Carbon Lockdown

Carbon Dioxide Removal Purchase Application

Fall 2022

General Application - Prepurchase

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

Company or organization name

Carbon Lockdown Project Benefit LLC

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

Silver Spring, Maryland, USA

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

Ning Zeng, Toby Bryce

Brief company or organization description

Carbon Lockdown Project (CLP) is a public benefit LLC founded by Dr. Ning Zeng of the University of Maryland to develop, advance, and scale durable carbon removal via Wood Harvesting and Storage in specially engineered Wood Vaults.

1. Project Overview[1]

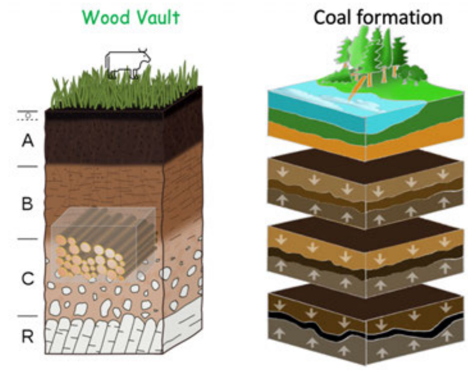
a. Describe how the proposed technology removes CO_2 from the atmosphere, including as many details as possible. Discuss location(s) and scale. Please include figures and system schematics. Tell us why your system is best-in-class, and how you're differentiated from any other organization working on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

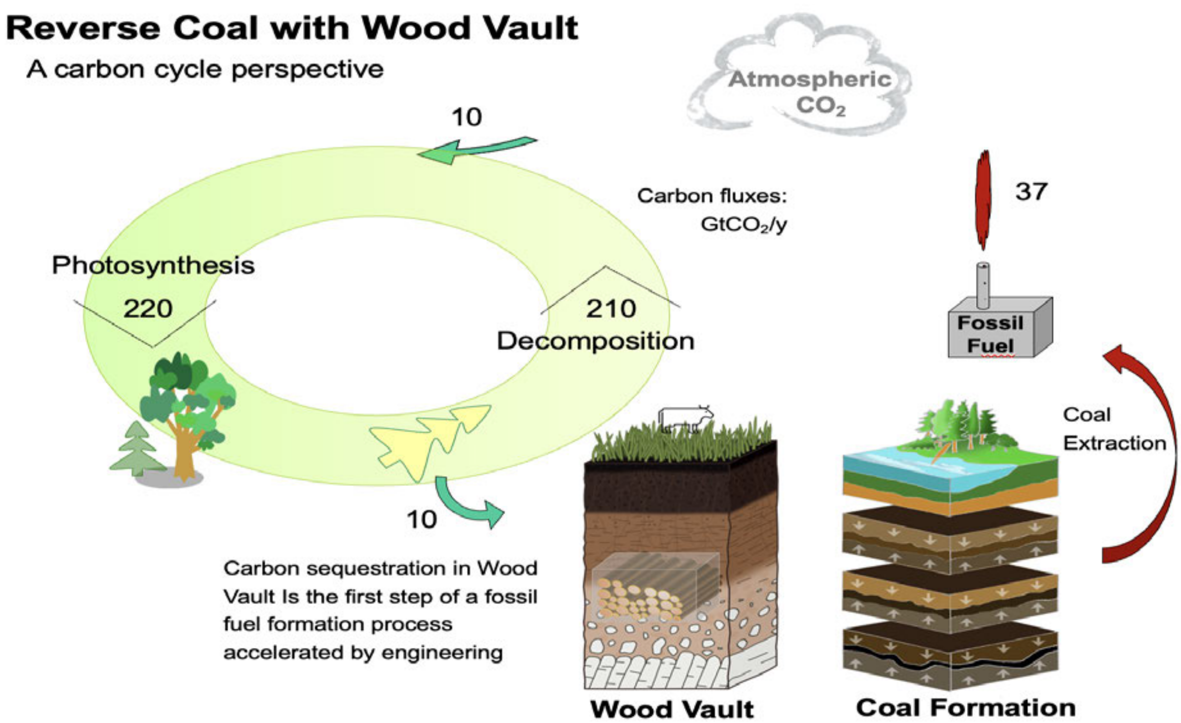
A. Wood Vault Overview

Wood Vault (WV) is a specially engineered structure that durably stores sustainably sourced

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

coarse woody biomass (CWB) based on the Wood Harvesting and Storage (WHS) method of CDR researched and developed by CLP Founder Dr. Ning Zeng. The science behind WHS can be summarized as a 'reverse coal' process in which carbon in the form of woody biomass is taken out of the "fast" photosynthesis-decomposition biotic carbon cycle and transferred to a "slow" geological carbon cycle via human engineering, as illustrated below (See Zeng et al., 2013 for a [quantitative estimate of WHS potential]).





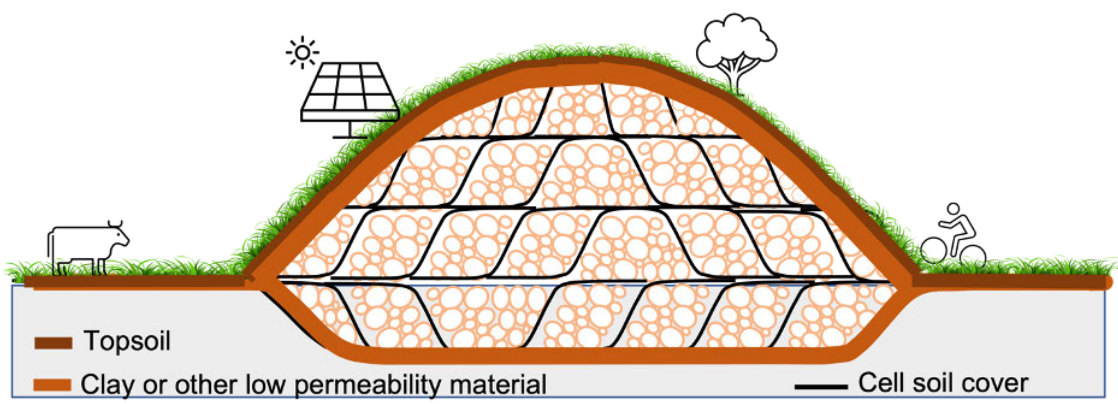
High durability is achieved by burying CWB in an anaerobic subterranean environment several meters below ground, away from the active biosphere (vegetation, soil, and decomposers) that's typically limited to the first meter of the soil profile. CLP's patent-pending WV design ensures an oxygen-depleted environment that prevents wood decomposition, and initiates the re-fossilization of carbon. See Section 2 and the Addendum for more detail on the science behind WHS and WV.

The operational steps of WV involve:

1) Site analysis: soil permeability; soil composition (sand/silt/clay/organic); hydrology; topography; community and environmental impact.
2) Source CWB that would otherwise be left to decay, mulched, or burned (i.e. with the baseline that its constituent carbon continues in the fast carbon cycle, released to

atmosphere immediately, or within few years), optimizing for short distance of transport to minimize cost and CO2 emissions;

3) Stockpile the CWB on site temporarily before burial, sorting CWB to confirm minimum diameter of 10cm per the WV protocol.
4) Baseline measurement of soil carbon at the Wood Vault site, and a nearby control site.
5) Conduct biochemical analysis of CWB feedstock to determine moisture content, carbon content, and baseline for future MRV. (See Section 4 for details.)
6) Construction of Wood Vault: site preparation, excavation (See Fig below for an illustration of Wood Vault Version 1, nicknamed Tumulus for its partially below-ground characteristics). Place subsoil and organic topsoil separately.
7) Prior to burial, weigh the CWB to determine exact mass for subsequent conversion to CO2e. (See Section 4 for details.) Then bury the CWB in batch at a time interval optimized to minimize operational cost and above-ground decay before burial;
8) Backfill the trench with the excavated subsoil, then topsoil. Compact the soil with the excavator as soil is backfilled to further lower permeability for better sealing.
9) Seed the ground with grass.
10) After rehabilitation, soil settling, and grass re-establishment (~1 year), optionally transition the land to additional productive use such as grazing, recreation, solar farm, forestry, light construction, or combinations thereof e.g. agrivoltaics.
11) Continual monitoring of the site using sensors, flux measurements, 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. See Section 4 for detail on the MRV process.



Wood Vault Version 1.1: Burial Mound (Tumulus)

B. Comparison with other methods

WHS and WV are a hybrid Nature+Engineering method of CDR. CO2 is captured by trees via photosynthesis for 'free', with an estimated global CDR scaling potential between 2-10 GtCO2/y (Zeng et al. 2013; Zeng and Hausmann 2022) achievable in the next 20 years.

The WHS method requires no complex technology and only minimal sorting and processing of feedstock, i.e., we bury raw woody material, which is a key advantage for its simplicity and low-cost. Additionally WHS / WV does not employ any thermal conversion of biomass (which in the case of pyrolysis for biochar typically emits 50%+ of the initial CO2e) and thus sequesters 100% of the feedstock's carbon.

WV is durable CDR we can scale today, to multi-Mt by 2025 and 10Mt+ by 2030. The only scaling constraint for WV is uncertainty with respect to MRV and durability, along the lines of the uncertainty that Frontier and Carbonplan illustrated for 6 other CDR methods in the recent work on verification confidence levels (VCLs).

C. CLP Potomac MRV Demonstration Project

The purpose of this proposed Potomac MRV Demonstration Project is to amplify CLP's investment in MRV and establish a WHS/WV research site near University of Maryland, where Dr. Zeng teaches, in an effort to begin to address – and accelerate the reduction of – uncertainties associated with WHS/WV as a method of durable CDR, so as to facilitate the more rapid scaling of CLP, WHS/WV, and terrestrial biomass sequestration more generally.

The CLP Potomac MRV Demonstration project is located in Charles County, southern Maryland, 25 miles south of the Capital Beltway (I-495) near the Potomac River. The Wood Vault will occupy 1/4 acre of a 20-acre CLP owned plot. Soil is a heavily weathered red clay (ultisol) with a low permeability, ideal for sealing the chamber to ensure anaerobic condition.

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

1. Wood Vault Construction

WV construction is at **TRL 6**. Feedstock collection, transport, stockpiling, and construction of Wood Vault to ensure anaerobic condition involve mature technologies in forestry and civil engineering. The main challenge is operational, i.e. how to put these together efficiently. Achieving TRL 9 does not require new technology, but rather operational learning and economies of scale. Dr. Zeng has conducted two prototype projects, detailed below:

From 2007-2010, the Carbon Sinks Team conducted a 3-year field experiment where multiple wood samples were buried at various depths down to 1 meter at the Wye Lab on the Eastern Shore of Maryland. The results showed burial, even in shallow and non-ideal soil conditions, can extend wood preservation from a few years on the surface to several decades.

In 2013, the Montreal Project constructed a demo Wood Vault and buried 35t of CWB in a trench (20m by 8m, 4-5m deep). In 2021, wood samples were retrieved from the site and analyzed in the lab for their density, mechanical strength and chemical composition. Samples from below 1m show no sign of decay and have no loss of carbon within the experimental error bar. Additionally, an ancient red cedar log was excavated from 2m below surface during the 2013 excavation, which was carbon dated at 3775 years old. Lab analysis shows the interior of this ancient wood has had little degradation and carbon loss. Because our Wood Vault design requires clay sealing similar to the buried ancient log's environment, this 'natural experiment' and numerous archaeological and geological evidence strongly support the

1000+ years durability achievable with a well-constructed Wood Vault. See more detailed analysis in the Addendum. **2. Scientific uncertainty and MRV** We assess the MRV for WHS and WV to be **TRL 4**. While the basic scientific principles behind WV are sound and the evidence supporting durability are strong, there is a lack of data on the practical application of this novel technology for durable CDR. The primary goal of this proposed CLP Potomac MRV Demonstration Project is to build a 2000t WV and integrate an extensive range of MRV technology and techniques to assess in terms of ensuring the durability of stored carbon and the overall integrity of WV operation. We expect the results of this Project, over the coming decade, to significantly reduce the uncertainty (as illustrated by the recent Frontier/Carbonplan VCL vision) associated with WHS, WV, and terrestrial biomass sequestration more generally as a means of durable CDR. See detailed description of the Project's MRV plan in Section 4.

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

Key performance parameter	Current observed value (units)	Value assumed in NOAK TEA (units)	Why is it feasible to reach the NOAK value?
Cost	$250/t	$40/t ($20-50/t range)	CO2 capture via photosynthesis is 'free'. Site selection will be optimized to minimize feedstock collection and transport costs (and CO2 emissions). The engineering involves collecting, transporting, and burying CWB, which costs will decline with enterprise and project-level scale, and cumulative operational learning. In addition to scale, the primary driver of decreasing cost of WHS and WV will be reducing uncertainty about MRV, durability, and feedstock sourcing and baselines – which will commensurately reduce the need for the current level of discounting and buffer/escrow that significantly increases current per-t cost.
Carbon Efficiency	~78%	98%+	A key advantage of WHS and WV is the inherent carbon efficiency of the

			process – i.e. 100% of the feedstock CO2e is sequestered. Actual process emissions from feedstock collection and Wood Vault construction are <5% even at current scale, and these will decline to <2% at NOAK scale. CLP currently discounts its net sequestration to reflect uncertainty with respect to MRV and durability. As mentioned above, a key purpose of this Potomac MRV Demonstration Project is to overinvest in MRV in order to accelerate learning and reduce these uncertainties.
Scalability	2000t	100,000t	We think of NOAK TEA in terms of Wood Vault Units (WVUs) of 100Kt, which is the mass that can be sequestered in an area of 1 hectare. After initial WV demonstrations on CLP-owned property, we plan to scale primarily by co-developing projects with solar developers, mine operators, real estate developers, the forestry sector, and other deployment partners. CLP targets FOAK 100Kt project scale by 2025. Then CLP will seek to increase the number of projects delivered annually by scaling the team and CLP's geographical reach to achieve NOAK 100Kt project (which we define as 10Mt+ aggregate global delivery) by 2030.

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

CLP is a start-up established in 2022. The leadership team includes: • Dr. Ning Zeng, Founder and CEO. Dr. Zeng is the inventor of the WHS concept and Wood Vault technology with two patents on Wood Vault engineering and MRV. A professor at the University of Maryland, Dr. Zeng is a recognized expert on the carbon cycle, a Reuters Top Climate Scientist, and 3-time contributor to the IPCC reports. • Toby Bryce, Head of Commercialization. Bryce is a commercial advisor to early-stage carbon management companies and active in the CDR ecosystem via policy advocacy

and market development work with the OpenAir Collective.

- Head of Deployment, in the process of hiring.

Dr. Zeng has worked on WHS for 15+ years and authored the 2008 paper that originated the idea of wood burial for carbon sequestration, followed by a series of peer-reviewed publications culminating in the 2022 Zeng and Hausmann overview of Wood Vault as CDR. Dr. Zeng has led multiple WHS demonstration projects, including the Gemstone Carbon Sinks project (2007-2010) and the Montreal Project (2013-present) in order to advance the science and practice of WHS and WV. (Peer-review paper recapping Montreal Project results in process, and additional detail in Addendum.)

CLP has been supported by seed funding from the Maryland Energy Innovation Accelerator (MEIA), and the company is in the process of publishing a prototype "Wood Vault Operating Protocol" with a well-established partner in the CDR sector. Once initial WV demonstration projects have been funded, CLP will seek to raise seed equity capital to build out the team and fund CLP's IP strategy. Some further equity funding may be required, however CLP anticipates that the bulk of the capital required on a go-forward basis will be project finance (supplied in many cases by deployment partners in the solar, forestry, mining, etc sectors).

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

Partner	Role in the Project	Level of Commitment
ARM Group LLC	Site survey, permitting, WV engineering and construction	Confirmed project partner
USDA/Forest Service Northeast Climate Hub	Soil and hydrology expertise; Environmental and ecological integrity; independent LCA analysis; community outreach	Confirmed project partner
Eastern Shore Forest Products Inc	Nearby source of CWB feedstock.	Intention to collaborate
Agricultural and Community Development Services LLC	Securing wood source and outreach with local/state forestry sector	Confirmed project partner
University of Maryland	Scientific consulting; monitoring; sample analysis	Confirmed project partner

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

We expect WV construction to be complete, and CDR delivery to occur, within 1 year of funding, or by the end of 2023. The MRV portion of the project will continue intensively for a minimum of 10 years, with the capital expenditure supported by this project funding and research and analysis supported by Dr. Zeng's University of Maryland Environmental Monitoring Lab (EML).

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

CDR starts and ends when the Wood Vault is complete and capped in Q4 2023. Two relevant factors to determine *net* CDR are baseline and durability of storage. These are discussed in the Biomass Supplement and Section 2 of this proposal.

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

Year	Estimated gross CDR capacity (tonnes)
2023	50,000
2024	250,000
2025	500,000
2026	1,000,000
2027	2,500,000
2028	5,000,000
2029	7,500,000
2030	10,000,000

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

	Milestone description	Target completion date (eg Q4 2024)
1	Land purchase	Q1 2023

2	Obtain permit	Q2 2023
3	Accumulate sufficient volume of CWB feedstock	Q3 2023
4	Complete Wood Vault construction and capping	Q4 2023

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

CLP has two directly relevant patents: 1) IoT based sensor technology for monitoring, 2) Wood Vault engineering. (See Addendum for references.) We will continue to advance and refine the WHS/WV technology and expect to develop more IP in the coming years.

k. How are you going to finance this project?

CLP has been supported to date by seed funding and other in-kind support from the Maryland Energy Innovation Accelerator (MEIA). We are seeking Frontier's funding support for this Potomac MRV Demonstration Project with a focus on advancing MRV technology and techniques, and a goal to reduce uncertainty with WHS and WV as a method of durable CDR.

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

CLP is in active discussions with other CDR buyers for an additional 10-20Kt of net sequestration on the site of the Potomac MRV Demonstration Project, and we are advancing the opportunity to list a project on this site with Puro for Pre-CORC funding. We are additionally in active discussions with solar developer and mining company project partners for projects that could deliver another 20-50Kt of CDR in the 2023-24 time-frame; and have a lengthy pipeline of project partners who have expressed interest in the WV opportunity.

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

CLP is not expecting additional revenues from this project beyond potential funding from Frontier.

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

Risk	Mitigation Strategy
Financing	Project financing is the primary risk CLP faces. We are mitigating this risk by seeking funding from multiple sources (as described above).
Market Validation	CLP is seeking to advance market validation of WHS/WV and terrestrial biomass sequestration more generally via the forthcoming co-publication of a Wood Vault Prototype Operating Protocol with an established partner in the CDR sector with strong scientific credibility that has been reviewed by a panel of academic, commercial, and NGO CDR experts.
MRV Uncertainty	Dr. Zeng's nearly two decades of research are foundational to the idea of durable CDR via terrestrial biomass sequestration, and CLP feels confident as to the verifiability and durability of CDR via WHS and WV. However WHS / WV have limited deployment history and performance data sets so understandably there is uncertainty on this point. The Potomac MRV Demonstration Projects seeks to address and start to reduce this uncertainty by investing heavily in MRV and long-term monitoring in order to accelerate the building of a historical data set to demonstrate the durability of the Wood Vault method.

2. Durability

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

CLP asserts a lower bound of durability for CDR via the WV method of 1,000 years. The upper bound is effective geologic sequestration of 100,000+ years. The durability of the CO2e sequestered via CLP's burial of CWB in a WV is ensured by two primary factors:

(1) The site's low-permeable Piedmont red clay (ultisol) creates an anaerobic environment by preventing water/air movement that can import oxygen into the burial chamber. Without oxygen, the majority of decomposers present in biologically active soil including fungi, insects, and most microorganisms cannot survive.

(2) This leaves methanogenic bacteria as a potential area of concern. However, these bacteria do not have the enzyme necessary to digest lignin, the glue-like polymer that holds together and protects cellulose. For this reason CLP's WV protocol stipulates the use of CWB with a minimum diameter of 10cm as feedstock, which is indigestible to methanogens. More detail on this question is provided (with references) in the Addendum.

In terms of supporting CLP's durability assertions, we point to data from Dr. Zeng's 2013 Montreal Project, which constructed a demo Wood Vault and buried 35t of CWB in a trench (20 by 8 meters, 4-5 meters deep). In 2021, wood samples were retrieved from the site and analyzed in the lab for density, mechanical strength and chemical composition, as well as microscopic analysis of cell structure with scanning electron microscope (SEM). Samples from below 1 meter show no sign of decay and have no loss of carbon within the experimental error bar. Additionally, an ancient red cedar log was excavated from 2 meters below surface during the 2013 excavation, which was carbon dated at 3775 years old. Lab analysis shows the interior of this ancient wood has had little degradation and carbon loss compared to modern red cedar. See the addendum for quantitative analysis.

Because CLP's Wood Vault protocol requires clay sealing that significantly exceeds the buried ancient log's environment (Montreal soil permeability 1 x 10^{-8} m/s, the 10Kt site 2 x 10^{-9} m/s), this 'natural experiment' strongly supports the 1000+ years durability achievable with a well-constructed Wood Vault. Preliminary results of the Montreal project are found in This Is CDR Ep.24 (20min) or Science on Tap presentation (1hr) by Ning Zeng. Detailed results are described in two scientific papers in preparation with sample results in Addendum.

The upper limit of our estimate comes from archeological/geological evidence (See Zeng and Hausmann 2022 Section "Durability: lessons from archaeological and geological evidence”). For example, preserved Neanderthal wooden tools have been found dating back to times as old as 300,000 years ago while geological preservation of wood of 25 million years old was found in clay pits similar to the Wood Vaults we are building. See Mustoe (2018) for a review of “Non-Mineralized Fossil Wood”.

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

There is little to no risk of physical reversal of CDR with a properly constructed WV in a site (like the one proposed for this Project) that meets the specified soil permeability and other conditions. Natural geologic disturbances such as earthquakes in this region have extremely low probability of occurrence.

The fundamental science of biological decomposition and thus the scientific theory behind the durability of CDR via WHS and WV are well-established. The primary purpose of this Potomac MRV Demonstration Project is to collect data to support this theory and demonstrate that the anaerobic conditions of the burial chamber are sustained over time with negligible methane generation, which will serve to reduce uncertainty and further substantiate CLP's durability assertions.

The primary socioeconomic risk of CDR reversal comes from potential excavation by future land owners. The State of Maryland has a well-established statute for conservation easement, which CLP will execute and incorporate into the title of the land for perpetuity.

3. Gross Removal & Life Cycle Analysis (LCA)

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

Gross tonnes of CDR over project lifetime	2780
Describe how you calculated that value	Gross CWB buried (2780t) - discount for storage uncertainty (556t or 20%) - other uncertainties (160t or 8% of Net Carbon Sequestered or NCS) - fossil CO_2 emissions (64) = 2,000t net CO_2e sequestration. See PFD below for the full carbon flow.

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

35t stored in the 2013 Montreal Project

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

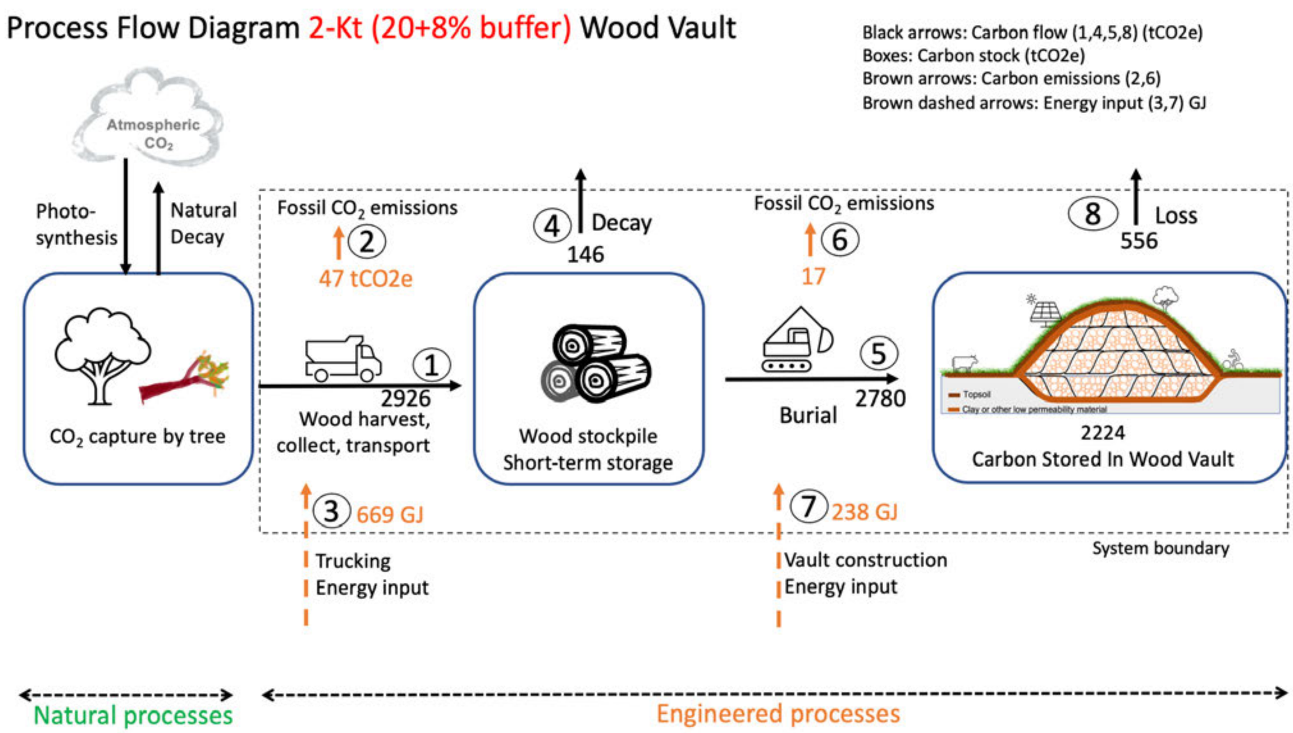
N/a.

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

Gross project emissions over the project timeline *(should correspond to the boundary conditions described below this table)*	620
Emissions / removal ratio *(gross project emissions / gross CDR–must be less than one for net-negative CDR systems)*	0.223
Net CDR over the project timeline *(gross CDR - gross project emissions)*	2000

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

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



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

1. Natural process of photosynthetic capture of CO2 is outside the WHS system boundary – which starts from collection and transportation of CWB – because the WV method employs residual (waste) woody biomass (not dedicated biomass production).
2. CLP conservatively estimates a decay rate of 5% of initial mass of stockpiled CWB (146t), which emission would happen in a baseline, no-intervention scenario (burning/mulching) and thus **is not included** in process emissions.
3. Discount / buffer of total 20% **is included** in the calculation of net sequestration to account for the uncertainty in durability. (Even though this carbon loss would also have happened in a baseline, no-intervention scenario.)

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

Process Step	**CO_2(eq) emissions over the project lifetime (metric tonnes)**	**Describe how you calculated that number. Include references where appropriate.**
(2) transport of waste wood	47	0.016 tCO2 per ton-25mile transport. We multiply the 0.004/t from Environmental Defense Fund Green Freight Handbook by a factor of 4 to account for smaller trucks in our operation.
(6) Wood Vault construction/site maintenance/MRV	17	0.003 tCO2/ton is used as CO2 emission factor for excavation; 0.3 gallon diesel consumed per cubic meter of volume. See construction industry data. Then multiply by 2 to account for site management (stock sorting etc.). Also includes site maintenance and MRV activity's carbon footprint.
(8) Discount for durability uncertainty	556	We are applying a 20% discount to gross CO2e sequestered to account for durability uncertainty.
Discount for MRV uncertainty	160	We are applying an 8% discount on NCS for MRV and other uncertainties (see 4c on MRV below).
		Note: Our Montreal project operation data is consistent with the above estimate which is based on well established industrial operations. Montreal project overall emission factor is somewhat smaller than this 2Kt project due to shorter transportation distance.

4. Measurement, Reporting, and Verification (MRV)

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

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

Puro.earth recently released a Woody Biomass Burial Methodology. The forthcoming CLP Wood Vault Operating Protocol conforms to Puro's methodology, while offering greater rigor to site selection and analysis; feedstock parameters; WV construction; buffer; and MRV.

The MRV uncertainty with respect to WHS and WV primarily pertains to potential decomposition (durability), and secondarily confirming the theoretical absence of risk of methane generation. CLP's MRV plan for the Potomac MRV Demonstration Project employs a number of measurement and analysis methods in parallel.

1. Pre-burial: Baseline biochemical analysis of soil and feedstock.

1. Baseline measurement of soil carbon at the Wood Vault site, and a nearby control site, including analysis of soil organic matter and communities of microorganism.
2. Biochemical analysis of the CWB feedstock is conducted once the requisite volume has been stockpiled to measure carbon and moisture content and other key factors:

    a. Visual and microscopic examination (optical and SEM)
    b. Density
    c. Mechanical Strength
    d. Chemical composition of wood: lignin, cellulose, hemicellulose
    e. Carbon Content
    f. Water Content

2. Pre-burial: Weighing CWB feedstock.
For the quantification of gross CDR, we use the Weighing Method outlined in the WV Operating Protocol. The CWB to be buried is weighed and conversion of measured mass is converted to CO_2e according to the following U.S. Forest Service formula:

CO2e stored = Mass of wood × (1-Water content) × Carbon content × 44/12

This method of measuring gross CDR has very low uncertainty, compared to other methods such as the Volume Method which may be deployed in parallel for site management purposes.

3. Monitoring of burial environment for CO_2, O_2, CH_4, temperature, humidity, pressure, pH, using continuous low-cost sensor and periodic sampling with gas well. In a well-constructed Wood Vault, CO_2 concentrations will initially briefly increase while O_2 concentrations steadily drop as the leftover oxygen buried in the chamber is consumed by a small number of residual decomposers. Both will level off within weeks to months, with the final O_2 concentration settling to zero, killing any remaining decomposers. Because of the CWB feedstock's protective lignin, there should theoretically be no material generation of CH_4.-- which CLP's MRV protocol will confirm. Once these key variables settle into a demonstrable equilibrium, the Vault can be considered to exist in a geologically stable state. CLP's Potomac MRV Demonstration Project will continue to monitor these factors for an initial ten-year term.

4. Flux measurement for CO_2 and CH_4 with soil flux chamber. To monitor potential methane generation and leakage, install a soil flux chamber to monitor flux of CH_4 and CO_2. The instrument must be installed immediately after capping of the Vault. The location should be where interior gas is most likely to accumulate and escape, such as at the top of a Tumulus dome. The instrument should not be mounted above backfilled organic rich topsoil, but directly above the sealing clay layer that covers the buried wood so that it only detects flux coming out of the burial chamber, not biological activities in the topsoil. Significant CH_4 flux originating from inside the burial chamber over a long period of time is an indicator of Vault failure. This flux measurement should continue for the effective lifetime of the project.

5. Monitoring Soil Settlement, Vault Integrity and Site Management

Some initial soil settling is inevitable after the final capping of a Wood Vault as pore space in between woody biomass is filled with settled soil. Follow these steps to monitor soil settling and the overall Vault integrity:

1) Conduct surveys using a traditional standard survey technique or aerial/drone technology.
2) Build a 3-dimensional model of the Vault, with accurate information of its geometry, location of woody material, pore space vs. wood ratio, and other relevant data.
3) Repeat the survey annually until settlement is deemed complete, then with lower frequency: 10 years for the first 50 years and 25 years afterwards.
4) Compare the survey data from multiple time periods to determine whether soil has completely settled. Cross check the data with gas monitoring of the burial chamber interior. Record vegetation, land use and management. Use the 3-D Vault model to quantify any change.

6. Re-excavation and Analysis of Buried Wood Samples

This is considered the definitive answer to the durability question. This is also a great strength of Wood Vault compared to many other CDR methods in its verifiability.

Re-excavate CWB samples from the WV and repeat the biochemical analysis outlined in Step 1 above every 10 years for the first 50 years, and every 25 years afterwards.

7. Mechanistic Carbon Cycle Modeling and Prediction

1) Measure soil and vegetation carbon, compare with baseline measurements taken pre-burial (Step 1 above), and use the data to calibrate a carbon cycle model to simulate carbon recovery in the disturbed area.
2) Develop mechanistic models that simulate the fate of buried wood based on the physical setting, chemical environment, and biological decomposition processes.
3) The models will be calibrated by historical data and ongoing experiments. Eventually, this will establish quantitative capability in predicting the durability and guide future management of the Vaults. This process is akin to how we predict climate with climate models.

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

> See details in 4a above. Wood Vault is inherently easier to monitor and verify than many other CDR methods. The most direct approach is re-excavation and direct sampling as described above and demonstrated in our Montreal project. Combined with gas monitoring, flux measurement and 3D modeling of the Vault, we will be able to confirm the durability with confidence, as well as collect data that will allow us to better extrapolate out over time and further substantiate durability assertions of 1,000+ years and beyond..

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

In the first column, list the quantification components from the Quantification Tool relevant to your project (e.g., risk of secondary mineral formation for enhanced weathering, uncertainty in the mass of kelp grown, variability in air-sea gas exchange efficiency for ocean alkalinity enhancement, etc.).

In the second column, please discuss the magnitude of this uncertainty related to your project and what percentage of the net CDR should be discounted to appropriately reflect these uncertainties. Your estimates should be based on field measurements, modeling, or scientific literature. The magnitude for some of these factors relies on your operational choices (i.e., methodology, deployment site), while others stem from broader field questions, and in some cases, may not be well constrained. <u>We are not looking for precise figures at this stage, but rather to understand how your project is thinking about these questions.</u>

See this post for details on Frontier's MRV approach and a sample uncertainty discount calculation and this Supplier Measurement & Verification Q&A document for additional guidance.

Quantification component Include each component from the Quantification Tool relevant to your project	**Discuss the uncertainty impact related to your project** Estimate the impact of this component as a percentage of net CDR. Include assumptions and scientific references if possible.
Storage	Very low uncertainty (<1%): CWB feedstock is weighed and subject to biochemical analysis before burial to measure moisture content and confirm carbon content of dry biomass. Formula we use is well known: CO_2e = Weight of wood × (1-Water content) × Carbon content × 44/12. Measurement process further detailed in this Section 4.
Feedstock Counterfactuals	Low uncertainty (<5%). CLP's Wood Vault Operating Protocol requires the use of unmerchanted residual CWB that would otherwise be burned, mulched, or left to rot. Attestation from a

	credible organization will be required with our wood source. Counterfactual storage is zero to a few years max (i.e. not climate-relevant time-frame), and the only counterfactual use is temporary, as mulch.
Indirect Land Use Change	Very low uncertainty (<1%). The land use footprint of WV is very small compared to the quantity of CWB buried in the WV (0.1Mt/ha), and this project will require 0.25 acres (~ 0.1 ha). After enclosure and settline (~1 year), the surface of the Vault can additionally be repurposed for agriculture, solar farm, recreation, or other productive use.
Materials and Energy	Very low uncertainty (<1%). WV construction requires minimal material input. Transport and excavation will use energy and emit CO2. Emissions can be estimated via well- established conversion metrics (miles of transport, cubic meters of excavation, etc.) as outlined in Section 3 of this proposal.
Storage Monitoring and Maintenance / Leakage	Medium uncertainty (20%). Carbon storage via the WV method offers 1,000+ year durability in theory, as described in Section 2, but practical uncertainty as to the method exists due to limited data sets to fully substantiate this assertion. The purpose of this project is to invest heavily in MRV (as outlined in this Section 4) to build a data set that over time will help to substantiate a durability assertion for WV of 1,000+ years (and eventually, in the coming decades, 100,000+ years).

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

> We discount 28% to account for durability and MRV uncertainty, plus 2.3% fossil fuel emissions of machine operation. This is included in our offer of 2,000t CO2e net CDR based on the full LCA carbon accounting (see PFD).

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

> The Potomac MRV Demonstration Project will be the first large-scale WV purposefully designed and implemented for CDR. Reducing uncertainty relating to WV MRV and durability/leakage is the primary project objective.
>
> Building on 15 years of research and two small-scale pilot projects, we aim for the following (outlined in detail previously in this Section 4):
>
> - Develop monitoring system with sensors, flux measurements, 3D Vault modeling
> - Establish a standard procedure for sampling and lab analysis.

> - Develop mechanistic modeling capability to predict durability based on Vault engineering details and environmental conditions such as permeability, capping thickness, soil hydrology and climate.

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

> Puro.earth earlier this year published a Woody Biomass Burial Methodology that CLP's WV method conforms to. We are further developing a more rigorous protocol with a highly respected third-party partner in the CDR sector that will be published in the coming months. This Potomac MRV Demonstration Project will have USDA/FS Northeast Climate Hub as a partner who will conduct independent assessment and life cycle analysis.

5. Cost

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

a. What is the levelized price per net metric tonne of CO_2 removed for the project you're proposing Frontier purchase from? This does not need to exactly match the cost calculated for "This Project" in the TEA spreadsheet (e.g., it's expected to include a margin), but we will be using the data in that spreadsheet to consider your offer. Please specify whether the price per tonne below includes the uncertainty discount in the net removal volume proposed in response to question 4(d).

> $250/t CO_2e (includes discount for MRV and durability uncertainty)

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

Component	Levelized price of net CDR for this project ($/tonne)
Capex	50
Opex (excluding measurement)	50
Quantification of net removal (field measurements, modeling, etc.)[2]	100

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

Third party verification and registry fees (if applicable)	0
MRV uncertainty discount / buffer	50
Total	250

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

Parameter with high impact on cost	Current value (units)	Value assumed in NOAK TEA (units)	Why is it feasible to reach the NOAK value?
Capex	$50	$0	For this initial MRV Demonstration CLP will be purchasing land, however for the vast majority of future projects, the expectation is that the land will be owned by a partner who is planning subsequent use, e.g. agriculture, solar development, agrivoltaics, mine reclamation, forestry, real estate development, recreation, etc.
Opex (excluding measurement)	$50	$25	On the one hand we expect per-t opex (feedstock collection, transport, stockpiling; WV construction) to decrease significantly with scale and operational learning. On the other hand we expect increased competition for “waste” biomass by the time CLP reaches NOAK potentially to increase that component cost of opex.
Quantification of net removal	$100	$5	Per-t MRV costs will reduce dramatically with scale and as they are operationalized. They are purposely high for the current project due to small scale and the desire to invest heavily in MRV for demonstration and data collection purposes.
Third party verification and registry fees	$0	$5	With our USDA/FS partnership we do not anticipate verification or registry costs with this MRV Demonstration Project, however at NOAK scale we estimate that these costs could reach ~10% of per-t cost.

MRV uncertainty discount /buffer	$50	$5	We are applying an elevated MRV uncertainty "discount" to this initial MRV Demonstration project, however we expect uncertainty to be lower by the time we reach NOAK scale, and/or for the discount to convert to a ~10% buffer that gets released over time post project completion.

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

> We are confident of our cost analysis for the current project, up to FOAK. For NOAK and beyond, the feedstock component of opex is the cost component where we have the lowest long-term confidence.
>
> We are confident that there exists sufficient unmerchanted residual biomass for WHS / WV to reach Gt scale in isolation. However in a world where multiple biomass-based CDR methods are seeking to reach Gt scale, there is likely to be competition for feedstock. This is not a problem for the current decade, or even the early 2030s, however an issue that WHS/WV and other biomass-based CDR methods will begin to face in the 2035-40 time-frame.

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

> They are similar, with differences less than 15%.

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

> The only obstacle to commercializing and scaling WHS /WV is market validation and acceptance of the method as durable CDR. The primary purpose of this proposed project is to invest heavily in MRV and transparently collect data that will begin to reduce this uncertainty.

6. Public Engagement

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

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

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

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

> CLP has purposefully engaged with a range of stakeholders regarding the WHS/WV method of CDR, including state and local government, NGOs, potential feedstock suppliers (forestry sector, tree removal companies, and mulch facilities), as well as local farming communities on Maryland's Eastern Shore. Examples include:
>
> - Regional USDA and U.S. Forest Service personnel
> - State of Maryland - Forest Service, Department of Natural Resources, and State Climate Change Commission
> - Charles County, Maryland
> - Sustainability NGOs in Southern Maryland and on Maryland's Eastern Shore
> - Agricultural communities in Southern Maryland and on Maryland's Eastern Shore
> - Mulch facilities and private tree removal companies in Southern Maryland and on Maryland's Eastern Shore

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

> Dr. Zeng and CLP's engagement with relevant stakeholders and communities has developed through mostly a person-to-person 'social-networking' approach over the past 5-10 years rather than via any sort of programmatic work with external consultants or advisors. Some examples:
>
> Our engagement with USDA/FS NE Climate Hub involves a bi-weekly conference call. USDA has started an independent LCA analysis. They have arranged two webinars on the potential of Wood Vault within USDA including the Chief Economist's office and Forest Products Lab. They will be making a documentary film of our project as a new opportunity for rural development.
>
> Another example is the Deal Island Peninsula Partnership. University of Maryland (CLP is a UMD spinoff) has long worked with the Partnership on local sustainability issues such as wetland preservation, and they are natural partners for CLP. Community engagement with them will focus on local environmental, social and economic impact.
>
> Engagement with MD Dept of Natural Resources (DNR) since 2021 has helped in identifying sustainable wood sources and connecting with other state and local stakeholders.

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 engagements have helped CLP tremendously in understanding local circumstances as well as government and community perspectives. We are continually impressed by stakeholder enthusiasm for the idea of WHS and CDR, as well as their local knowledge with respect to WV siting options, wood sourcing, and potential deployment partners.

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

Robust and proactive public, community, and stakeholder engagement is a core CLP value. As WHS / WV scales to a higher volume of larger (100Kt WVU) projects, stakeholder engagement will need to be systematized and operationalized. Given CLP's partnership model, in many cases WV projects will be able to leverage existing community engagement e.g. in the case of partnering with a solar developer. CLP and project partners will center public engagement at an early stage of all deployment planning.

Engaging with government planners to understand and better quantify residual CWB feedstock availability in light of other biomass uses will be critical. CLP is already in close contact with the US Forest Service on this question, and this outreach will need to be replicated with other nations as WHS / WV scales globally.

7. Environmental Justice[3]

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

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

WV creates minimal negative externalities (outlined in Section 7b below), thus the primary environmental justice concern of this Potomac MRV Demonstration Project is to ensure it consults and benefits the local community and stakeholders. WHS and WV represent a compelling commercial opportunity for rural landowners, including small scale farmers, who can benefit from incremental income from carbon markets and potentially tax credits from the easements required for the long-term legal protection of WVs. Additionally WV construction

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

will inherently employ local workers and contracting businesses, so those economic benefits will stay in the community.

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

Several elements of environmental justice are critical to the implementation of any WV project. The first is economic justice. A WV 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 completely minimize environmental and ecological damage. This is achieved by measures like quality control of the residual CWB feedstock for burial in WVs, preventing contaminants from entering local soil or water systems; and careful site selection, site preparation, and WV construction to avoid erosion and minimize disturbance to soil carbon. The transport and excavation associated with any Wood Vault will be limited and temporary. WV only employs solid waste wood biomass (e.g. tree trunks and large branches) and thus would leave leaf and branch litter on the forest floor when working with forestry / timber projects to minimize nutrient export. WV otherwise creates no negative externalities.

8. Legal and Regulatory Compliance

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

We have not sought a formal legal opinion, however we have inquired regarding what permitting might be required to implement the proposed Potomac MRV Demonstration Project – see Section 8b below. More generally we have been advised that permitting regimes will vary somewhat widely by local jurisdiction, and from a project planning perspective to build 3-6 months into the project plan to secure the necessary approvals and permissions. CLP's plan to scale via project partners is likely to reduce the permitting challenge to some extent, in that partners like solar developers will already have a significant relationship with local government – and mine operators will typically already have the necessary permitting to fill mines with material in order to close them.

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

> The relevant code is in Charles County Division 1: Code of Public Local Laws, Chapter 133 Trash Disposal) (https://ecode360.com/26905357). For permitting to use land for wood burial, we will ask for a waiver of usual landfill permitting by arguing: 1) the material to be buried is non-toxic clean wood; 2) once securely buried, it's not a waste, but of value (carbon credit). Our inquiry indicates that such waiver will be approved on a case-by-case basis. We do not foresee major hurdles given the benign nature of the process. One USDA expert we consulted, who is familiar with the process, thinks a permit may not be necessary to bury wood on private property. Nonetheless, we do plan to ask for a waiver, which would create a precedent for future projects under this new technology. This permitting process will be carried out in collaboration with the ARM Group, an environmental engineering firm specializing in civil engineering projects.

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?

> N/A

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 WV, however we plan to coordinate the project with relevant local authorities and regulatory agencies. See (a) and (b).

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

> No.

9. Offer to Frontier

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

Proposed CDR over the project lifetime (tonnes) *(should be net volume after taking into account the uncertainty discount proposed in 4(c))*	2000 tCO_2e
Delivery window	By 12/31/2023

(at what point should Frontier consider your contract complete? Should match 1(f))	
Levelized Price ($/metric tonne CO_2) *(This is the price per tonne of your offer to us for the tonnage described above)*	$250/t$CO_2$e

Application Supplement: Biomass

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

Feedstock and Physical Footprint

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

> Residual coarse woody biomass (CWB) with a minimum diameter of 10cm.

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

> CLP's forthcoming Wood Vault Operating Protocol requires as feedstock unmerchanted residual (waste) CWB that would otherwise burn or decompose. We do not have formal supply agreements, however we have confirmed feedstock availability from a number of nearby sources, which are listed in the Addendum.

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

> For this 2Kt Potomac MRV Demonstration Project we anticipate that much of the CWB feedstock volume can accumulate at the project site for little or no cost by tree removal companies who would otherwise be delivering to nearby mulch facilities where they in many cases would be charged a tipping fee.
>
> CLP will supplement this volume as needed with dedicated transport from nearby feedstock partners. For the purposes of project costing and LCA estimates we are assuming an average transport distance of 40km (25 miles) for 3Kt of gross feedstock and $0.125/t/km. The

corresponding CO_2 emissions are calculated at $47tCO_2e$, 2% of net sequestered carbon. These calculations will be actualized during project CO_2 emissions and cost accounting.

Over the next decade, we expect per-t feedstock cost to decline with more extensive feedstock partnerships, economies of scale, operational learning, and intelligent siting of WV projects (to minimize feedstock transport cost and emissions). In the 2035-40 time-frame it is possible that these cost declines could cease, or possibly reverse somewhat, in the event of competition for residual CWB feedstock – which is the reason for the range of uncertainty for long-term minimum per-t cost of CDR via WHS/WV.

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

	Area of land or sea (km^2) in 2022	Competing/existing project area use (if applicable)
Feedstock cultivation	Zero. Waste wood does not use dedicated land	N/a
Processing	$4000m^2$ (0.4ha or 1 acre) for temporary feedstock stockpile	Land parcel with no current productive use.
Long-term Storage	1000 m^2 (0.1ha or ¼ acre) for 2Kt Wood Vault	Land parcel with no current productive use. (Can be repurposed after ~1 year for soil settling.)

Capacity

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

CLP's WV Operating Protocol requires the use of unmerchanted residual coarse woody biomass (CWB). Globally 1-2 $GtCO_2e/y$ (Zeng et al., 2013). US $200MtCO_2e/y$ (Perlack et al., 2005 – does not include fire-thinning, storm waste, and other potential sources).

Additionality and Ecosystem Impacts

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

The unmerchanted CWB residuals CLP uses as feedstock are either burned, mulched, or otherwise left to decompose *in situ*. In every case the constituent carbon is re-emitted in a short period of time, from immediate in the case of burning to a few years in the case of mulch. (To ensure additionality, the CLP WV Operating Protocol specifically precludes use of

CWB feedstock that would otherwise be destined for landfill, which can provide a more lengthy period of wood preservation.)

Counterfactual use of CLP's CWB feedstock is limited to mulch, which offers limited economic value that is far outweighed by the value of the CDR via WV.

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

CLP employs as feedstock unmerchanted residual coarse woody biomass (CWB) from forestry, real estate development, storm waste, or tree removal. Counterfactual baseline and alternative use are outlined in Section 6 above.

In terms of WHS/WV merits relative to other BiCRS methods:

- High operational TRL, ready to deploy at Mt scale in the coming years.
- *De minimis* capex. Low opex. (This proposed Demonstration Project is somewhat costly due to small scale, land purchase, and heavy investment in MRV. However we expect CLP and WV to be delivering <$100/t CDR within 2-3 years.)
- Distributed. WVs can be sited and constructed (site conditions permitting) proximate to feedstock in order to minimize transport costs and logistics.
- Very high carbon efficiency relative to biochar, bio-oil, and other biomass-based CDR methods that employ thermal conversion with no CCS.
- Relative to BECCS processes – higher TRL, far lower cost (capex and opex), not required to transport feedstock to a single centralized location, ready to deploy at scale in the immediate term.
- Relative to BiCRS methods that employ agricultural residues or residual fine woody biomass (leaf matter and twigs/branched <10cm in diameter) – which do not directly compete for CWB feedstock – WHS/WV create significantly lower risk of nutrient export. See Addendum for reasoning.

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

In terms of potential negative impacts:

- It is critical to limit feedstock to clean coarse woody biomass (CWB), as CLP's WV Operating Protocol directs, in order to avoid potential contamination of the soil surrounding the WV.
- Site-level erosion must be carefully considered and minimized during WV site prep and construction. For this reason the WV Operating Protocol directs that topsoil be carefully removed and stored separately from subsoil during WV construction, and then replaced over the WV's low-permeability subsoil cap. Disturbance to soil carbon must be monitored during the WV's first several years, however soil carbon will renew over time, can be supplemented if needed, and any carbon loss will be temporary.
- Methane generation is a potential concern with any sort of biomass sequestration. Lignin protects the CWB that is required by CLP's WV Operating Protocol from methanogens. Detailed reasoning with references in the Addendum.
- Competition with agriculture and other alternative use is a concern with land-based CDR approaches. WV is very spatially efficient (0.1MtCO_2e/ha), and after ~1 year of settling the land can be repurposed for agriculture, solar development, recreation, and other productive use.
- Nutrient export (from the biosphere to the geosphere) is a concern with any CDR via biomass sequestration. For reasons outlined in the Addendum this is not a concern for the WHS/WV method unless/until it comes to be practiced at intensive multi-Mt scale in a small geographic region. Such WV "mega-projects" will need to incorporate ecosystem level monitoring for N, P, and other key nutrients – however this is not an issue CLP expects to need to address this decade.