stripe

Living Carbon

Carbon Removal Purchase Application

General Application

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

Company or organization name

Living Carbon PBC

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

San Francisco Bay Area, USA

Name of person filling out this application

Laurel Mills, Yumin Tao, Maddie Hall

Email address of person filling out this application

[redacted]

Brief company or organization description (10 words)

Advanced biotechnology company developing permanent biopolymers for carbon removal in plants

1. Overall CDR solution (All criteria)

a. Provide a technical explanation of the proposed project, including as much specificity regarding location(s), scale, timeline, and participants as possible. Feel free to include figures and system schematics.

Terrestrial plants are the primary source of carbon biomass on the earth, drawing down ~450Gt of the ~550Gt of carbon stored in our biosphere (Milo et al. 2018). Biological carbon capture benefits from the self-replicating nature of cells, reducing the energy costs and intensive human management needed to scale up carbon removal. Unfortunately, much of the carbon that is stored in plants and biomass return to the atmosphere each year. The transient nature of all living organisms limits the ability of plant life to store biomass for an extended period of time without human intervention or pyrolysis.

Meanwhile, despite their tendency toward higher costs and lower throughput, engineered solutions for carbon removal have the ability to store carbon for an extended period of time. Our goal is to develop a CDR method that achieves both the self-replicating nature of biology and permanence of engineered solutions. This would be a step level change for the Carbon Dioxide Removal field.

Luckily, microbes that use CO_2 to produce a highly recalcitrant and decay-resistant biopolymer already exist. By increasing the expression level of this biopolymer called sporopollenin, Living Carbon will develop proof of concept for permanent biological carbon sequestration. The development of sporopollenin-producing algae will demonstrate the role gene editing and advanced biotechnology can play in carbon removal and increase support for further research in the field.

Living Carbon is undertaking a discovery project to increase the production of sporopollenin for carbon sequestration over 10- to 100-fold longer durations compared to other nature-based solutions. Sporopollenin makes up the fabric of the outer shell (exine) of plant spores and pollen (Mackenzie et al., 2015). Referred to as “the diamond of the plant world”, sporopollenin is the toughest biopolymer nature has ever produced, providing the basis for the extraordinary durability in exine. In fact, intact exine has been found in sedimentary rocks some 500 million years old (Mackenzie et al. 2015).

The molecular structure of sporopollenin has only been elucidated in 2019, thus producing this biopolymer using synthetic biology approach has not been possible until now. The extreme inertness of sporopollenin has previously blocked breakdown of the polymer for biochemical characterization. The 2019 study found that pine sporopollenin is composed of aliphatic-polyketide-derived polyvinyl alcohol units cross-linked to 7-O-p-coumaroylated C16 aliphatic units via a dioxane moiety featuring an acetal (Li et al., 2019).

On the other hand, the pathway for sporopollenin biosynthesis is relatively clear from genetic studies, which consists of 7-8 genes (Grienenberger and Quilichini, 2021). The elucidation of the sporopollenin biopolymer structure provides the way to assess whether each step and the overall pathway is successfully engineered using synthetic biology approaches. We aim to be the first organization to increase the expression level of sporopollenin and apply it for permanent carbon removal.

For details about our key steps for sporopollenin pathway engineering, please see the attached confidential detailed experimental plan.

The applications of sporopollenin for permanent carbon storage could span a wide range of plants and contexts. Living Carbon is aiming to first successfully engineer sporopollenin in microalgae due to their photosynthetic efficiency and growth rate compared to terrestrial plants. If this milestone is achieved, it will be an immense scientific breakthrough in the permanent storage of carbon in plants, with potential to be applied across a range of species, plant structures, and storage options.

This application outlines a plan for a microalgae-based pilot project for permanent carbon sequestration in sporopollenin. This deployment option will not require any arable land because microalgae is typically cultivated in desert ponds. We expect that as we move through the delivery phases there will be significant improvements to the life cycle emissions and scalability of microalgae cultivation, and also that there will be widespread demand for permanent biological sequestration that facilitates other paths to scale.

Our initial delivery milestones are based on *Auxenochlorella protothecoides*, a microalgae species in which sporopollenin has been identified as a component of the outer cell wall (He et al., 2016). *Auxenochlorella protothecoides* is slower-growing than the typical species used in techno-economic analyses of microalgae for biofuels and other applications of large-scale cultivation. Our priorities for increasing throughput and reducing cost are (1) increasing the expression levels of sporopollenin in the target species to 20-25% by dry biomass, and (2) successfully engineering expression in faster-growing species.

Following solar-powered desiccation of the biomass (which is common in algae production), the biomass composed of sporopollenin could be stored at the surface without requiring any transport or burial. This is due to the recalcitrant nature of sporopollenin which can be stored like bicarbonate or coal, compared to the rest of the dehydrated algal biomass which will decay at a natural rate.

We can only speculate as to the decomposition rate of the non-sporopollenin biomass if it is protected by a highly recalcitrant, sporopollenin-containing cell wall (and plan to measure this via soil sampling). However, the sporopollenin content will last for up to millions of years as an inert dust that can be integrated with the soil, similar to the deployment solution used for enhanced mineral weathering. Marine algae is commonly used as fertilizer in coastal areas, so there may be soil co-benefits as the rest of the biomass breaks down.

Verification of permanence will be conducted at two points:
(1) Lab-based verification of the sporopollenin concentration in the algal cells.
(2) Soil sampling for verification of algae biomass in the soil to measure above-ground storage.

b. What is your role in this project, and who are the other actors that make this a full carbon removal solution? *(E.g. I am a broker. I sell carbon removal that is generated from a partnership between DAC Company and Injection Company. DAC Company owns the plant and produces compressed CO_2. DAC Company pays Injection Company for storage and long-term monitoring.)*

We are engineering algae to express sporopollenin in cell walls, enabling highly durable (>1000yrs) carbon removal through photosynthesis without additional plant material post-processing (eg. pyrolysis or other complex processes typically required to increase photosynthetic carbon stability). Our initial delivery will be in microalgae through building or partnering for cultivation.

c. What are the three most important risks your project faces?

1. **Expression of high (up to 20%) sporopollenin content by dry weight in the cell walls.** We have initiated this research project and the greatest technical risk is expression of high enough sporopollenin to create a sufficient inventory of permanent carbon storage credits. We have intermediate goals of 0.01% sporopollenin by 2024 and 1% by 2025 before achieving 20% by 2028. The baseline level of sporopollenin in *A. protothecoides* is approximately 0.001% as a 10

nm thickness outer cell wall layer (He et al. 2016), in a 6 um / 6000 nm cell (Vander Wiel 2017).

2. **Ability to maintain algae throughput / growth rate.** Sporopollenin biosynthesis starts during the mid to late reproductive growth phase in flowering plants. Energy-intensive metabolic activities are directed towards this phase of reproductive growth. This may demand higher energy costs in order to synthesize sporopollenin in vegetative tissue, leading to a tradeoff with overall growth rate. Energy and nutrient consumption occur during enzymatic reactions to make precursors/monomers and polymer assembly. Enzyme reactions do recycle energies (ATP, NADPH, etc). There is no other element on the molecular structure of sporopollenin other than carbon, oxygen and hydrogen. This is beneficial because sporopollenin would not deplete ecosystems of other valuable nutrients that would otherwise have been utilized by different organisms.

   We are starting with *A. protothecoides* because it is one of the green algae species producing sporopollenin naturally, and thus has higher probability of success for production enhancement. However, *A. protothecoides* is a mixotrophic species with a slower growth rate than many commonly cultivated microalgae. We will also work simultaneously on engineering a faster-growing autotrophic species for sporopollenin production.

3. **Life cycle emissions at the pilot scale (1% sporopollenin) will probably not result in net negative carbon removal.** Increasing production levels of sporopollenin to even 1% of dry biomass in microalgae will be a fundamental breakthrough in the potential for permanent carbon sequestration in plants. At these levels it will be a challenge to ensure net carbon removal based on the life cycle emissions of the demonstration project. Based on the current state of the art of algae cultivation in the desert, it should be possible to use an existing system and/or design one that relies primarily on renewable energy. However, some fertilizer use will still be required until we can expand to autotrophic species projected in 2027, which is the greatest source of emissions in the first two years.

d. If any, please link to your patents, pending or granted, that are available publicly.

Provisional patent applications have been filed. None are available publicly at this moment.

e. Who's the team working on this? What's your team's unfair advantage in building this solution? What skills do you not yet have on the team today that you are most urgently looking to recruit?

Living Carbon has a 30-person team with expertise in multidisciplinary areas of plant biotechnology including plant biology, synthetic biology, molecular and biochemical biology, tissue culture and transformation, plant physiology, etc. In two years, Living Carbon has grown into a leader in providing synthetic biology solutions to increase carbon capture and storage. Our photosynthesis enhanced trees are capable of increasing CO2 assimilation by 27% based on accumulation of up to 53% more above-ground dry biomass (https://www.biorxiv.org/content/10.1101/2022.02.16.480797v1). With USDA approval, we are now working to commercially plant photosynthesis enhanced seedlings for accelerated carbon capture and have secured 3,000 acres for carbon projects.

We have also made progress in increasing metal accumulation in woody tissue of trees. Engineered trees to increase nickel accumulation are currently under evaluation. Supported by DOE's ARPA-E grant, a high affinity copper transporter has been identified from a copper hyperaccumulator Larrea using RNAseq technology, and validated using yeast functional complementation assay. Gene constructs to overexpress the high affinity Cu transporter plus/minus our nickel accumulation trait in target tree species have been made and are in the process of plant transformation. We estimate that trees with the enhanced nickel/copper accumulation trait will be 50% less susceptible to fungi-mediated decay, the predominant path for CO2 release from dead wood in the forest. On a yearly basis, wood decay releases 10.9 gigatons of carbon which is equivalent to fossil fuel emission worldwide (9.7 gigatons).

We have in-house expertise in synthetic biology for biosynthesis pathway engineering. Our scientists have experiences with thousands of recombinant protein expression and activity evaluations, and optimization of a biosynthesis pathway consisting of 40 enzymatic reactions. We recently expanded to a 20,000 square foot biotech laboratory space. We have established a Mass Spec lab and possess the ability to perform MS analytical work for identification and quantitation of sporopollenin monomer and precursor. We are in the process of establishing a collaboration for NMR spectroscopy analysis. Living Carbon has also begun discussion with pilot partners for algae production and will make the choice to build or buy.

2. Timeline and Durability (Criteria #4 and Criteria #5)

a. Please fill out the table below.

	Timeline for Offer to Stripe
Project duration *Over what duration will you be actively running your DAC plant, spreading olivine, growing and sinking kelp, etc. to deliver on your offer to Stripe? E.g. Jun 2022 - Jun 2023. The end of this duration determines when Stripe will consider renewing our contract with you based on performance.*	Pilot scale delivery from 2025-2028
When does carbon removal occur? *We recognize that some solutions deliver carbon removal during the project duration (e.g. DAC + injection), while others deliver carbon removal gradually after the project duration (e.g. spreading olivine for long-term mineralization). Over what timeframe will carbon removal occur?* *E.g. Jun 2022 - Jun 2023 OR 100 years.*	During the sporopollenin synthesis during algae growth

Distribution of that carbon removal over time *For the time frame described above, please detail how you anticipate your carbon removal capacity will be distributed. E.g. "50% in year one, 25% each year thereafter" or "Evenly distributed over the whole time frame". We're asking here specifically about the physical carbon removal process here, NOT the "Project duration". Indicate any uncertainties, eg "We anticipate a steady decline in annualized carbon removal from year one into the out-years, but this depends on unknowns re our mineralization kinetics".*	0.30% in 2025 5.25% in 2026 10.49% in 2027 83.96% in 2028
Durability *Over what duration you can assure durable carbon storage for this offer (e.g, these rocks, this kelp, this injection site)? E.g. 1000 years.*	Up to of millions of years (only reversal risk is combustion, addressed below)

b. What are the upper and lower bounds on your durability claimed above in table 2(a)?

1 - 500 million years *Number/range*

c. Have you measured this durability directly, if so, how? Otherwise, if you're relying on the literature, please cite data that justifies your claim. *(E.g. We rely on findings from Paper_1 and Paper_2 to estimate permanence of mineralization, and here are the reasons why these findings apply to our system.* OR *We have evidence from this pilot project we ran that biomass sinks to D ocean depth. If biomass reaches these depths, here's what we assume happens based on Paper_1 and Paper_2.)*

We have not measured the durability directly, nor has anybody. The permanent nature of carbon durability of sporopollenin has been inferred in literature from primarily two areas of research: a) The discovery of intact exine (primarily consisting of sporopollenin) in sedimentary rocks some 500 million years old (Mackenzie et al. 2015); b) The extreme inert nature of sporopollenin has been reported in numerous publications. Sporopollenin is recalcitrant to nearly all harsh chemical treatment, physical conditions, and enzymatic reactions.

d. 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?

Sporopollenin is extremely chemically and physically recalcitrant and its durability does not depend on any particular storage modality as long as the temperature does not exceed 300 degrees C (Khandekar et al. 2020).

The only theoretical physical risk to our project would be wildfire, which we consider a low risk because we do not intend to site projects near any fuel sources. Wildfire ignitions happen in the desert but these tend to be fast-moving brush fires which are limited in spread and size. As a result they do not become the type of catastrophic fires that threaten infrastructure and buildings. As we scale we will conduct careful site selection to minimize the risk of proximity to ignition hazards or fuel sources. We are familiar with risk modeling for our forest carbon project sites and there are commercially available tools to model wildfire risk.

Socioeconomic risks are low - even if the material were removed from project sites, there is no incentive to combust sporopollenin.

e. How will you quantify the actual permanence/durability of the carbon sequestered by your project? 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.)*

During the R&D phase of this project, analytical protocols based on mass spec and solid state NMR spectroscopy analysis will be fully developed to measure and quantify the amount of sporopollenin in the overall algae biomass, at multiple time points during algal growth cycle. Mathematical models will be developed along the R&D process during phases of strain optimization with varied environmental growth conditions. In the production facility, multiple small quantities of samples will be removed at the end of the algae growth cycle and subject to sample treatment such as thioacidolysis. Measurement and quantitation of sporopollenin in the samples will be performed using analytical methodologies developed in the R&D phase including: 1) LC-MS methodologies to detect and measure the formation of sporopollenin precursors and monomers. Such protocols have previously been reported from multiple academic labs. 2) Thioacidolysis and solid state NMR analysis methodologies to determine the formation of sporopollenin biopolymers. This is the methodology most recently developed in Li et al (2019). The proportion of sporopollenin in the sample biomass will be used to determine the actual permanence/durability of the carbon sequestered in sporopollenin in the overall biomass. After a few seasons of scaled production in multiple sites, sporopollenin yield data can be utilized to predict the actual amount of permanence.

To verify permanent carbon storage, sporopollenin produced in the production algae strain will be separated from the rest of biomass by simple treatment such as acid lysis followed by centrifugation. The extracted sporopollenin will be subject to various chemical/physical/biochemical treatment including harsh chemical, elevated temperature, physical force such as pressure, enzyme cocktail incubation, etc.

3. Gross Capacity (Criteria #2)

a. Please fill out the table below. **All tonnage should be described in metric tonnes here and throughout the application.**

	Offer to Stripe (metric tonnes CO_2) over the timeline detailed in the table in 2(a)
Gross carbon removal Do not subtract for embodied/lifecycle emissions or permanence, we will ask you to subtract this later	Initial offer to Stripe: 2025 - 3.5 tCO_2 at 1% sporopollenin 2026 - 17.5 tCO_2 at 5% sporopollenin 2027 - 35 tCO_2 at 5?% sporopollenin 2028 - 280.2 tCO_2 at 20% sporopollenin Total: 336.2 tCO_2 *E.g. XXX tCO_2*
If applicable, additional avoided emissions e.g. for carbon mineralization in concrete production, removal would be the CO_2 utilized in concrete production and avoided emissions would be the emissions reductions associated with traditional concrete production	N/A *E.g. XXX tCO_2*

b. Show your work for 3(a). How did you calculate these numbers? If you have significant uncertainties in your capacity, what drives those? *(E.g. This specific species sequesters X tCO_2/t biomass. Each deployment of our solution grows on average Y t biomass. We assume Z% of the biomass is sequestered permanently. We are offering two deployments to Stripe. X*Y*Z*2 = 350 tCO_2 = Gross removal.* OR *Each tower of our mineralization reactor captures between X and Y tons CO_2/yr, all of which we have the capacity to inject. However, the range between X and Y is large, because we have significant uncertainty in how our reactors will perform under various environmental conditions)*

These are based on *A. protothecoides* production in a theoretical 5000 pond-acre commercial algae cultivation system.

We assumed a 10 g/m^2 per day growth rate in a 25,000 liter, 100m^2 pond that operates for 330 days/ year. This is conservative because we assumed that *A. protothecoides* has a slower growth rate than typical cultivated microalgae.

We calculated scenarios for 1%, 5%, and 20% sporopollenin by dry biomass as our R&D advances from the initial phase of POC to production strain for scale. Sporopollenin is approximately 65% carbon by dry weight (May et al. 1975). The recently solved molecular structure revealed that sporopollenin is composed of carbon, oxygen, and hydrogen. There are no other elements revealed in sporopollenin, thus it does not contain any limiting nutrient element such as nitrogen, potassium, and phosphorus. We assume that one ton of carbon equals 3.66 tons of CO2 captured.

Concentration of sporopollenin	Annual CO2 sequestered per acre of pond (tCO2e)	Size of pond space (acres)	tCO2e permanently sequestered
1%	0.35	10	3.5
5%	1.75	10	17.5
5%	1.75	20	35
20%	7	40	280.2

c. What is your total overall capacity to sequester carbon at this time, e.g. gross tonnes / year / (deployment / plant / acre / etc.)? Here we are talking about your project / technology as a whole, so this number may be larger than the specific capacity offered to Stripe and described above in 3(b). We ask this to understand where your technology currently stands, and to give context for the values you provided in 3(b).

We have stored 0.79 tCO2e of carbon to date in hybrid poplar trees and expect to store 196,000 tCO2e over the lifetime of our existing forest carbon projects.

Although we have developed a decomposition resistance trait for trees that slows the re-release of forest carbon back into the atmosphere, we will not have the capacity to permanently sequester carbon until our sporopollenin-expressing algae have been produced. After this milestone is reached our capacity will scale according to (1) the expression levels of sporopollenin up to 20% (2) the growth rate of the species we are engineering and (3) our production capacity.

Our percentage of sporopollenin relative to total biomass is expected to increase as our R&D progress advances. We assume 1% sporopollenin by total biomass in 2025 and 20% by 2028, remaining at 20-25% for the foreseeable future because we expect any further percentage to take too great of a metabolic toll on the cell.

 # metric tonnes CO_2/yr

d. We are curious about the foundational assumptions or models you use to make projections about your solution's capacity. Please explain how you make these estimates, and whether you have ground-truthed your methods with direct measurement

of a real system (e.g. a proof of concept experiment, pilot project, prior deployment, etc.). We welcome citations, numbers, and links to real data! *(E.g. We assume our sorbent has X absorption rate and Y desorption rate. This aligns with [Sorbent_Paper_Citation]. Our pilot plant performance over [Time_Range] confirmed this assumption achieving Z tCO_2 capture with T tons of sorbent.)*

(1) **Assumptions about sporopollenin duration of storage and percentage of carbon in sporopollenin:** This is based on literature review of sporopollenin recalcitrance (Mackenzie et al. 2015; Li et al. 2019) and its elemental composition (May et al. 1975).
(2) **Expression of 20% sporopollenin in vegetative tissue:** this is the most uncertain assumption in our model. If we can achieve this in algae, we will have the basis for permanent carbon sequestration at any scale that is supported by state of the art algae manufacturing technology. We have modeled an increasing range with a cap at 20%.
(3) **Total algae biomass that can be farmed at state of the art facilities:** This is variable depending on our production partner but we have taken example baseline numbers from a 2016 NREL techno-economic analysis assuming a 5000 acre commercial-scale algae cultivation facility, modeled for the growth rate of *A. protothecoides.*

<200 words

e. Documentation: If you have them, please provide links to any other information that may help us understand your project in detail. This could include a project website, third-party documentation, project specific research, data sets, etc.

- Li FS, Phyo P, Jacobowitz J, Hong M, Weng JK. The molecular structure of plant sporopollenin. Nat Plants. 2019 Jan;5(1):41-46. doi: 10.1038/s41477-018-0330-7. Epub 2018 Dec 17. PMID: 30559416. https://pubmed.ncbi.nlm.nih.gov/30559416/
- Sarah Mary Haiken Sclarsic, “A Bioengineering Roadmap for Negative Emissions Technologies”, MIT MS thesis, 2021. https://dam-prod.media.mit.edu/x/2021/02/14/Sclarsic-MS-21.pdf (see p. 20 “Sporopollenin”

4. Net Capacity / Life Cycle Analysis (Criteria #6 and Criteria #8)

a. Please fill out the table below to help us understand your system’s efficiency, and how much your lifecycle deducts from your gross carbon removal capacity.

	Offer to Stripe (metric tonnes CO_2)
Gross carbon removal	336.2 tCO2e bound by 2028

<table>
<tr><td></td><td>Should equal the first row in table 3(a)</td></tr>
<tr><td>Gross project emissions</td><td>High emissions scenario (all energy from renewables but need fertilizer): 375.42

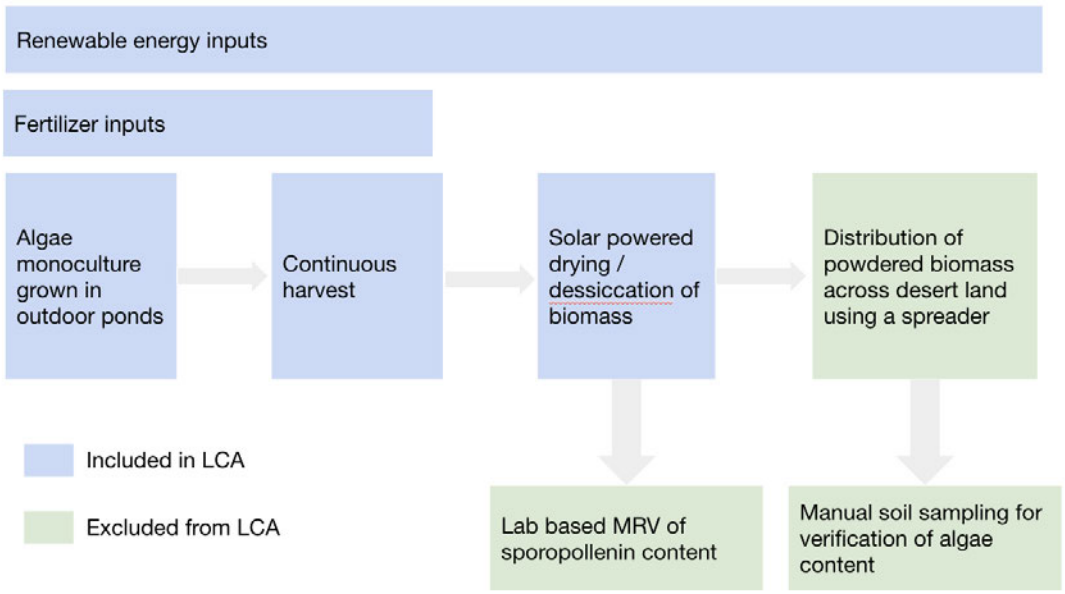
Low emissions scenario (all energy from renewables and don’t need fertilizer due to move toward autotrophic species): 17.27

Should correspond to the boundary conditions described below this table in 4(b) and 4(c)</td></tr>
<tr><td>Emissions / removal ratio</td><td>High emissions scenario (renewables, fertilizer):
<table><tr><td>Year</td><td>% sporopollenin</td><td>Ratio</td></tr><tr><td>2025</td><td>1</td><td>13.3</td></tr><tr><td>2026</td><td>5</td><td>2.7</td></tr><tr><td>2027</td><td>5</td><td>2.7</td></tr><tr><td>2028</td><td>20</td><td>0.67</td></tr></table>
Low emissions scenario (renewables, no fertilizer):
<table><tr><td>Year</td><td>% sporopollenin</td><td>Ratio</td></tr><tr><td>2025</td><td>1</td><td>0.62</td></tr><tr><td>2026</td><td>5</td><td>0.12</td></tr><tr><td>2027</td><td>5</td><td>0.12</td></tr><tr><td>2028</td><td>20</td><td>0.03</td></tr></table>
Gross project emissions / gross carbon removal: should be less than one for net-negative carbon removal systems, e.g. the amount emitted is less than the amount removed</td></tr>
<tr><td>Net carbon removal</td><td>229.4 tCO2e

In this scenario we are assuming fertilizer usage in the first two years and use of an autotrophic species in the following two years as the % of sporopollenin increases</td></tr>
</table>

	Gross carbon removal - Gross project emissions

b. Provide a carbon balance or "process flow" diagram for your carbon removal solution, visualizing the numbers above in table 4(a). Please include all carbon flows and sources of energy, feedstocks, and emissions, with numbers wherever possible *(E.g. see the generic diagram below from the CDR Primer, Charm's application from 2020 for a simple example, or CarbonCure's for a more complex example).* If you've had a third-party LCA performed, please link to it.



c. 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 LCA literature review includes the full algae feedstock growth stage, including energy use and macronutrient fertilizers. Algae LCAs often use a burden-free process of drying the biomass using solar energy, which we assumed as well.

We have not included:

1. R&D emissions including lab-based measurement of sporopollenin content.
2. Distribution of biomass using a fertilizer spreader. Based on the acreage in typical agricultural fertilizer applications, one machine should be sufficient for our pilot project. We are assuming that it will be paired with one electric tractor, which will use the same renewable energy sources as the rest of the project. Thus it is not explicitly included in the LCA.

3. Manual soil sampling.

d. Please justify all numbers used 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.

The LCA for algae cultivation above is based on a literature review of 12 different LCAs of algae cultivation that were conducted between 2002-2011. These LCAs were published in connection with the growing interest in algae biofuels at the time. They span a range of freshwater and marine species and are measured in terms of kgCO2e / kg algae biomass produced (Hander et al. 2012).

We calculated scenarios using the average emissions intensity of the 12 LCAs under three scenarios

(1) At baseline emissions intensity for production in 2002-2011

(2) Assuming usage of renewables

(3) Assuming usage of renewables and autotrophic species that do not require fertilizer.

We assumed that we would require fertilizer for mixotrophic growth in the first two years of proof of concept. However, we plan to use autotrophic species for production scale growth and assumed scenario (3) for the second two years of delivery.

e. If you can't provide sufficient detail above in 4(d), please point us to a third-party independent verification, or tell us what an independent verifier would measure about your process to validate the numbers you've provided.

We would be able to provide more detail about the exact system components and LCA with either a production partner under contract, or advisors to help us design the project.

5. Learning Curve and Costs (Backward-looking) (Criteria #2 and #3)

We are interested in understanding the learning curve of different carbon removal technologies (i.e. the relationship between accumulated experience producing or deploying a technology, and technology costs). To this end, we are curious to know how much additional deployment Stripe's procurement of your solution would result in. (There are no right or wrong answers here. If your project is selected we may ask for more information related to this topic so we can better evaluate progress.)

a. Please define and explain your unit of deployment. (*E.g.* # of plants, # of modules)

Outdoor harvesting ponds (which we are likely to use as opposed to photobioreactors) are

measured in m^2 which we have converted to **acres of pond space**.

b. How many units have you deployed from the origin of your project up until today? Please fill out the table below, adding rows as needed. Ranges are acceptable.

Year	Units deployed (#)	Unit cost ($/unit)	Unit gross capacity (tCO_2/unit)	Notes
N/A	N/A	N/A	N/A	N/A *<50 words*

c. Qualitatively, how and why have your deployment costs changed thus far? (*E.g. Our costs have been stable because we're still in the first cycle of deployment, our costs have increased due to an unexpected engineering challenge, our costs are falling because we're innovating next stage designs, or our costs are falling because with larger scale deployment the procurement cost of third party equipment is declining.*)

The deployment costs, yield, scale, and stability of algae farming in outdoor farms are continuing to fall while Living Carbon pursues our R&D solution. We do not have direct influence over the deployment cost of algae production but we are in discussions with prospective partners about anticipated trends.

d. How many additional units would be deployed if Stripe bought your offer? The two numbers below should multiply to equal the first row in table 3(a).

# of units	Unit gross capacity (tCO_2/unit)
2025 - 10 total acres of pond	1% concentration - 0.35 tCO_2e / acre
2027 - 20 total acres of pond (10 additional)	5% - 1.75 tCO_2e / acre of pond
2028 - 40 total acres of pond (20 additional)	20% - 7 tCO_2e / acre of pond
Number	*# tCO_2/unit*

6. Cost and Milestones (Forward-looking) (Criteria #2 and #3)

We are open to purchasing high cost carbon removal today with the expectation the cost per ton will rapidly decline over time. We ask these questions to get a better understanding of your potential growth

and the inflection points that shape your cost trajectory. 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 expect to work with you to understand your milestones and their verification in more depth. If you have any reservations sharing the information below in the public application format, please contact the Stripe team.

a. What is your cost per ton of CO_2 today?

As an early stage startup, we are heavily investing in R&D on technology and product development. We are excluding R&D costs from our cost per ton and basing our cost estimates on the current state of the art of algae production.

Our costs below are shown according to gross tons of CO2 removal to demonstrate the magnitude of the decline in the cost curve corresponding to increases in sporopollenin production without a requiring change in facility design or size.

1% sporopollenin proof of concept delivery: $19,000 / ton

5% sporopollenin: $3,800 / ton

20% sporopollenin: $950 / ton

For net removal we reach an average **$2,320 / ton** for the entire delivery window 2025-2028.

This is expected to decrease after 2028 due to (1) increase in sporopollenin throughput (2) production economies of scale (3) technical breakthroughs on the algae production front.

$/ton CO_2

b. Help us understand, in broad strokes, what's included vs excluded in the cost in 6(a) above. We don't need a breakdown of each, but rather an understanding of what's "in" versus "out." Consider describing your CAPEX/OPEX blend, non-levelized CAPEX costs, assumptions around energy costs, etc.

This cost is inclusive of all capital costs (cultivation costs, construction, pond lining, etc.), and operating costs (labor, power, chemicals, etc.). The costs are based on a 2016 NREL techno-economic analysis of algae cultivation which assumed a $452 minimum biomass selling price.

We did not explicitly include the price of a fertilizer spreader machine to distribute the algae for storage. Row crop spreaders for fertilizer distribution are available for around $26,000 to $47,000 and we expect that one of these can be used for the entire pilot project size (Stoltzfus Spreaders 2015).

c. How do you expect your costs to decline over time? Specifically, what do you estimate your cost range will be as you reach megaton and then gigaton scale? We recognize that at this point, these are speculative and directional estimates, but we would like to understand the shape of your costs over time.

Our initial costs for 20% sporopollenin in 2028 are based on 2016 estimates of the cost per ton of algae biomass cultivation ($452 / ton).

We expect to cap the percentage of sporopollenin in the cell at around 25% to avoid inhibiting cell function, but there can be further improvements such as engineering sporopollenin in faster-growing autotrophic species,

From conversations with various algae experts we expect declines in the cost of algae production over time. We expect a cost of closer to $300 / gross ton of CO2 removal based on future breakthroughs in algae production alone, which can be further reduced by the bioengineering advances described above.

$/ton CO_2

d. Where are the primary areas you expect to be able to achieve cost declines? E.g., what are the primary assumptions and sensitivities driving your cost projection? What would need to be true for a long-term cost of <$100/ton to be achievable with your technology? (i.e., you are able to negotiate an x% reduction in CAPEX at scale and purchase renewable electricity at $y/kWh)

We expect our costs to decline on two fronts:

1. As we increase the percentage of sporopollenin engineered in the algae, up to an estimated maximum of 20-25%. We believe this illustrates the exciting and unprecedented potential for biotechnology to non-linearly improve the efficiency of carbon sequestration: once we achieve a certain baseline of sporopollenin production in the target organism, increasing its expression and moving to different organisms should be a faster process with associated reductions in throughput of CO2 sequestration using the same deployment / algae cultivation infrastructure.

2. The costs of algae production should decrease with economies of scale and also improvements in engineering efficiency. We can attain economies of scale by increasing demand for this solution as our % of sporopollenin increases. Further optimizations to the cost and emissions intensity of algae cultivation are outside the scope of Living Carbon's work but they are expected in the next few years.

e. In a worst case scenario, what would your range of cost per ton be? We've been doing a lot of purchasing over the past few years and have started to see a few pieces that have tripped people up in achieving their projected cost reductions: owned vs leased land, renewable electricity cost, higher vendor equipment costs, deployment site adjustments, technical performance optimization, supporting plant infrastructure, construction overruns, etc. As a result, we'll likely push on the achievability of the cost declines you've identified to understand your assumptions and how you've considered ancillary costs. We would love to see your team kick the tires here, too.

In a worst case scenario, we have assumed a 30% reduction in algae throughput / 30% cost increase compared to our (already conservative) base case scenario. In this case our cost per gross ton would be as follows:

1% sporopollenin proof of concept delivery: $25,332.77 / tCO2e

5% sporopollenin: $5,066.66 / tCO2e

20% sporopollenin: $1266.64 / tCO2e

f. List and describe **up to three** key upcoming milestones, with the latest no further than Q2 2023, that you'll need to achieve in order to scale up the capacity of your approach.

Milestone #	Milestone description	Why is this milestone important to your ability to scale? (200 words)	Target for achievement (eg Q4 2021)	How could we verify that you've achieved this milestone?
1	Analytically confirmed the production of sporopollenin precursors and monomers in A. protothecoides	Having analytical methodology developed for detection of sporopollenin precursors and monomers is vital to the success of pathway engineering. The overall objective is to increase the production of sporopollenin, so verification of sporopollenin production in the reported strain is essential, and knowing the existing productivity in the strain provides the basis for improvement	Q3 2022	Analytical methodologies for identification and quantitation of sporopollenin precursors and monomers have been described in the literature. A report will be produced to compare our methodologies to literature reports. Samples can be sent out for third party verification if desired.
2	Two milestones: 1).	Needless to say,	Q1 2023	The identification

	Complete natural species screening for higher yield strain; 2). Methodologies developed for detection and measurement of sporopollenin polymers	having the enabling technology for polymer determination is essential. This milestone will provide initial assessment on the degree of natural variations on sporopollenin production.		and quantitation of sporopollenin will be performed using methodologies described previously including LC-MS analysis and solid-state NMR analysis. Samples can be sent out for third party verification if desired.
3	Two milestones are to be reached: 1) Provide evidence that precursor(s) and/or monomers can be increased in A. protothecoides; 2) Production of sporopollenin precursors and monomers in another fast growing species	While the effort will be centered on enhancing the productivity of sporopollenin in A. protothecoides which we will need more time post Q2 2023 to see the results, we will start the work early on engineering the biosynthesis in a fast-growing species in preparation for production strain creation	Q2 2023	The identification and quantitation of sporopollenin will be performed using methodologies described previously including LC-MS analysis and solid-state NMR analysis. Samples can be sent out for third party verification if desired.

i. How do these milestones impact the total gross capacity of your system, if at all?

Milestone #	Anticipated total gross capacity prior to achieving milestone (ranges are acceptable)	Anticipated total gross capacity after achieving milestone (ranges are acceptable)	If those numbers are different, why? (100 words)
1	0 tons CO2 / year capacity *Should match 3(c)*	0 tons CO2 / year capacity	Prior to Q2 2023, our milestones will be discovery-oriented toward the target of reaching 1%

			sporopollenin before the first delivery milestones in 2025
2	0 tons CO2 / year capacity	0 tons CO2 / year capacity	See above
3	0 tons CO2 / year capacity	0 tons CO2 / year capacity	See above

g. How do these milestones impact your costs, if at all?

Milestone #	Anticipated cost/ton prior to achieving milestone (ranges are acceptable)	Anticipated cost/ton after achieving milestone (ranges are acceptable)	If those numbers are different, why? (100 words)
1	N/A *Should match 6(a)*	N/A	The goal of these milestones is to enable us to begin production at 1% sporopollenin *<100 words*
2	N/A	N/A	*<100 words*
3	N/A	N/A	*<100 words*

h. If you could ask one person in the world to do one thing to most enable your project to achieve its ultimate potential, who would you ask and what would you ask them to do?

We would ask companies who are farming algae at scale to consider adding a carbon removal product stream and considering pathways for us to partner.

i. Other than purchasing, what could Stripe do to help your project?

(1) Advance the narrative around advanced biotechnology as a potential step change in CDR that needs early support and broad acceptance

(2) Introduce us to potential production partners

7. Public Engagement (Criteria #7)

In alignment with Criteria 7, Stripe requires projects to consider and address potential social, political, and ecosystem risks associated with their deployments. Projects with effective public engagement tend to do the following:

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

The following questions are for us to help us gain an understanding of your public engagement strategy and how your project is working to follow the White House Council on Environmental Quality's draft guidance on responsible CCU/S 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 your 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.

Our external stakeholders for the pilot plant will mainly be local government / permitting agencies. There would be reduced need for community engagement compared to our other carbon removal projects (forest carbon) due to the remote nature of the site.

More broadly, we expect this project to call attention to advanced biotechnology and gene editing solutions as a response to climate change. Our experience with engineered trees has been that stakeholders usually respond with optimism and excitement, but that it is critical to openly engage stakeholders and build transparency and scientific credibility around our projects.

We believe it is important to begin production at 1% sporopollenin on a 10 acre site in 2025 not only to deliver initial proof-of-concept tons to Stripe, but also to collect data and view the pilot project as a field trial. This would help us understand the algae growth rate at scale, develop the capacity for consistent and reliable MRV of sporopollenin production, and test the most efficient methods of above-ground storage for dehydrated biomass. Reaching pilot production scale with 1% of sporopollenin the target species will also help us test potential biomass containment strategies (to improve measurement accuracy) before increasing throughput.

By choosing sporopollenin and microalgae as our next project beyond photosynthesis enhancement in trees, we aim to show that advanced biotechnology can increase not only the rate but also the permanence of CO2 capture and set a precedent for early stage research on other bioengineering solutions to climate change.

Toward the end of our initial delivery window in 2028, we anticipate that solutions to engineer natural processes such as solar radiation management may be more frequently discussed as

climate mitigation strategies. We believe advanced technology should be catalyzed now to provide alternative mitigation strategies in which the carbon cycle is brought back into balance through improved expression of powerful natural processes. This will also build support for additional research funding going toward early investigation of bioengineered solutions.

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.*

We have experience working with federal, state, and local regulators with regard to our forest carbon projects. If we locate the pilot project outside the US we will likely seek external consultants, advisors, and/or lawyers to assist. Our approach is to hire local experts to help with the planning and execution of projects near communities. We also have created a Forestry Advisory Board and Scientific Advisory Board to expand the number of stakeholders we are engaging with on a deep level. We currently work with a USDA consultant who has 25 years experience at the agency. We have partnerships with local forestry association like the Georgia Forestry Association and collaborate with research universities to provide third party analysis of our data.

We have engaged with the public and the media regarding biotechnology as a solution to climate change in connection with our photosynthesis enhancement and decomposition resistance traits in trees.

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?

Our R&D roadmap leading to the first production milestone incorporates lessons learned from our work on photosynthesis enhancement and external communication of research results.

From our work with communities and stakeholder on photosynthesis-enhancement in trees we have learned to do the following:

- Provide context around the philosophy, mission, and approach of Living Carbon, which results in broader understanding and acceptance of our work
- Share why and how an organism is engineered provides needed nuance around genetic engineering and limits heuristic and emotional responses
- Relate directly to the needs of our stakeholders as opposed to talking about indirect benefits

d. Going forward, do you have changes planned that you have not yet implemented? How do you anticipate that your processes for (a) and (b) will change as you execute on the work described in this application?

We will need to decide within the next year which jurisdiction our pilot project should be located in, which will affect our plan for regulatory engagement.

8. Environmental Justice (Criteria #7)

a. What are the potential environmental justice considerations, if any, that you have identified associated with your project? Who are the key stakeholders?

We expect limited environmental justice risks associated with the algae cultivation facilities due to their remoteness and lack of proximity to communities.

b. How do you intend to address any identified environmental justice concerns?

More broadly, we believe generating broad acceptance of advanced biotechnology as a solution to climate change is critical to climate justice and mitigating its effects on the most vulnerable communities. Beyond CDR, there is potential for biotechnology to accelerate food production, rebalancing of ecosystems, sustainable phytomining to decarbonize and improve the ethics of supply chains, nature-based disaster resilience (for example, through photosynthetic enhancement of mangroves) and other solutions. Enhanced native plant species can be deployed in any suitable ecosystem, while more highly engineered, infrastructure-intensive solutions such as sporopollenin in algae can be designed to solve for complex challenges such as above-ground biomass sequestration with no arable land use.

There are non-linear cost reductions and increases in benefits associated with biological optimization, as demonstrated by our rapidly falling costs per pond-acre as we approach 20% sporopollenin and expand to faster-growing species. Research and acceptance of these types of exponential improvements should be made available more broadly to mitigate climate-related suffering to the maximum extent possible.

We intend to be transparent and engage with the public and the scientific community at each stage of our project R&D and deployment. This is not only to build trust and credibility around a groundbreaking bioengineering project, but also to set a precedent for applying biotechnology to the climate crisis in a thoughtful and transparent, but also ambitious and creative way.

9. Legal and Regulatory Compliance (Criteria #7)

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

We have not received legal opinions specific to sporopollenin but we have engaged with the USDA with regard to our engineered hybrid poplar and loblolly pine trees. We are familiar with the regulatory process for genetically engineered organisms in the US. Our photosynthesis enhanced have been approved as exempt from this regulation and can be deployed at commercial scale.

b. What domestic permits or other forms of formal permission do you require, if any, to engage in the research or deployment of your project? 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.

Based on our initial experimental design, these organisms would not include genes from species outside of their own gene pool and would thus not be subject to the regulations in 7 CFR part 340 of APHIS. The path to confirming this exemption status is the Request for Confirmation Exemption Request. This is a very similar process to the "Am I Regulated Process," that Living Carbon submitted nine requests through all with a positive response from USDA. USDA has already responded to confirmation of exemption requests for many gene edited organisms. We would expect this process to take 6-9 months.

If we decide to include genes from other organisms outside of the gene pool, we will require permits or forms of permission to conduct sporopollenin research outside the laboratory. We have experience obtaining these permits for our trees without difficulty. In the worst case scenario, we could partner with research institutions that have experience obtaining these sorts of permits if we apply and are rejected for some reason.

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?

If our gene edited organisms are confirmed as exempt under APHIS 7 CFR part 340 of APHIS, then our organisms would be subject to any import laws from another country but would be unblocked from exporting internationally.

If we are to build or partner to site the algae cultivation facility in another country, we will be subject to any local regulations on genetically engineered organisms. We may also be influenced by international treaties such as the Cartagena Protocol on Biosafety which has been described as a de facto trade agreement and influences the development of local biotechnology regulations.

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.

We have conducted preliminary research on the legal frameworks for advanced biotechnology and gene editing in countries with the most desert land and suitable climates for algae cultivation. Often regulatory frameworks developed for GMO foods do not contemplate or mention their use for other purposes. For example, in Morocco, there are stringent regulations on GMOs for food but they are allowed for animal feed. We believe it will be possible to influence new regulatory frameworks that enable biotechnology for climate mitigation, especially in the creation of an inert substance such as sporopollenin that is not intended for consumption by humans or animals and contributes a valuable solution to the climate crisis.

e. Has your CDR project received tax credits from any government compliance programs to-date? Do you intend to receive any tax credits during the proposed delivery window for Stripe's purchase? If so, which one(s)? (50 words)

No. *<50 words*

10. Offer to Stripe

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

	Offer to Stripe
Net carbon removal *metric tonnes CO_2*	229.4 tCO2e *Should match the last row in table 4(a), "Net carbon removal"*
Delivery window *at what point should Stripe consider your contract complete?*	2025-2028 *Should match the first row in table 2(a), "Project duration"*
Price ($/metric tonne CO_2) ***Note on currencies:** while we welcome applicants from anywhere in the world, our purchases will be executed exclusively in USD ($). If your prices are typically denominated in another currency, please convert that to USD and let us know here.*	$2,320 *This is the price per ton of your offer to us for the tonnage described above. Please quote us a price and describe any difference between this and the costs described in (6).*

Application Supplement: Biomass

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

Feedstock and Physical Footprint (Criteria #1)

1. What type of biomass does your project rely on? <100 words

Our project uses microalgal biomass that has been engineered to express up to 20% sporopollenin by dry weight in the cell walls. This will be initially in *Auxenochlorella protothecoides* before expanding to faster-growing autotrophic species

2. Are you growing that biomass yourself, or procuring it, and from whom?

Living Carbon is engineering the sporopollenin-expressing algal strains and either developing pilot-scale algae cultivation infrastructure ourselves or partnering with existing algae producers.

3. 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 2021	**Competing/existing project area use (if applicable)**
Feedstock cultivation	40 pond acres - 0.16km^2 *E.g. 1 km^2 (floating kelp array)* OR *N/A (procuring waste biomass)*	Not applicable - algae is commonly grown in the desert due to access to sunshine and non-potable water such as saline water
Processing	Minimal = 0.009m of processing space required for each m of feedstock cultivation *E.g. 0.1 km^2 (boat yard, manufacturing facility)* OR *0.5 km^2 (manufacturing facility for mobile biochar plants)*	See above

Long-term Storage	17.5 acres or 0.07 km^2 for a 40 acre pond footprint A 40 acre pond generates 588 tons of biomass per year and we assume 8.4 acres are needed for 1 application of 1 ton of biomass (based on how many acres are needed to apply a ton of fertilizer). We assume a conservative 4 applications of algae biomass per year (fertilizer is applied more frequently) *E.g. N/A (uncertainty in final state of kelp)* OR *2 km^2 (ag fields in which biochar is deployed)*	See above

4. Imagine, hypothetically, that you've scaled up and are sequestering 100Mt of CO_2/yr. Please project your footprint at that scale (we recognize this has significant uncertainty, feel free to provide ranges and a brief description).

	Projected # of km^2 enabling 100Mt/yr	**Projected competing project area use (if applicable)**
Feedstock cultivation	We assume that a 5000 acre facility growing an autotrophic species (approximately 2.6x more productive than A. protothecoides), and composed of 20% sporopollenin, can sequester around 91,055 tons of CO2 annually. This corresponds to approximately 190,000 tons of biomass which is NREL's 2016 projection for the output of a 5000 acre commercial algae facility. 100MT / year sequestration would require 1098 commercial facilities of this size, each sequestering 91,055 tons of CO2 annually. We estimate around 22,222 km^2 of algae pond area required to cultivate this much feedstock. This	None - isolated desert

	is a conservative estimate because further improvements to the biomass throughput of algae cultivation are possible.	
Processing	If we assume 1098 facilities are needed, and that each is 3,500 m^2 in size, we would need around 3843 square km for processing.	None - isolated desert
Long-term Storage	Conservative estimate: 661 km^2 based on 8.4 acres per ton of biomass and 4x application of biomass per year (probably lower because fertilizer is applied more frequently than 4x a year which is our assumed spread rate of algae biomass)	None - isolated desert

Permanence, Additionality, Ecosystem Impacts (Criteria #4, #6, and #7)

5. How is your biomass processed to ensure its permanence? What inputs does this process require (e.g. energy, water) and how do you source these inputs? (You should have already included their associated carbon intensities in your LCA in Section 6.)

The sporopollenin requires no processing beyond algae cultivation to ensure its permanence, and any processing to maximize the efficiency and verifiability of storage will not affect the permanence outcome. We expect minimal energy requirements for MRV to verify either the concentrations of sporopollenin in the algae (conducted in a lab), or the concentrations of algae in the soil (conducted via manual soil sampling).

6. (Criteria 6) If you didn't exist, what's the alternative use(s) of your feedstock? What factors would determine this outcome? *(E.g. Alternative uses for biomass include X & Y. We are currently the only party willing to pay for this biomass resource. It's not clear how X & Y would compete for the biomass resources we use.* OR *Biomass resource would not have been produced but for our project.)*

Alternative uses for algae production facilities include farming of biomass for other purposes, including food, animal feed, supplements, fertilizer, cosmetics, and biofuels. Sporopollenin-expressing algae would not exist absent demand for permanent sequestration.

7. We recognize that both biomass production and biomass storage can have complex interactions with ecological, social, and economic systems. What are the specific negative impacts (or important unknowns) you have identified, and what are your specific plans for mitigating those impacts (or resolving the unknowns)? *(200 words)*

Regarding storage, sporopollenin is an inert, non-toxic substance that is unlikely to cause ecosystem effects even if it is ingested by animals. For this reason it has been considered for application in the cosmetic, food, and pharmaceutical industries. It can safely be rubbed on skin, ingested, injected, or inhaled (Barrier 2008).

The most significant environmental factors related to the pilot plant will be the source of water and the extent to which nutrients / fertilizer are required. If the algae solution is to scale, it will be important to ensure that intake water is either from the ocean or wastewater, to avoid competing with freshwater uses. This means scaling will also require us to move from *A. protothecoides* into autotrophic (not requiring additional nutrient inputs) and marine (able to grow in saltwater) species. We expect to move to autotrophic species by 2027.

Water and nutrient requirements of the pilot facility would be limited by its smaller size, and ecosystem effects from the pilot algae cultivation facility are likely to be similar to other desert infrastructure projects. We can optimize these requirements further when scaling beyond the initial 10 acres. Careful site selection will be required to minimize impacts on desert ecosystems.

8. Biomass-based solutions are currently being deployed around the world. Please discuss the merits and advantages of your solution in comparison to other approaches in this space.

Living Carbon has considered other plant systems (such as switchgrass and hemp) for the expression of sporopollenin and concluded that algae has the potential to sequester the most carbon with the least arable land use and most flexible storage solution.

Our technological breakthrough compared to other biomass-based solutions is usage of the photosynthetic process and the plant's metabolism, rather than human-made energy sources, to sequester carbon permanently. Other nature-based solutions that are fueled by photosynthesis lack permanence, while permanent biomass solutions such as bio-oil and biochar are comparatively energy-intensive and expensive.

If we are able to successfully express sporopollenin in an autotrophic algae species, this results in permanent carbon sequestration with minimal energy requirements. Land and water availability has been successfully solved by other algae producers and the production costs and emissions intensity will continue to improve.