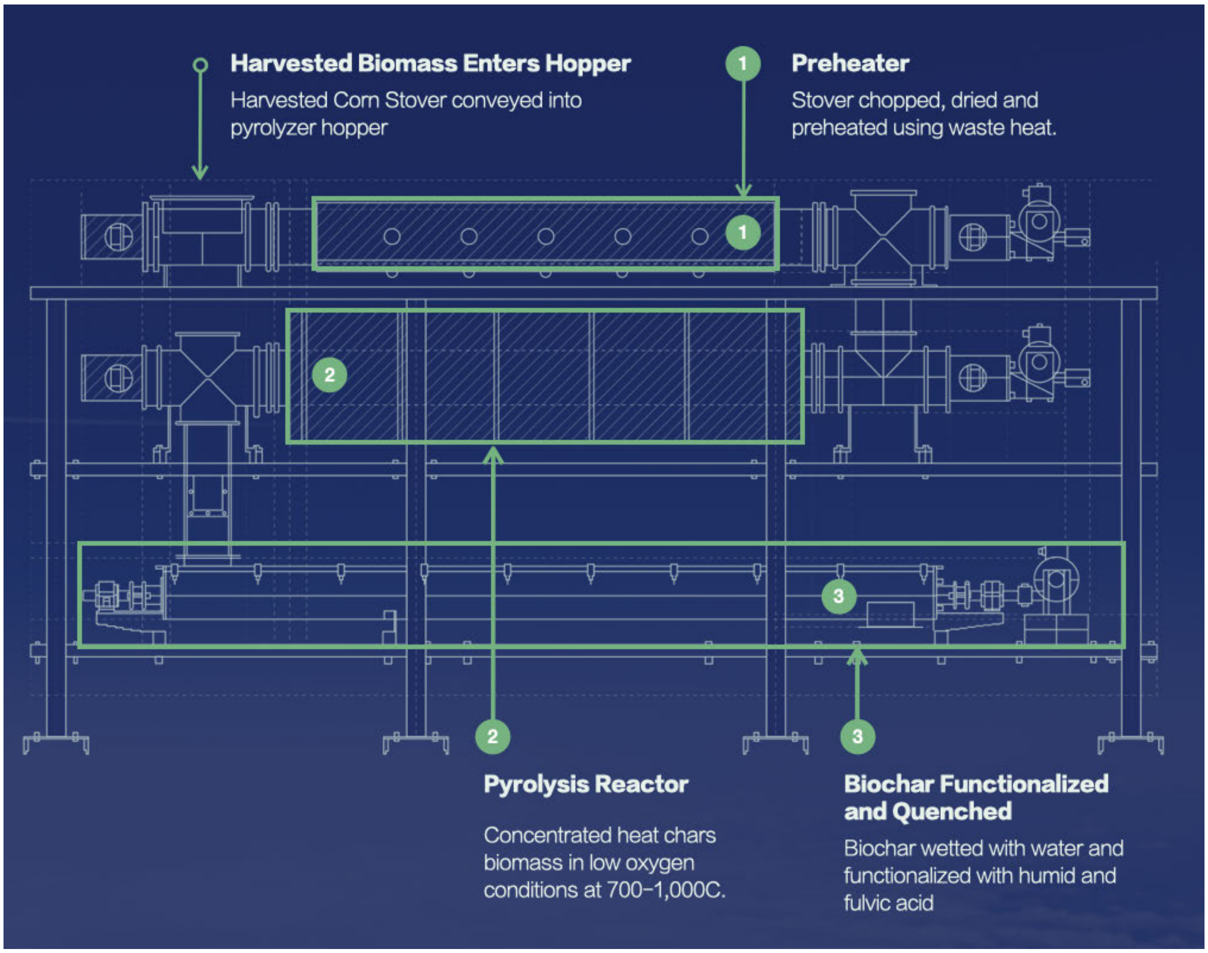


Figure 2: Diagram of CR Pyrolysis Reactor

Elevated temperatures are critical for the production of durable biochars (e.g., high aromaticity and low O:C ratio). When combined with high ash feedstocks, such as corn stover, these elevated reactor temperatures also produce a biochar with a relatively high pH (10s or low 11s) for sustained buffering capacity of acidic soils. While the yield of high pH, 1,000 year + durable biochar is lower per ton of feedstock, it is considered more valuable in an agronomic context as it allows for the replacement of chemical soil amendments such as agricultural lime.

Climate Robotics seeks a pre-purchase agreement to support the deployment of this technology on partner farms in Coastal Texas and Arkansas, delivery of CDR to Frontier, and the development and testing of a new MRV protocol to ensure accurate measurement and verification of the 1,000-year+ fraction of the biochar. We will produce over 1,000 MT of biochar across various reactor temperatures from 700-1,000C, representing a gross, permanent removal of 1,545MT of CO2. We will apply these biochars to agricultural soils at standard application rates to evaluate agronomic performance and will conduct analysis of samples to determine optimal reaction conditions for maximizing yield of 1,000 year+ biochar.

Today, three common methods to assess carbon durability in biochar are: 1) C structural analysis (e.g., ^{13}C NMR, XPS, etc); 2) oxidation resistance (e.g., Edinburgh Stability Test; H_2O_2 and heat); and 3) models of biochar persistence and extrapolation of decay based on elemental ratios of H:C and O:C (Leng et al 2019).

A meta-analysis of elemental ratios for carbon stability shows the relationship between processing conditions and H:C and O:C ratios (Ippolito et al 2020). When biochar is produced at >500C and contains an H:C ratio of <0.7, the carbon has a half-life in soil (t1/2) >100 years (Budai et al 2013). When the O:C is 0.2 - 0.6, the carbon in the biochar has a half-life of 100-1,000 years; and when O:C is below 0.2, the carbon has a half-life >1,000 years (Spokas 2010). These criteria have been adopted by the International Biochar Initiative and the European Biochar Certification for carbon stability as an alpha protocol, a low cost analytical means to validate C stability. Newer models account for environmental conditions, such as soil temperature, on biochar decomposition rates (Fang et al 2015; Woolf et al 2021).

More advanced structural analyses (e.g., ^{13}C NMR, XPS, etc) and oxidation resistance tests (e.g., Edinburgh Stability Test; H_2O_2 and heat) are considered superior to elemental analysis, as they define the mechanisms responsible for carbon durability (Leng et al 2019). Specifically, oxidation resistance tests are designed to volatilize the entire labile carbon fraction of biochar representing the conservative maximum amount of stable carbon in the material irrespective of environmental and soil factors known to stabilize biochar carbon in-situ (e.g. migration of biochar particles deeper into the soil profile resulting in reduced oxygen environments and greater resistance; and the incorporation of biochar particles into microbially inaccessible organo-mineral aggregates). With feedstock and process condition specific data sets, models that correlate oxidation resistance (total durability) to mechanistic tests (e.g. structural analysis by ^{13}C NMR or XPS to determine why materials are resistance), can be developed and combined with inexpensive elemental proxy tests (e.g. O:C and H:C) to reduce uncertainty in long term durability measurement.

Models based on measurement of elemental ratios (O:C, H:COrg etc) have received the most attention due to their cost-effectiveness, reproducibility and the widespread availability of labs with sufficient testing capacity (Spokas 2010; Budai et al 2013). However, given that these elemental ratios are ultimately a proxy for long term biochar decay rates (100-to-10,000 yrs) based on short term soil incubation experiments (<3 yrs), there is likely significant error and uncertainty associated with use of these models alone. Models that incorporate the accelerated decay of the entire labile carbon fraction and corresponding mechanistic determination of C-C aromatic bond strength represent a conservative approach to long duration carbon accounting, and this prepurchase agreement will further serve to bolster the development of more rigorous biochar carbon stability methods.

Agronomic analysis will be conducted by partner organizations including Farmers Business Network. Advanced analyses, such as NMR, will be conducted by partner organizations including Rice University. Our project will address the key issues that have limited the growth of previous biochar projects.

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.

Please see confidential addendum

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?

Please see confidential addendum

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?

Jason Aramburu has over 15 years of experience developing biochar projects in the US, Latin America and East Africa. He has an extensive network of farmers, offset verifiers and credit purchasers and successfully negotiated the Company's other significant offtake agreements. Morgan Williams, PhD has an advanced degree in soil science from UC Berkeley and has over 15 years of experience building and deploying self-contained biochar production systems, developing MRV/testing protocols for biochar, and running large scale field trials. Dr. Williams also runs CR's internal soils lab, with capabilities including thermogravimetric analysis and high-throughput soil chemistry testing. Daniel Mulqueen, PhD has an advanced degree in Mechanical Engineering and over 15 years of experience designing, building and operating continuous biomass pyrolysis systems. Peter Rellinger has over 25 years of experience in mechanical and CAD design at Halliburton and Schlumberger, and led development of the Company's trailer mounted rotary ovens. Justin Smith has over 10 years experience in mechanical and hydraulics engineering at Halliburton. Luis Gomez has over 25 years experience in process automation and electrical engineering. The Company is in the process of recruiting a senior controls engineer to assist Mr. Gomez in developing low cost and scalable controls systems. The Company also seeks to onboard an agricultural engineer to assist with modification of forage harvesting systems for its future, TRL-9 system. This skillset is not required for the current, proposed pre-purchase project at TRL-6.

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
Carrie Masiello, Rice University	Advanced biochar characterization services (e.g., 13C NMR, XPS, etc)	Confirmed Project Partner
Kurt Spokas, PhD,	O:C Ratio testing, advisory services	Confirmed Project Partner

USDA ARS		
Farmers' Business Network	Field Trial support, 3rd party verification, introductions to farmers	Confirmed Project Partner

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?

The project is expected to reach full completion by June 2024. Construction of the proposed mobile pyrolysis system is already underway and expected to complete by end of Q4, 2022. Delivery of removals will occur between June 2023 and March 2024, followed by up to 3 months of additional soil sampling, testing and laboratory characterization of biochar with final report-out in June 2024.

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.

CDR under this pre-purchase agreement is expected to commence in June 2023, following successful commissioning and testing of the mobile pyrolysis system. CDR delivery (eg production of biochar and application to soil) will occur primarily between June 2023 and March 2024. This schedule is based on the projected availability of waste biomass and the projected planting schedule in the proposed geographies (Texas and Arkansas).

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	10000
2024	30000
2025	100000
2026	200000
2027	400000
2028	800000
2029	1400000
2030	2800000

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	Commissioning and build completion of Mobile Pyrolyzer	Q4 2022
2	Development and testing of MRV Protocol	Q2 2023
3	Commencement of Biochar Production/CDR	Q3 2023
4	Completion of Biochar Production/CDR	Q3 2024
5	Completion of Report-out and public release of final MRV protocol draft	Q4 2024

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

We have filed three US patent applications, with filing numbers and status below, along with international PCTs. The patents have not yet been published by USPTO. We are happy to provide full text of the applications upon request and will include a summary in the confidential addendum. We may look to file additional patent applications specific to the proposed TRL-9 system and MRV/testing protocol.

Currently filed applications:

“Autonomous Device for In-Field Conversion of Biomass into Biochar" Priority Filing Date June 19, 2020 Type: Utility, Non-provisional Status: Allowed (17/353,770), Continuation Filed Attorney Docket No: 3887-083791

“METHOD FOR PRODUCING GRAPHIC CARBON NANO-PARTICLE MATERIAL AND PRODUCTS PRODUCED BY SAID METHOD” Priority Filing Date June 6, 2022 Type: Utility, Provisional Status: Provisional Attorney Docket No: 3887-062864

“METHOD FOR IMPROVING CARBON YIELD, CARBON STABILITY, AND AGRONOMIC VALUE OF BIOCHAR AND THE ASSOCIATED CARBON PRODUCT” Priority Filing Date June 6, 2022 Type: Utility, Provisional Status: Provisional Attorney Docket No: 3887-069799

k. How are you going to finance this project?

We have raised capital from private investors and VCs to cover the R&D cost associated with developing the mobile pyrolysis technology. We have also raised sufficient equity and non-dilutive capital to cover the initial purchase and construction costs of the mobile pyrolyzer, and have already begun production of the unit. We will finance the R&D associated with development and testing of the 1,000 year + MRV protocol as a component of the proposed pre-purchase agreement. We will finance the cost of production and delivery of the CDR as a component of the proposed pre-purchase agreement. The proposed pre-purchase agreement represents a small percentage of the expected economic lifespan and capacity of the mobile pyrolysis system. Any additional CDR that can be delivered during the economic lifespan of this mobile pyrolysis system will either be sold to Frontier under a subsequent purchase agreement, or to one of CR's other offtake partners.

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.).

We have two additional contracts signed with two other major buyers of CDR credits. These contracts represent an aggregate purchase of over 150,000 MT of CO2 by end of year 2026. Any additional credits available from this project that are not purchased by Frontier will be sold to these buyers under the existing contracts.

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.

A major goal of this project is to evaluate the agronomic performance of 1,000+ year biochar in commercial corn production in the Southern and Mid-Southern US. We are working closely with the Farmers' Business Network to conduct multi-season, 3rd party yield analysis and soil chemistry analysis following treatment of fields with biochar. Capturing statistically-significant agronomic data requires significant time, so we do not expect to have any statistically-significant crop yield data until 2024 or 2025. Absent statistically-significant data demonstrating yield improvement or other agronomic benefit, we expect it will be challenging to charge farmers and landowners a fee for biochar. Given this uncertainty, we do not anticipate any additional revenue streams beyond the CDR payment for the life of the proposed project.

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
Manufacturing Risk	We are building multiple TRL-6 units in parallel, both in-house and via a contract manufacturer to mitigate any manufacturing risk. We are confident we will have sufficient capacity to execute the proposed project.
Project Execution	We have already delivered over 1,400 MT of CO2 for other buyers and are confident in our ability to deliver the proposed tonnage. Likewise, our team has over 3 decades of experience developing and delivering large scale biochar production projects.

Financial Risk	The Company is well-capitalized and has already pre-sold over 150,000 MT of CO2 to other buyers. Additional funding is not required to build and deploy the equipment needed for this project. In the event Frontier declines to purchase additional tonnage from CR, beyond the Pre-purchase, we are able to sell these additional tons to already-contracted buyers.
MRV Risk	CR is proposing to develop and test a new MRV protocol to verify 1,000+ year biochar. It is possible that development of this MRV protocol will be unsuccessful, or late. To mitigate this risk, we have structured the project in a stepwise fashion, and will develop and test the protocol before delivering CDR.
Ecosystem Risk	Our project depends on availability and access to agricultural waste biomass. In the event that severe weather or other ecosystem risk makes access difficult to certain plots of land, CR has a pipeline of over 20,000 acres of corn crop throughout the Southern and Mid-Southern US.

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?

The ratio of Oxygen:Carbon (O:C) in biochar has traditionally been used as a proxy for biochar durability (Spokas 2010). Based on the Spokas model, a biochar sample with O:C ratio between 0.1 and 0.2 will exhibit a half life in soil between 1,000 and 10,000 years.

Kuzyakov et al 2014 conducted an 8.5 year field trial of biochar permanence using labeled carbon radioisotopes. Biochars were produced at a reactor temperature of 400C using radioactively-labeled samples of perennial ryegrass. After 8.5 years, the study indicated a mean residence time (MRT) of 4,000 years under field conditions. Based on this assumption, up to 75% of the biochar produced under these conditions would remain in soils after 1,000 years.

According to Chaterjee et al, 2020, a biochar produced at 400C has an O:C ratio of 0.13. This indicates the biochar samples produced in Kuzyakov et al would be expected to have a half-life of at least 2,000 years, largely consistent with their observed mean residence time of 4,000 years.

In our own testing of corn-stover derived biochars, we realized an O:C of 0.13 or less at reactor temperatures between 700 and 1,000C, correlating to a half life of >2,000 years. Based on the above studies, it is a reasonable assumption that corn-stover derived biochars produced at reactor temperatures at or above 700C-1,000C will consistently demonstrate a half life of at least 2,000 years, with a lower-bound of 70% of the carbon present after 1,000 years. In terms of the upper bound for durability, we estimate up to 80% of the carbon to be present after 1,000 years, pending additional testing to validate this assumption.

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?

> The biggest durability risk faced by any biochar project is rapid decomposition of the biochar in the soil. Decomposition rate of a biochar in soil is measured by proxy using O:C ratio, as described above. As described elsewhere in the application, we plan to extend testing beyond O:C to provide additional confidence and precision in our estimation of decomposition rate. That said, we are confident we can reliably produce a biochar with O:C ratio <0.13 from corn stover, representing a half-life of at least 2,000 years with conventional testing methodologies (75% of carbon remaining after 1,000 years). Physical durability risks for biochar projects primarily center around application methodology: dusting/blowing of biochar and fire/combustion risk. We mitigate dusting by applying the biochar at or near the soil surface using a spreading system derived from manure and fertilizer application. We mitigate combustion risk by using a disking harrow to incorporate the biochar into the top 10cm of soil, following the recommendations of the Verra Carbon Standard methodology for biochar. By following these protocols, the risk of physical reversals due to fire or wind is considered de minimis.

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	1,545 MT CO2.
Describe how you calculated that value	We assume a single pyrolysis system will be devoted exclusively to delivering CDR to Frontier for 1 year (1,500 operating hours), and based this off the Gross CDR tonnage in the LCA/TEA.

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.

> Please see confidential supplement.

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.

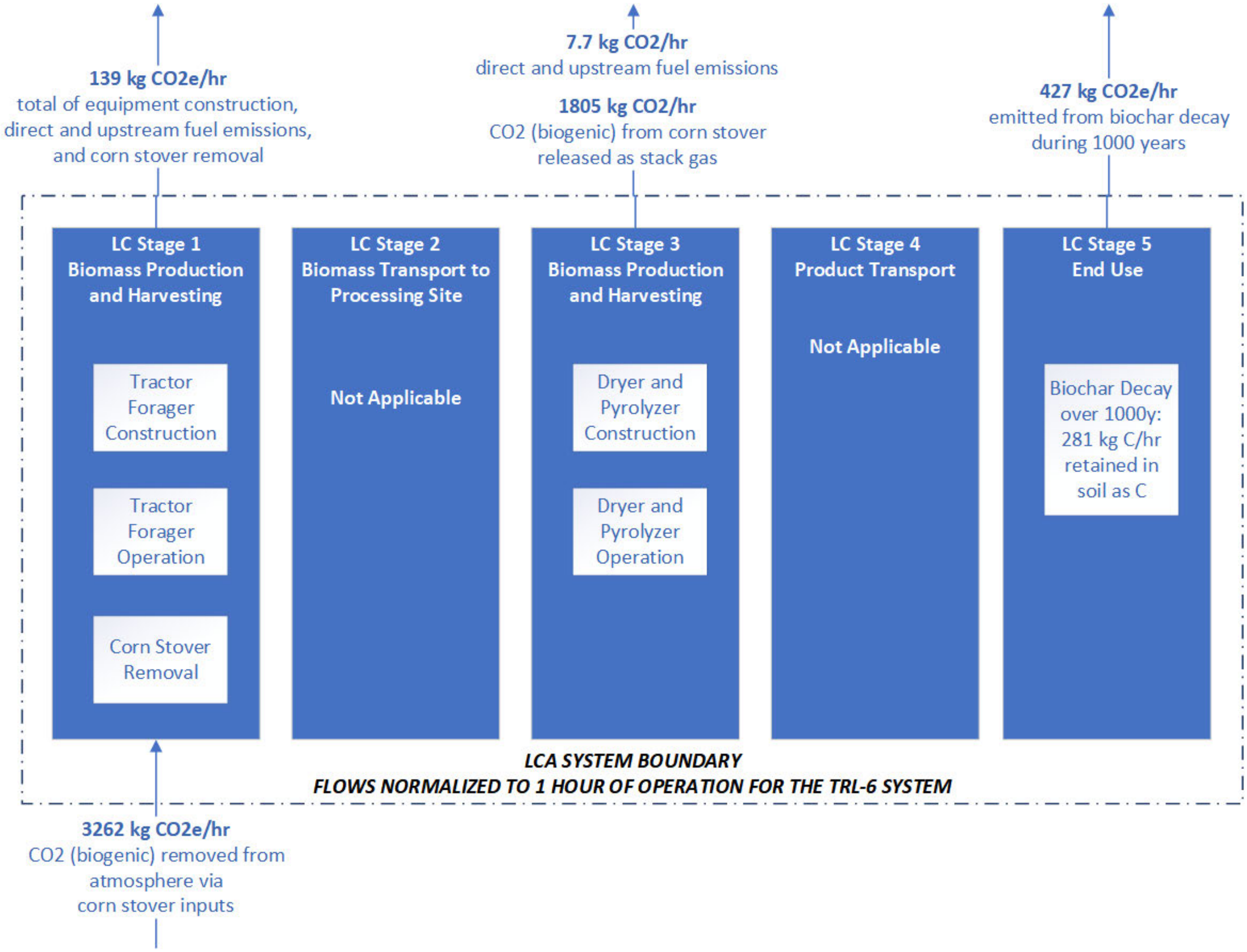
According to Dai et al 2020, a meta-study of >150 peer reviewed trials, biochar amended soils show a grand mean crop plant productivity response (PPR) of 16% regardless of biochar/soil conditions and crop type. It is conceivable that our project could result in avoided or reduced fertilizer emissions if farmers/landowners reduced their use of chemical inputs proportionally to compensate for any increase in PPR. However, we do not have sufficient confidence in the PPR impact of our biochar at this time to include these avoided emissions in any CDR calculations. It will require through the end of the proposed project to capture any statistically significant yield or PPR data from the proposed project. Moreover, we find the majority of farmers prefer to maximize crop yield, particularly during times of high input cost. Given this, we do not expect many farmers would elect to reduce their use of chemical inputs when combined with biochar, and will instead opt to maximize yield.

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)*	220 MT CO2
Emissions / removal ratio *(gross project emissions / gross CDR–must be less than one for net-negative CDR systems)*	0.142
Net CDR over the project timeline *(gross CDR - gross project emissions)*	1,325 MT CO2

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



2.

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

Our pyrolysis system represents a discrete piece of industrial equipment, mated to an off the shelf tractor, so the totality of our system is within the bounds of the LCA. The primary emissions relevant to the LCA are emissions from the tractor itself, and emissions from the burning of the propane pilot light on board the system. Emissions from the flare stack of the pyrolyzer are due to combustion of pyrolysis gas, which is considered carbon-neutral as it is derived from the pyrolysis of biomass.

b. 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](#).

Process Step	CO_2(eq) emissions over the project lifetime	Describe how you calculated that number. Include references where appropriate.

	(metric tonnes)	
Stage 1: Biomass production and Harvesting	208.05 MT CO_2e	A combination of modeling emissions associated with stover removal (source), modeling emissions associated with construction of the tractor, and measured fuel consumption of the tractor during operations.
Stage 3: Biomass Production and Harvesting	11.55 MT CO_2e	A combination of modeling emissions associated with the construction of the biomass pyrolysis system, and measured emissions when operating the system.
Stage 5: End Use	640.5 MT CO_2e	This figure is based on our modeling of the decomposition rate of biochar in soil over 1,000 years, based on the Spokas 2010 model, using the lower bound of durability.
Stage 3 CO_2 from stover released as stack gas	2,707.5 MT	These emissions are due to combustion of biomass-derived pyrolysis gas, and are considered carbon neutral
(include additional rows as needed)		

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.

> A comprehensive MRV protocol for 1,000 year + biochar is a deliverable of this pre-purchase agreement. We will model our protocol off the existing 100 year biochar MRV protocols from European Biochar Certificate (EBC) and Verra Carbon Standard (VCS). Like the VCS methodology, our proposed MRV protocol limits feedstock sources to biomass wastes. We require an LCA of the process and equipment. We model emissions associated with biomass production and harvesting, as robust data already exists for row crops like corn. Embodied emissions from agricultural and pyrolysis equipment are modeled using DOE estimates. Operating emissions associated with biomass conversion are measured using the particular pyrolysis system and tractor/prime mover to be used in the proposed project. Like EBC, we require annual retesting of pyrolysis systems to meet spec. Modeling end-use/application is analogous to EBC, but adds additional layers of testing. We ensure all biochars meet or exceed IBI Standard for elemental analysis, pH and volatile matter (H:COrg<0.7). We require comprehensive annual testing of 360 aggregate biochar samples for any given project up to 10,000 MT CO_2e per year. For larger volumes, additional testing may be required. We exceed requirements of

VCS and EBC in requiring an O:C ratio of 0.13 or less, correlated with a half life of 2,000 years in soil. Finally, our MRV protocol requires 13C NMR, XPS, and accelerated chemical degradation (e.g., H2O2 and heat: the Eidenberg Stability Protocol) analyses of biochar samples to validate carbon stability with a higher degree of confidence. A goal of the proposed pre-purchase agreement is to determine appropriate standards, frequency and number of samples for these additional tests. Frequency/number of samples will be balanced with the cost of testing, and expected price per MT of CO2 to ensure robust measurement and high confidence as well as sufficient profit margins to drive growth in the industry.

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.)*

Durability will be modeled using the Spokas 2010 model for O:C, with a requirement of O:C less than or equal to 0.13 across at least 360 aggregate biochar samples per project (up to 10,000 MT CO2e per year). An O:C of 0.13 or less is correlated with a 2,000 year half life in soil. The Spokas model correlates O:C ratios, which can be measured in any standard soil lab, with data from 13C NMR and other advanced analyses. At the time of publication, these analyses were difficult to readily obtain on the scale needed for a biochar project developer. Over 12 years, test availability has increased in the US, making it feasible for project developers to conduct advanced biochar testing/characterization directly. We will require 13C NMR, XPS, and accelerated chemical degradation (e.g., H2O2 and heat: the Eidenberg Stability Protocol) analyses of biochar samples to validate carbon stability with a higher degree of confidence. Development of an appropriate standard for 1,000+year biochar, and testing frequency/protocol is a deliverable of this pre-purchase proposal. Care will be taken to ensure testing is sufficiently rigorous, but not cost-prohibitive for project developers.

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	We consider the uncertainty impact of measuring the mass of CO2 stored in the biochar to be negligible (<1%). The reason is that our system precisely measures the tonnage of feedstock in, and tonnage of biochar out. According to the VCS biochar methodology, if biochar is incorporated or ‘disked’ into the top 10cm of soil, any losses due to wind or erosion are de minimis.
Leakage	We consider the uncertainty impact of leakage to be low (1-5%), as we follow the VCS recommendation for application and disking of biochar into the top 10cm of soil. This methodology ensures biochar is incorporated into the topsoil.
Feedstock Storage Counterfactual	We consider the uncertainty impact of feedstock storage counterfactual to be low (1-5%), as we focus on the use of corn stover. The most common tillage practice today for stover is continuous no till with whole residue, where whole residues (not chopped residue) are left on the surface of the soil. In our LCA we already account for changes in soil organic matter concentration associated with this practice.
Feedstock Use Counterfactual	We consider the uncertainty impact of feedstock use counterfactual to be low (1-5%), as corn stover has approximately 50% of the crude protein found in corn grain, making an unsuitable feedstock for most livestock. Furthermore, cattle have difficulty digesting the cob and stalk (source), which can lead to animal health issues that reduce yield. Farmers in the US generally opt for no-till with whole residue, or conservation tillage.
Indirect Land Use Change	We consider the risk of indirect land use change to be low (1-5%) as our emergent MRV protocol requires the use of waste feedstocks, similar to the VCS methodology. A scenario could occur where the yield benefits of biochar application in low pH, tropical soils increase farm profitability so much that farmers look to expand their land holdings. However, research indicates that technological advances which increase agricultural productivity tend to result in a net savings of land.
Materials	We estimate the uncertainty associated with materials to be low (1-5%), as we are building discrete, mobile biochar production systems whose embodied emissions can be readily and accurately modeled using DOE figures, rather than complex centralized pyrolysis plants. In addition, we do not currently use any exotic mineral catalysts or feedstocks which might be difficult to model.
Energy	We estimate the uncertainty associated with energy use to be

	negligible (<1%), as our only inputs of energy are diesel fuel and propane whose emissions can be measured accurately using eia data and sensors onboard the tractor and pyrolysis system.
Storage Monitoring and Maintenance	In a biochar system, the primary storage, monitoring and maintenance risk is due to durability of the biochar in soil, eg its rate of decomposition. The Spokas 2010 model is the current standard for estimating decomposition, and we would flag the uncertainty impact when using this model alone as low to medium (5-20%) according to thresholds defined in the Carbon Plan tool. Based on the results of Chaterjee et al, 2020, we would expect 25% of the carbon in a given biochar sample to decompose over 1,000 years, provided that biochar has an O:C ratio of 0.13 or less, however O:C measurement has significant uncertainty. Our proposed MRV protocol will provide greater certainty around durability than is currently possible with the Spokas model, with a goal of reducing uncertainty to 'low (1-5%).

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?

> If we are successful in development and testing of our 1,000+ year MRV protocol for biochar, we would reduce the uncertainty associated with storage monitoring and maintenance to low (1-5%), with all other individual values as outlined above. In aggregate, we would suggest discounting net CDR by 10% to address any remaining uncertainties.

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.?

> Our project will significantly reduce uncertainty around storage, monitoring and maintenance of CDR in biochar systems by increasing certainty around biochar durability. The Spokas O:C model is a proxy for direct characterization and measurement of biochar durability. We propose to directly characterize biochars and measure their durability with high accuracy through 13C NMR, XPS, and accelerated chemical degradation (e.g., H_2O_2 and heat: the Eidenberg Stability Protocol). These tests will be conducted alongside standard O:C testing to increase confidence in durability at 1,000 years or more. A deliverable of this pre-purchase project will be a set of standards and testing protocols for these advanced analyses. We will also look to assemble a database of university and 3rd party laboratory partners who can perform these tests with sufficient throughput for biochar project developers. The outcome will be a robust methodology and implementation strategy for measuring yield of 1,000+ year biochar at scale with high confidence. We will make this methodology available to the global community of biochar producers.

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)?

Biochar testing and characterization will be conducted in partnership with Carrie Masiello @ Rice University and Kurt Spokas @ USDA ARS. Upon successful development of our 1,000 + year testing protocol, we may seek to partner with a 3rd party such as VCS or Carbon Direct, to further develop and publish the methodology. CDR delivery and auditing will be performed by an existing 3rd party verifier in the Texas/Mid South region, such as B Carbon.

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).

$377/tonne CO_2 without including the uncertainty discount in 4(d)

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

Component	Levelized price of net CDR for this project ($/tonne)
Capex	$128/MT
Opex (excluding measurement)	$121/MT
Quantification of net removal (field measurements, modeling, etc.)[2]	$30/MT
Third party verification and registry fees (if applicable)	$15/MT
Revenue Share with Farmer/Landowner	$20/MT
Climate Robotics Margin	$63/MT
Total	$377/MT

[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.

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?
Levelized CapEx per MT CO2	$128/MT CO2	$26/MT CO2	The NOAK system is based on a self-propelled forage or combine harvester, whereas the current unit is based on tractor-mounted harvester. The CapEx associated with a self-propelled harvester is only 2-3x higher than a tractor, whereas the harvesting throughput is more than 20x greater. Furthermore, there are several subsystems specific to the pyrolyzer that are not substantially more expensive at the larger scale, eg the electronics, sensors, controls systems etc.
Annual Duty cycle	1,500 hours	2,000 hours	Self-propelled harvesters are typically used with continuous duty cycles in excess of 2,000-4,000 hours per year, with 12+ year lifespans, whereas tractors are generally used more sporadically.
Levelized OpEx per MT CO2	$121/MT CO2	$29/MT CO2	Self-propelled harvesters deliver greater fuel economy than a tractor-mounted system. They can also be readily driven by a single trained operator.

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

We have less confidence in the economic lifespan and maintenance cost of our pyrolysis system, as we do not have 10+ years of operational duty cycle with our pyrolysis systems. We also have lower confidence in our cost of labor, as availability of farm labor is highly dependent on grain prices. It is possible that we will have to pay more for labor during times of high grain prices. Finally, our BOM cost for the FOAK TRL-9 system is an estimate but subject to change as we get closer to producing this future system.

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.).

The CDR costs in the TEA spreadsheet are largely consistent with our own models, with the exception of the significant capex multipliers going from bare erected cost to total overnight cost. It's important to recognize that we are not building a permanent installation or plant, so there are unlikely to be significant unknown CapEx costs other than the BOM and labor required to build and deploy each pyrolysis system. Likewise, we are leveraging off the shelf tractors/forage harvesters which have known retail prices. A lower multiple is likely reasonable at scale, particularly given the fact that mobile industrial and agricultural equipment can realize significant discounts at high production volumes.

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.)

Off the shelf tractor automation kits would make it easier to commercialize our technology, as we could eliminate the need for a human operator in the cab of the tractor and control navigation remotely or autonomously.

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.

Coastal and South Texas, as well Arkansas (the proposed project locations) are traditionally low-income areas with many hispanic and African American farming communities. Community members were consulted to gather market research and information to better understand the agricultural practices of the region, to ensure that biochar production and application fits within these established practices and to identify key stakeholders. In the case of the proposed project sites, many of the farm workers employed by large farmers/landowner are members of these marginalized communities and represent key stakeholders. These workers and community members sometimes have small farms and land holdings of their own, which are effectively competitors with larger, neighboring farms.

Community members were eager to learn more about the proposed project, as they are interested in developing additional agricultural revenue streams. Furthermore, there was found to be a strong desire for short term/contract employment in these regions among community members.

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.*

We have directly engaged with members and leaders of these communities in the regions where we currently operate, or intend to operate. We have provided an overview of biochar, pyrolysis and the proposed project. Thus far, we have conducted all engagements directly. We have not produced a report at this time, but in general communities were open to the implementation of the project, as they saw it as a means for crop yield improvement and job creation.

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?

We have learned that members of these marginalized, rural communities are eager for new employment opportunities, particularly around carbon sequestration. We have also learned that many community members have their own small land holdings, and are eager to learn if they can use biochar as well.

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?

Going forward, we will seek to reserve a portion of our projected capacity for production and/or delivery of biochar to farms owned by members of marginalized communities. They traditionally own the smallest or lowest-quality plots of land, and can benefit greatly from the agronomic benefits of biochar. We will also seek to hire and train local staff/operators whenever possible.

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

[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

and safety, plant siting, distribution of impacts, restorative justice/activities, job creation in marginalized communities, etc.

Members of marginalized communities have traditionally been excluded from owning or farming the largest, highest-value plots of land. In many cases, they are forced to farm marginal land. In addition, members of these marginalized communities tend to be the most affected by climate change, as they lack sufficient safeguards/crop insurance. As a for profit business, we must target larger farms/land holdings for the bulk of our production, as there are significant costs associated with switching from farm to farm. It can be challenging to service smaller, more distributed producers/landowners. It is important to recognize that by servicing large landowners, we may further increase their profits relative to members of marginalized communities.

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

We plan to donate a portion of the biochar we produce, and/or reserve production capacity specifically for smaller farms and members of marginalized communities. This will allow us to ensure the benefits of biochar production are distributed more equally to all members and stakeholders in the community. In addition, we will look to train and hire operational and support staff locally in the communities where we operate whenever possible.

8. Legal and Regulatory Compliance

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

We have not yet received a legal opinion regarding deployment of our solution, however similar sized mobile pyrolysis systems developed by other companies have been operated on US farms in Texas and Arkansas for several years without issue.

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.

Currently no permits are required to engage in R&D or deployment of our project in Texas and Arkansas other than meeting the International Biochar Initiative Standard for soil use, which we have already met. In all regions where we operate, crop/residue burning is allowed at will. At large scale, or in more regulated states such as California, we may need to secure air quality permits and/or register our biochar as an approved soil amendment. We are confident in our ability to secure these needed permissions in the future if applicable.

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?

We do not expect our solution is subject to regulation under any international legal regimes, and we have no plans to expand outside the US in the next 24 months.

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.

As we currently make no direct claims about the agronomic or yield benefits of our product, we are not required to register our biochar as a soil amendment with state departments of ag. If we determine that there is statistically significant yield benefit, we will likely look to register our biochar as a soil amendment. This is a straightforward process in most US agricultural states.

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.

We do not intend to receive any tax credits.

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))*	1,192 MT CO2
Delivery window *(at what point should Frontier consider your contract complete? Should match 1(f))*	Q4 2024
Levelized Price (\$/metric tonne CO_2) *(This is the price per tonne of your offer to us for the tonnage described above)*	\$419/MT CO2

Application Supplement: Biomass

(Only fill out this supplement if it applies to you)

Feedstock and Physical Footprint

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

> The proposed project relies on corn stover from commercial corn cultivation in the US South and Mid South (Texas, Arkansas etc).

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

> We have agreements in place for access to over 20,000 acres of high density row crop cultivation in the southern US and Mid South, representing over 100,000 MT of feedstock annually. We contract with landowners to provide access to the feedstock, and to accept application of the resultant biochar. As biochar technology is still relatively new, farmers request a revenue share of each MT of CO2 sequestered in their soil.

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?

> Our process is unique in that our pyrolyzers can harvest feedstock directly in the field, similar to a combine or forage harvester. When operating in-field, emissions directly associated with feedstock collection are de minimis as our pyrolysis system replaces a pass with a tiller or light disking implement which would have occurred anyway. Our process also replaces a pass with a manure spreader which would normally be required to apply the biochar to the soil. Given our unique operating model, feedstock collection does not add meaningful cost to the overall operating cost of the pyrolysis system. The only additional costs are the additional BOM/capital costs associated with the harvesting implement we use to capture the corn stover.

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	Feedstock for our 2022 CDR deliveries was sourced from	Currently there is no competing use for this land as it is all under active commercial corn cultivation.

	approximately 4 km^2 of agricultural land.	
Processing	All processing occurs onboard the pyrolyzer, which has a foot print of approximately 14 square meters.	The pyrolyzer itself is mobile so it can be relocated if the land is needed for other uses.
Long-term Storage	Biochar was applied to 4 km^2 of agricultural land to meet 2022 CDR deliveries	Under our model, the same land is used to source the feedstock and apply the biochar, so there is no competing use.

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.

> Global corn stover production is approximately 1 Billion metric tons (MT) per year. Based on our LCA, conversion of 1 MT of Corn Stover to biochar sequesters 454 kg CO2 for 1,000+ years. Therefore, the global theoretical CDR capacity of corn stover alone is 454 Million Metric Tons of CO2.
>
> We have also collected early, promising performance data from other agricultural waste feedstocks, such as rice straw and sugarcane waste. These feedstocks are available globally at the scale of hundreds of millions of tons per year, and represent promising future feedstocks for in-field biochar production.

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)

> The most common counterfactual for corn stover in the US is continuous no-till (CNT) of the whole residue (eg the output of the combine harvester is left to decompose undisturbed and unchopped on the soil surface). We account for the carbon sequestration associated with CNT in our LCA. Some farmers choose to till stover under the soil (eg inversion tilling) however this practice releases more CO2 than CNT. Corn stover is generally a poor feedstock for cattle and other ruminants due to the low crude protein content and difficulty of digesting the cob and stalk. In many developing countries, and some rural US counties, stover is still burned in-field.

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?

Of the potential uses for stover, the most compelling alternatives to our proposal are deep ocean burial, and bio-oil sequestration. Those studies which have evaluated deep ocean burial of stover bales show significant decomposition in as few as 5 years due to consumption by macro organisms and microorganisms on the ocean floor, including crabs. Furthermore, sinking a low bulk density material like baled stover requires significant quantities of concrete (or other) weights to counteract buoyancy. Finally, transportation of bulk stover from the corn belt to the deep ocean results in significant emissions. By our analysis, deep ocean burial of 1MT baled stover results in up to 578 kg of direct and indirect CO_2e emissions, before any deductions due to decomposition are considered:

286kg CO_2e (truck transport of stover) + 270kg CO_2e (cement production emissions) + 22.2 kg CO_2e (ocean transport of bale + cement to burial site) = 578 kg CO_2e emissions per MT Stover.

Charm Industrial's public, bio-oil sequestration methodology claims a net sequestration of 1MT CO_2e for every 1.446MT of gross CO_2e sequestered as bio-oil. Therefore this process presumably sequesters 504 kg CO_2e for each MT of corn stover pyrolyzed based on average bio-oil yields of other fast pyrolysis systems. However, harvesting of stover has been shown to catalyze loss of soil carbon and increase erosion. At scale, loss of soil carbon and topsoil erosion due to stover harvesting may represent a barrier to farmer adoption, or significantly increase the cost of stover feedstock. However, evidence indicates that replacement of stover with biochar can mitigate these losses. Furthermore, many commercial corn farms in North America are located long distances from potential subsurface sequestration facilities, which can increase the cost, emissions and complexity associated with transport/sequestration.

Based on our LCA, our process sequesters a similar volume of CO_2 per MT of corn stover compared to bio-oil sequestration, but likely better mitigates the soil carbon losses and erosion risk associated with stover harvesting. Furthermore, our process eliminates the need to transport feedstock or end-products off the farm. Finally, if we are successful in the development of our 1,000 year+ MRV protocol, it will be possible to accurately and precisely measure the amount of CO_2 permanently sequestered in biochar.

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)?

A current unknown is the expected plant productivity response (PPR) of commercial corn to high pH, durable biochar application at scale, and the potential secondary impacts of increasing PPR on grain markets and prices. As discussed above, meta studies indicate a grand mean plant productivity response of +16% in response to biochar application. In 2021, Iowa's corn growers set a record for an average yield of 205 bushes of corn per acre (source). Assuming this record yield were increased by 16%, that would represent an additional 32.8 bushels of corn. Today's spot price for a bushel of corn is $6.27, indicating that at the grand mean PPR for biochar observed above, a corn farmer could earn an additional $206 dollars per acre. This price is insufficient to cover the cost of biochar production and application at our current TRL. At present, farmers/landowners typically request a revenue share of any carbon credits generated on their land due to the early stage of biochar technology. Even at scale, it is not guaranteed that farmers will be willing to pay the full value of these agronomic benefits.

We have partnered with Farmers Business Network to conduct a multi-year field trial assessing soil chemistry and crop yield response on corn fields in the Southern US following amendment with high pH, durable biochar. These data will help us to determine the expected PPR of biochar at various reaction temperatures/conditions, and the farmer's willingness to pay for increased yield. If plant PPR and farmers' 'willingness to pay' prove sufficient to offset some of the costs associated with biochar production and application, CR will adjust its CDR pricing model, and/or retire some credits to compensate for any concerns around additionality.

Finally, we are in process of gathering data from other agricultural waste feedstocks, such as rice straw and sugarcane waste. These feedstocks are available globally at the scale of tens to hundreds of millions of tons per year as well, and represent promising future feedstocks for in-field biochar production.