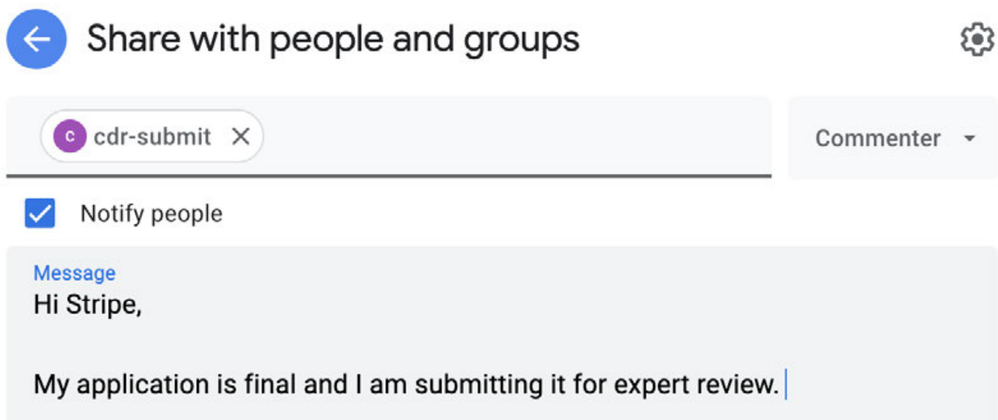
Carbon Lockdown Project

Carbon Removal Purchase Application



- **Your submission constitutes your consent for Stripe to make your full application and all of its content available publicly under a CC-0 “Public Domain” License, regardless of whether or not Stripe selects you for purchase.** For more details, see “Why we make applications public”.

What we’re looking for

Please refer to Stripe’s carbon removal target criteria for a characterization of projects Stripe is excited to support. For clarity, we’ve slightly modified these criteria since our purchasing start in 2020, but their spirit remains the same. Our 2022 criteria are:

1. **Physical footprint**: Takes advantage of carbon sinks less constrained by arable land
2. **Capacity**: Has a path to being a meaningful part of the carbon removal solution portfolio (>0.5Gt CO_2/yr by 2040)
3. **Cost**: Has a path to being affordable at scale (<$100/ton by 2040)
4. **Durability**: Stores carbon permanently (>1,000 years)
5. **Verifiability**: Uses scientifically rigorous and transparent methods for monitoring and verification

6. **Additionality**: Results in net new carbon being removed rather than taking credit for removal that would have occurred regardless

7. **Public engagement and legal compliance**: Legally compliant, responsibly and actively engaging with the public to determine and mitigate possible risks and negative externalities

8. **Net-negative lifecycle**: Results in a net reduction in atmospheric CO_2

This application is meant to solicit high quality information such that we can evaluate you against the above criteria. There's no rubric that will give you points for specific answers. Instead, we are seeking to build a comprehensive understanding of your carbon removal solution. We value clear and accurate information over romanticization, and welcome citations and links to real data where appropriate.

Please be aware that your application and all content you provide here will be made public at the conclusion of Stripe's purchase cycle, to support transparency and knowledge-sharing in the field.

Why we make all applications public

Commercial-scale permanent carbon removal is a nascent field. We've developed this application and our overall purchase philosophy with the goal of advancing transparency and knowledge-sharing across the field, hopefully enabling impact beyond the dollar amount of any particular purchase we may make.

All applications to our earlier purchase cycles were made public, and can be accessed here. We're grateful to all our projects for providing this level of transparency. Making applications public enables derivative academic works and independent analysis from nonprofits like CarbonPlan (example here, here), and we've heard from a wide range of investors, engineers, and scientists that the corpus of applications is a valuable source of data on the current state of the field and opportunities for advancement.

For these reasons, we're again making applications from this purchase cycle public.

SPRING 2022 UPDATE: That said, we've heard feedback over the past year from the founder community that this level of transparency is tough, particularly for companies in stealth or in the process of patent filing. **We hear you and are making an adjustment this cycle.** The application should still serve as a comprehensive, standalone representation of the merits of what you're building, but we will allow for selective sharing of sensitive data directly with our expert review team through email exchange or the team interview outside of the public application. Please email the Stripe team at cdr-apply@stripe.com to identify and discuss any proposed public omissions.

We thank you not only for applying to our purchase, but for providing this valuable contribution to the field's collective knowledge via your public application.

Fine print

We intend to make the selection process as informal as possible. However, we do expect that (a) the content of your application is, to the best of your knowledge, complete and correct; (b) you do not include any content in your application that breaches any third party's rights, or discloses any third party's confidential information; (c) you understand that we will publicly publish your application, in full, at the conclusion of the selection process. You also understand that Stripe is not obliged to explain how it decided to fund the projects that are ultimately funded, and - although extremely unlikely - it is possible that Stripe may decide to not proceed, or only partially proceed, with the carbon removal purchase project. Finally, if you are selected as a recipient for funding, Stripe will not be under any obligation to provide you with funding until such time as you and Stripe sign a formal written agreement containing the funding commitment.

General Application

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

Company or organization name

Carbon Lockdown Project (CLP)

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

Silver Spring, Maryland

Name of person filling out this application

Ning Zeng & Henry Hausmann

Email address of person filling out this application

[redacted]

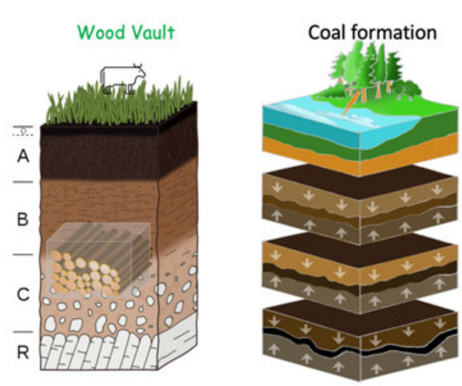
Brief company or organization description

Develop and Support Wood Harvesting and Storage (WHS) CDR projects

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.

We propose to build a facility, called Wood Vault (Figure to the right), that will store sustainably sourced natural waste wood (NWW) from the surrounding region. The woody material will be buried in a subterranean environment several meters below ground, away from the active biosphere (vegetation+soil+decomposers) that's typically within the first meter of the soil profile. Our patent-pending design ensures an oxygen-depleted environment that



prevents wood decomposition, and initiates the re-fossilization of carbon.

For siting of the facility, we will purchase 10 acre of land in Maryland by the Carbon Lockdown Project (CLP) (the actual pilot plot above the burial chamber is 1 acre).

The operational steps involve: (1) Receive urban natural waste wood that is currently disposed of in landfills or burned (i.e., a cost and carbon liability), at zero or negative cost; (2) Stockpile the wood on site temporarily before burial, ; (3) Construction of a Wood Vault: site preparation, excavation (See Fig. 2 below for an illustration of Wood Vault Version 1, nicknamed Tumulus for its partially-aboveground partially-belowground characteristics); (4) Burial of the stockpiles in batch at a time interval optimized to minimize operational cost and above-ground decay before burial; (5) Backfill the trench with excavated soil; (6) Place low-cost sensors inside the burial chamber and above ground to monitor the burial environment for CO2, O2, CH4, temperature, humidity, pressure, and pH, using our proprietary IoT based technology (Zeng and Martin, US patent US 10,802,009; see example at the SENSE project); (6) seed the ground with grass; (7) After rehabilitation and grass re-establishment (about 1 year), optionally apply the land to productive use such as grazing, recreation, solar farm, or a combination of them such as agrivoltaics; (8) Continual monitoring of the site using sensors above and periodic sampling to ensure the durability, reinforce the burial condition as needed, develop scientific and technical understanding, serve as a model project blueprint for future projects. More details can be found at Zeng and Hausmann (2022) and our pending patent.

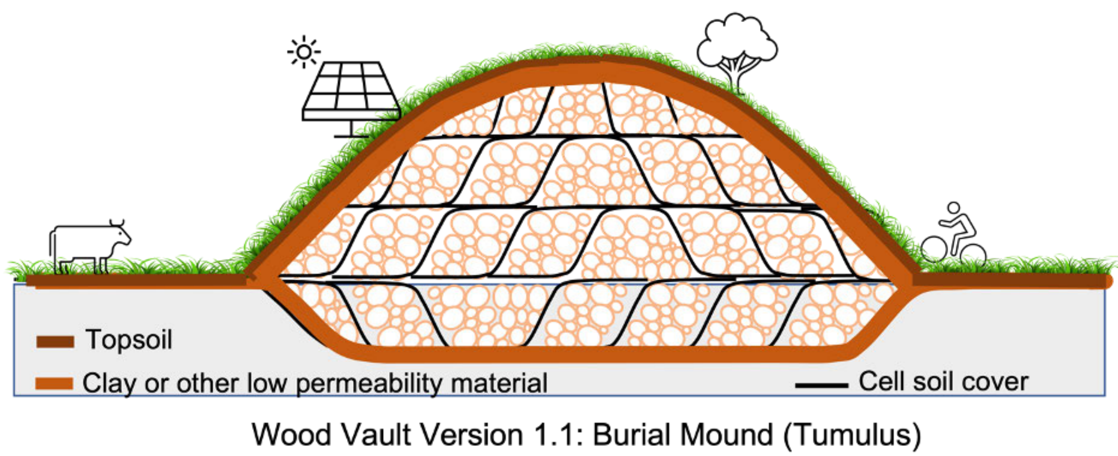


Figure 2. A basic Wood Vault unit partially aboveground, partially underground (Wood Vault Version 1.1: Burial Mound Tumulus). A prototype unit occupies 1 hectare of land (100 by 100 meters, or size of two soccer/football fields), 5 meters deep, 20 meters tall. The unit is divided into cells. Each cell is sealed as soon as it is filled. After closing of the top at final enclosure, the original topsoil is put back, grass and shallow rooted trees can be allowed to grow, then used as park, grazing land, cropland, solar Farm, or combination of these. Reddish brown represents clay or clay-like low permeability soil or liner to ensure anaerobic condition, while dark brown represents backfilled topsoil.

Our method is a Nature+Engineering combo method. CO2 capture is done by trees via photosynthesis for 'free', with an estimated global potential between 2-11 GtCO2/y (Zeng et al. 2013; Zeng and Hausmann 2022) achievable in the next 20 years.

Our method requires no complex technology and only minimum processing, i.e., we bury raw woody material, which is a key advantage for its simplicity and low-cost.

The durability of our buried wood is ensured by: (1) The site's Piedmont red clay (ultisol) creates anaerobic condition without the need to import clay soil somewhere else.The anaerobic environment created by the clay-sealed subterranean burial chamber that retards water/air movement, which prohibits common decomposers fungi and insects that are responsible for majority of the decomposition in the biologically active soil. (2) This leaves only anaerobic bacteria of some concern. However, they do not have the enzyme to digest lignin, the glue-like polymer that holds together and protects cellulose. They won't be able to establish colonies. (3) The wholeness of coarse woody biomass (CWB), recommended as the best practice, further delays the already near-zero probability of bacteria attack. Our Montreal demo project (35 tonne wood buried in 2013) shows fresh-wood like condition after 8.5 years of burial (see slide 19 of the SoT presentation). Quantitative analysis shows preservation longer than 1000 years (paper in preparation; see This Is CDR presentation (20min) or Science on Tap presentation (1hr) by Ning Zeng for preliminary results). Such longevity is also supported by numerous archaeological and geological evidence (Slides 24-27 of the SoT presentation). Our research has suggested the best practice for achieving high durability. Additionally, IoT based sensors will monitor gas concentrations and other environmental conditions continuously (see example at the SENSE project).

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 will act as project developer and project manager. Other actors are suppliers of urban natural “waste” wood (nearby municipalities or private waste management or tree-cutting firms; and contract excavators to construct the Wood Vault).

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

1) Funding.
2) Must protect against risk of Wood Vault being re-excavated.
3) Limited term of experimental data re. durability. (Many real-world examples however.)

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

- Zeng, N., and C. Martin, 2016: NETWORKED ENVIRONMENTAL MONITORING SYSTEM AND METHOD. US 10,802,009 B2. Date of Patent: Oct. 13, 2020.
- Zeng, N., Method and System for Wood Harvest and Storage, Carbon Sequestration and Carbon Management. US provisional patent application 63189184, filed on May 16, 2021. 77 pages. (Available upon request; A big picture description is in Zeng and Hausmann 2022)

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?

The team is led by Ning Zeng. Team members include Henry Hausmann, Randy Bowers, John Crye, Samantha Halstead Santez, David Tomberlin, plus a number of UMD students working on related scientific research. We also have a number of senior advisors in business, environment, activism, government and academics.

We have worked on this idea for 15 years since Ning Zeng's 2008 paper that originated the idea of wood burial for carbon sequestration. We have conducted multiple demo projects, including the Gemstone Carbon Sinks project (2007-2010) and the Montreal project (2003-present) (Slides 14-24 of the SoT presentation) in order to figure out the best science, technology and practical considerations (see This Is CDR presentation (20min) or Science on Tap presentation (1hr) by Ning Zeng for preliminary results and many other aspects of WHS and CLP). Ning Zeng has also been advising several other large-scale projects conducted by other entities under a variety of circumstances (wood sourcing and burial methods). CLP is starting Conversation in the Vault with Ning in April 2022, a monthly virtual community forum to exchange ideas and experience in practicing WHS.

Supported by seed money from the Maryland Energy Innovation Accelerator (MEIA), we are in the process of engaging two Energy Entrepreneurs in Residence (EEIRs) to join the team for company formation and pilot project deployment. Later this year, we will seek to raise seed equity capital to further build out the team. Some additional equity funding will then be required, however we anticipate that the bulk of the capital the company will require on a go-forward basis will be project finance.

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

a. Please fill out the table below.

	Timeline for Offer to Stripe
Project duration	*Secure site: 3-6 month*

	Wood collection 6 months *Wood Vault construction: 1 month (in parallel to Wood collection)* *Assuming funding available June 2022, and allowing a buffer for permitting and any other delays, we expect to have 10Kt securely buried by December 2023 at the latest*
When does carbon removal occur?	*Once the Vault is capped*
Distribution of that carbon removal over time	*All at the very end of the project year, when the vault is capped and sealed.*
Durability	*Summary based on Montreal project (8.5 years of burial) > 1000 years. See Slides 14-24 of* [the SoT presentation] *Preliminary detailed results:* *1) When cut open, visually looks like freshwood;* *2) No sign of degradation under microscope* *3) Recovered sample wood disc from 1.5 meter burial depth: no loss after 8.5 years within data error bar. Specifically,* *3.1) 0.3% loss of mechanical strength for 1.5meter buried wood disc after 8.5 years translates into 97% remaining after 100 years, e-folding time scale of 2880 years, assuming exponential decay;* *3.2) chemical composition analysis of lignin/cellulose content is ongoing and we should be able to provide*

	results during iteration.

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

1,000 to 100,000 years or longer (lower limit based on our Montreal project; upper limit based on geological and archaeological evidence)

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.)*

Yes, we have done a trial project scale in a farm outside of Montreal, Quebec. After 8.5 years of burial, we excavated a buried sample of wood and then analyzed the excavated material. This analysis included both material strength and carbon content of the samples. This analysis gave an e-folding lifetime of greater than 2800 years. The upper limit of our estimate comes from archeological/geological evidence (See Zeng/Hausmann 2022). Samples of preserved Neanderthal wooden tools have been found dating back to times as old as 300,000 years ago while geological preservation of wood of up to 44 million years old was found in clay pits similar to the ones we are building.

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?

Assuming the Vault is constructed properly, there should be minimal physical risk. The primary societal risk comes from potential excavation or construction by future land owners. Even if the land is owned by the project, it is difficult to ensure that any legal, scientific, or economic entity survives on the century to millenia time scale of this sequestration project. The best way to mitigate this is a conservation easement limiting what can be done on the property, buying insurance etc. Carbon Lockdown Project will need to work with future buyers and carbon markets on what insurance and other buffers and protection will make most sense.

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.)*

We have two primary methods to verify and assess durability for this pilot:

1. Periodic sampling
2. In situ sensors (see Zeng/Martin patent US 10,802,009 B2).

The periodic sampling is fairly straightforward, and will only be conducted to gain specific experimental data for initial pilot deployment(s). Every five years between deployment and 2050, we will excavate a sub chamber (cell) of the vault and retrieve buried wood before resealing the chamber. The excavation can be done quickly (over the course of a single day) and poses minimal risk to sequestration viability. Quick reburial works well as demonstrated in the Montreal project resampling (2021). The samples of wood can then be analyzed to determine how much they've deteriorated and get more precise estimates of permanence for the individual project.

The sensors will be set up to measure concentrations of key gasses (O_2, CO_2, CH_4, pH, temperature, pressure, water table in the burial chamber. Any radical shift in these gasses after the initial stabilization period could indicate some breach in Vault integrity, while continued steady state concentrations imply continued integrity.

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	12,431 tonnes
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	The accounting for this needs to be investigated further, and CLP does not plan to seek these credits, but depending on the source of the wood, a significant % of removals via WHS will also represent avoided emissions. I.e. for waste wood that would otherwise be burnt or left to decompose aerobically.

production	

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)*

Our calculations here are straightforward. One tonne of wood is approximately equivalent to one tonne of CO_2 (due to the carbon fraction of wood and the 3.7:1 ratio of CO_2:C; See Zeng and Hausmann 2022 footnote for more explanation). As such, after accounting for the carbon cost of transport and excavation; and adjusting for the estimated 90%+ durability at 1000 years (10,000t/0.9) – for this pilot we will bury (at minimum) 12,387t of natural waste wood, equivalent to 12,387t of CO_2. After subtracting process emissions and adjusting for durability, we have 10 Kt as net removal at 1000 years. All the key numbers are shown in the process flow diagram (PFD) below. More detailed calculation in the format of Excel or Python can be provided upon request. Note that our belief is that we are accounting for process emissions *very* conservatively here, and we expect process emissions to reduce substantially per tonne of CO2 sequestered as projects scale and CLP gains experience and learning.

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).

If CLP accelerates company formation and project deployment, the company can directly sequester at least 100 Kt CO_2 by 2025. We also intend to serve as process and method consultants for third-party projects with a goal of helping the WHS pathway achieve Mt scale globally within 3-5 years.

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.)

We conducted the Montreal Wood Vault Demo Project from 2013 to present and ongoing. The project demonstrated all the key components of a full commercial-scale CDR operation: (1) Carbon capture, done by natural photosynthesis but wood is sourced sustainably; (2) Processing (collection, transportation, stockpiling); (3) Construction of a Wood Vault, burial of wood; (4) Land rehabilitation: natural regrowth of grass on the site; (5) Measurement, reporting, and verification (MRV).

In March 2013, we buried 35 tonnes of natural waste wood (NWW; sometimes simply called yard waste, but we only took coarse woody material) in a 4-meter-deep trench at the corner of an agricultural field near Montreal, Canada. Eight and half years later in November 2021, a section of the burial chamber was excavated. Wood samples were retrieved from a depth of 1.2 meter in the main burial chamber and multiple sample discs buried in a connected smaller side trench at pre-defined depths (0.5m to 1.5m). We did not retrieve wood logs further down (burial was to 4-5m depth) due to resource limitation at the time of operation, though we expect to do so in the future which would provide longer-time preservation data.

The project in 2013 answered the following key questions: (1) Cost of operation; (2) Carbon emissions of operation; (3) How to minimize environmental impact while maximize potential co-benefits such as fire risk reduction, waste utilization, revitalization of rural communities; (4) Scalability of such operation to 1000 tonne and more. The sample retrieval in 2021 answered these main questions: (1) What's the durability of the buried wood; (2) What is the best method to ensure the longevity of buried wood under different conditions (partially, more research is needed!)

In summary, the Montreal Project has prepared CLP to scale our process to a 10Kt pilot. From pilot, our plan is to scale to a 100Kt project, then multiple 100Kt projects to achieve Mt scale before the end of the decade. Land use for building Wood Vault is small (0.1Mt CO2e sequestration per ha). The main limitation for WHS is sustainable wood sourcing, but the potential is substantial, for example, the US alone has over 300 Mt/y waste woody biomass currently unexploited (Perlack et al.)

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.

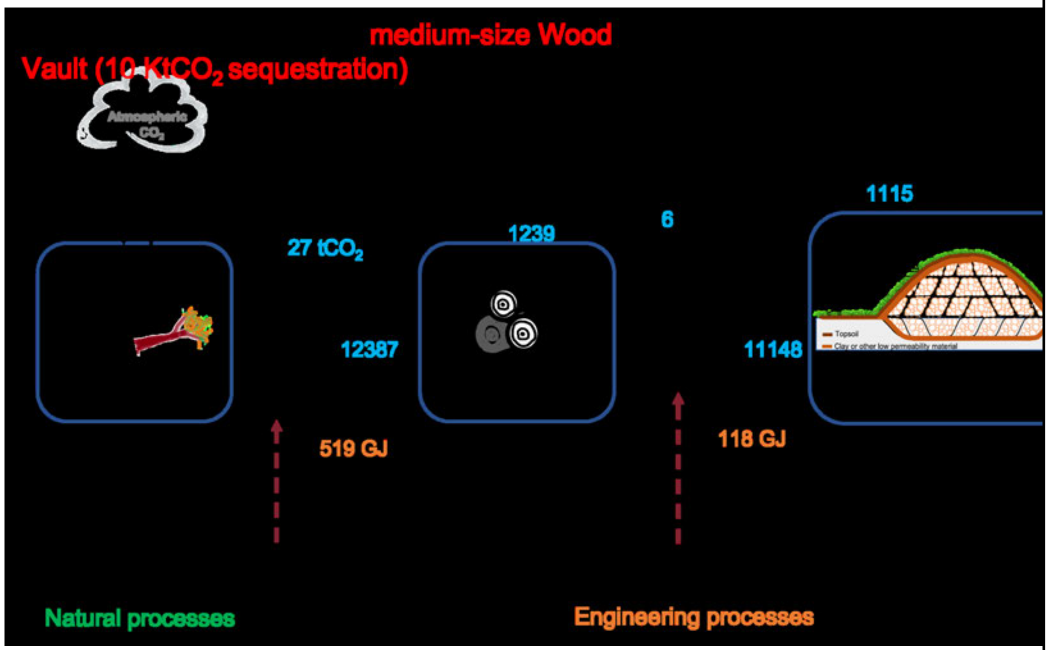
- Carbon Lockdown Project website
- Zeng and Hausmann, in press
- Preliminary data from the Montreal Project presented by Ning Zeng at the University of Maryland Science on Tap event, as well as This is CDR Episode #24

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	12,387 *Should equal the first row in table 3(a)*
Gross project emissions	2,387 *Should correspond to the boundary conditions described below this table in 4(b) and 4(c)*
Emissions / removal ratio	19.3% (or 33/10033=0.33% relative to the baseline the wood would otherwise decompose) *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*
Net carbon removal	10,000

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?

This PFD defines the boundary conditions to include CO2 capture by living woody biomass; transport of waste wood to the Vault site; site preparation, excavation, and burial.

<100 words

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 numbers above come from scaling up the measured numbers of the Montreal demonstration project, assuming that they will all scale relatively linearly. If anything, this conservative estimate will undercount the effectiveness of our project. As we scale the project up we will be able to make more efficient design choices, reducing fuel consumption and time biomass spends in temporary above ground storage.

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.

<100 words

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)*

The unit of deployment is a deci Wood Vault Unit (dWVU). A single WVU sequesters 100,000 tonnes of CO_2 on a hectare of land (See Zeng and Hausmann 2022 paper for definition), while a dWVU sequesters 1/10th of that.

<50 words

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
2013				35 tCO2 buried in a trench.

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.)*

Our costs have been stable because we're still in the first cycle of deployment. Capex is minimal, and we expect opex to decrease with scale and experience.

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)
1	10,000 tCO_2 in a single Wood Vault

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?

CLP is budgeting a per ton cost of net CO2e sequestered for the 10Kt pilot of $100/t, for a total cost of $1M. We expect these costs to decline substantially as we scale and optimize the process, MRV, etc. Zeng and Hausmann (2022) lays out the cost of large-scale operation.

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.

The primary costs included are the purchase of land, transport of waste wood, and the construction and filling of the vault. Given that disposal of waste wood in our region currently requires a tipping fee, we expect the natural waste wood employed for the pilot – and indeed for CLP's near- and medium-term future – to be free of cost.

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.

We expect costs to decline to $20-50/t at Mt scale. Gt scale could be the lower or upper end of this range depending on the scaling of other processes that use waste biomass as feedstock and the degree to which waste biomass becomes scarce and therefore an operating cost to CLP and WHS more generally.

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)

Over time, several factors will help us reduce costs as we scale up. First, as our reputation spreads, waste wood collectors will begin to see us as a valid alternative to their current wood disposal options. As such, we won't need to provide as much of an incentive, just beat the current market rate on tipping fees. This means Wood Vault projects can potentially go from collecting wood for free to charging a small tipping fee. On the other hand, if more operators (competitors) start to work on it, the demand for waste wood will change the price in the other direction. We thus still assume zero cost for waste wood in mid-term projection. Should WHS become even more popular, additional cost will potentially need to be included, as discussed in Zeng and Hausmann (2022).

Another cost reduction on the operation side will come from the inherent efficiency of economies of scale. As Wood Vault develops into an industry a small group will become expert in constructing them. These professional Wood Vault constructors will be able to construct a Wood Vault in less time and for lower cost than our current estimates.

Yet another cost reduction is MRV. The hardware (sensor system) is already low-cost based on our own development experience (my.sense.umd.edu) and others. Large-scale implementation as these are manufactured on industrial scale will further bring down the cost.

Finally we envision scenarios where land costs are reduced on average, or potentially eliminated entirely via deployment of WHS in the context of solar development / agrovoltaics; mine remediation; and colocation with municipal landfills to handle a given jurisdiction's urban wood waste.

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.

$50/tonne – if waste wood biomass becomes a cost. Competition for waste wood biomass could also reduce WHS's global scale potential. (But that would mean that other CDR pathways are valorizing the resource.)

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	Secure land	Needed for carbon burial	Q4 2022	We will show you the land deed (if owned by CLP), or agreement from another land owner
2	Wood stockpile of 13,000 tonne or more	Biomass needed for burial		Verifiable on site. We can send you the wood collection/measurement records
3	Wood vault construction and burial	Final step of actual burial		Verifiable on site during the final enclosure. The operation will be video recorded, and we will take photographs.

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	*0*	
2	*0*	*0*	
3	*0*	*12,387t*	Construction of Wood Vault complete and all CO_2e durably sequestered.

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	Land cost \$20,000-\$100,000 for 10 acres at \$2,000-10,000/acre (typical range for rural Maryland/VA/WV)	\$10/tonne	
2	Collect waste wood at zero cost, but including cost of transport, receiving wood, managing the site	\$25/tonne	
3	Wood Vault construction and burial	\$65/tonne	

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?

> Anybody who can fund CLP's path to Mt scale. We'll do the rest.

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

> Help CLP promote WHS as a viable pathway for durable CDR. There is a functional limit to how quickly CLP can scale direct projects so part of our business model is to provide technical support and MRV for third-party projects to scale the WHS pathway more broadly.

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.

> 1) Municipal waste management. Cities in our region typically pay to get rid of waste wood. We talked to, for instance, Gina Mathias, sustainability officer of the City of Takoma Park, who'd very much welcome our taking the wood away from the city's yard waste management facility.
> 2) Tree removal companies. They pay to get rid of waste wood (which is ultimately paid by the customers who need tree removal). We talked to 3 such companies who are happy to give us their wood (for free!).
> 3) Farmers, solar developers, landowners. This opens an alternative opportunity for them to get income on their land. In fact, we think WHS will create a new agro-industry that can transform rural economy.
> 4) Mining sector. WHS represents a significant incremental revenue opportunity / cost offset of the remediation of spent mines – e.g. coal mines in the Appalachian region. Additionally companies like Edelen Renewables (https://edelenrenewables.com/) are developing solar over former mines, with which WHS is 100% complementary.
> 5) Environmental groups. We work with The Chesapeake Climate Action Network (CCAN) and others to ensure this is done in an environmentally sound way. CCAN also helps with communication with regulatory agencies.
> 6) Governments. We have obtained seed money from Maryland Energy Innovation Accelerator (MEIA), who has supported us with entrepreneurship training, strategic planning, as well as connecting us with many stakeholders. One of our senior advisors is on the Maryland State Climate Commission.

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.*

> As described above. We have engaged with the stakeholders in a variety of ways by team members, advisors, and friends. We have not used any paid consultants.

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?

These interactions have brought us from 15 years of academic research to practical implementation.

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 do expect some modification and improvement, for example, best ways to preserve wood under a variety of conditions. However, we think the basic science is very solid and the technology is mature for implementation.

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?

The primary environmental justice concern of this project is to ensure it consults and benefits the local community and stakeholders, especially those in the local agricultural community. Small scale farmers are often left behind by development, but we hope that Wood Vault projects can benefit small scale farmers with income and tax credits. It is critical to ensure that everyone in the local community benefits from every Wood Vault project.
<100 words

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

Several elements of environmental justice are critical to the implementation of any WHS project. The first is economic justice. A WHS project can be a source of significant economic development by providing good jobs and acting as a conduit for monetary resources to enter a community. As such, it is critical that these economic gains are distributed equitably throughout the local community. It is especially critical to give resources and jobs to economically struggling groups such as small farmers. Another key element of environmental justice is to limit environmental and ecological damage. The goal isn't to solve a global problem at the cost of the local environment. This is achieved by measures like quality control on buried wood, preventing contaminants from entering local soil or water systems. All of this helps to ensure that all can benefit from each and every Wood Vault. The transport and excavation associated with any Wood Vault will be limited and temporary. WHS only employs solid waste wood biomass (tree trunks, large branches, waste wood from construction) and thus would leave leaf and branch litter on the forest floor when working with forestry / timber projects. WHS otherwise creates no negative externalities.

9. Legal and Regulatory Compliance (Criteria #7)

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

> We have not yet asked for official legal opinion on our specific projects. Informal consultation suggests that we only need to state that the ‘waste’ wood collected is not ‘waste’ because now it has carbon value, criterion being that somebody pays for it. Legally, we need to file a request for exemption from waste management control by stating that somebody (Stripe in this case) will pay for the wood buried, so it’s not waste but of value.

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.

> We do not expect permitting to be an issue on privately owned land; however we will certainly coordinate and consult with relevant local authorities and regulatory agencies. (Dr. Zeng’s University of Maryland affiliation will assist with this.) Additionally, we plan to add an easement condition to the land to ensure the long-term viability of the buried carbon.

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?

> No.

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.

> Clear regulatory guidance does not exist for WHS, however we plan to coordinate the project with relevant local authorities and regulatory agencies

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, at this phase we have not.

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*	**10,000 Tonnes of CO_2**
Delivery window *at what point should Stripe consider your contract complete?*	**Within 18 months of offer acceptance**
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.*	**\$100 per Tonnes of CO_2 Removed.** *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?

> CLP and the WHS pathway rely on natural waste wood (NWW), both from urban and rural sources. This includes urban waste from construction clearing, yard waste, natural disaster waste, wood cleared for fire suppression, and other sources.

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

> Our biomass source is external, primarily sourcing it from companies that already deal with waste wood. These companies already collect biomass from the sources mentioned in question 2. They already have the infrastructure to transport the biomass to a landfill or other disposal site. We just have to intercept it by offering the correct economic incentives, i.e., zero charge or reduction in tipping fees.

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	No additional footprint	
Processing	No additional processing: we bury raw wood.	
Long-term Storage	1 acre of land with wood buried underground. The surface can still be used for solar development, agro-voltaics, grazing, parks / recreation or other use. (At scale footprint is 10ha per Mt removal.) CLP also sees mine remediation (for example in nearby Appalachian coal country) as an	

	interesting deployment opportunity.	

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	*None, because this can be achieved by collecting waste wood only. At Gt scale there could be competition for waste wood biomass if multiple CDR pathways employ this feedstock scale.*	
Processing	No additional, short-term storage on site.	
Long-term Storage	1000 ha of land (10 km2*) for burial*	

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.)

There is little to no processing required for biomass in this project. While chemical treatment or charring of the edges of buried logs can help in less than ideal circumstances, it is not required in most Wood Vault projects (including the 10 kt project proposed here). The only factor needed to ensure durability is that the biomass is buried in an anaerobic environment and kept below and separate from the active ecological layer of surface soil. All of this is ensured by the engineering and design of the Vault and requires no additional chemicals, energy, or other add ons.

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.)*

The primary feedstock of this project is waste wood. As such, the alternative use is to sit in a landfill and rot, or in the case of waste from the forestry sector the alternative is that the wood will be burned in situ. In other words, the market doesn't currently provide an alternative use. In the future other biomass-based CDR pathways – biochar, bio-oil, BiCRS/BECCS, etc. – can potentially compete with CLP/WHS for this waste wood biomass resource. *<50 words*

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)*

Overall WHS has minimal risks and unknowns relating to ecological, social, and economic systems. As long as wood is properly inspected before burial, there should be no risk of chemical runoff or contamination. The only buried material is entirely natural biomass. One potential issue is the settling of ground after burial. Once the chamber is sealed, loose earth and soil will settle and fill in gaps in the buried biomass. This can lead to a lowering of ground level on the surface. As such, it is critical to hold off on any surface construction until after the settling has been observed to halt, and we would not recommend heavy structures be built over a Wood Vault. Beyond this, there are no major unknowns or risks to the surrounding environment.

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.

The primary advantage of our approach comes from the low cost and low tech nature of the process. WHS can be deployed globally with no specialized equipment. Additionally the durability of WHS exceeds that of any other biomass based CDR process that does not employ geologic sequestration of the CO_2 / carbon. At 0.1Mt removal potential per ha, WHS is quite space-efficient, especially considering that the land can subsequently be used for solar development, agro-voltaics, parkland, etc. Finally, the potential deployment of WHS for mine remediation is very compelling.