Lithos Carbon

Carbon Removal Purchase Application

General Application

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

Company or organization name

Lithos Carbon, Inc.

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

New Haven, CT; Atlanta, GA; Seattle, WA

Name of person filling out this application

Chris Reinhard, Mary Yap, Noah Planavsky

Email address of person filling out this application

[redacted]

Brief company or organization description

Low-cost and scalable CDR while improving crop yields

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.

Overview

Lithos deploys ex-situ carbon dioxide mineralization through enhanced rock weathering (ERW) on managed lands, with software for optimized deployment and novel, cost-effective empirical attribution. The process uses natural ground basalt as a catalyst for converting atmospheric CO_2 to dissolved inorganic carbon (DIC), which is transported to the ocean and remains stable for >10,000 years. Our partnered land managers accrue significant co-benefits, including crop yield increases of up to 40%, topsoil regeneration, improved soil moisture retention, enhanced drought and pest resistance due to silicate addition, and reduced CO_2 emissions from liming to regulate soil pH. We aim to establish a cost-effective and globally-scalable method that drives down the cost curve of ERW over time while concurrently improving food security and cropland health.

Location, timeline, and participants

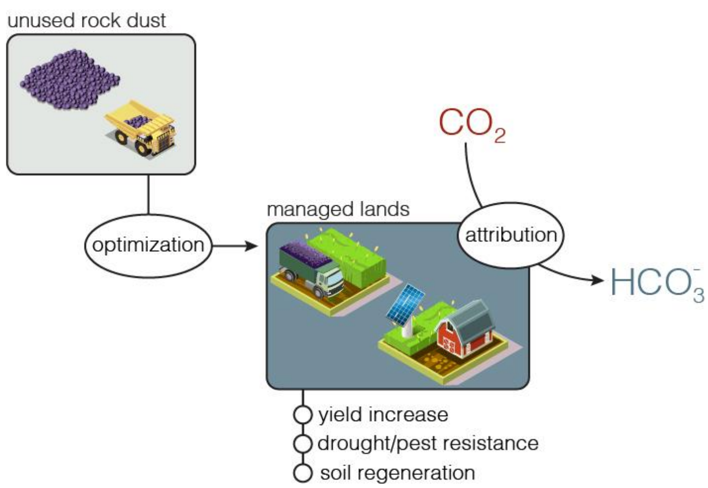


Fig 1. Schematic of our process

Basalt quarries for aggregate production generate two types of residues: (i) aggregates produced during crushing and milling operations, which are used as fine aggregates by the construction sector, and (ii) fines that remain from crushing and milling operations, which have limited commercial value as aggregate for construction. Data from operational basalt quarries abroad show that usable size fines can account for 18-20 wt% of aggregate production (but can be as low as 8 wt% for specialized production), and are commonly deposited in large quantities at quarries.

Basalt feedstock for our deployments in the upper Midwest is sourced in [redacted], and is transported largely via rail to minimize cost and CO_2 emissions during transport. Trucking is reserved for last-mile transport. This feedstock is derived from [redacted] and its removal and use in our deployment has the additional co-benefit of mitigating an existing environmental hazard in the [redacted]. Some feedstock for our Midwestern deployment may also be sourced from [redacted] via intermodal transport. Feedstock for deployment in the Southeast will be transported by rail and truck from [redacted], whose logistics and location eliminate first-mile cost and associated CO_2 penalty. Feedstock for deployment in the Northeast will be transported via truck from [redacted]. In these three cases basalt feedstock is derived from waste fines from construction aggregate production, initiating a circular economy and reducing additional energy costs (no mining, no grinding).

To reduce the carbon footprint of transport, we initiate engagements with farmers in proximity to feedstock sources. Our current focus has been on row-cropping agricultural systems in the Midwest. However, this year we will also deploy with additional crop types and pastureland covering diverse soil types and climates of the American Northeast and Southeast. In the Midwest, we will be deploying across multiple farms in Illinois (520 acres out of 5,960 acres available) growing row-cropped corn, soy, oats, hay, alfalfa, pasture, and assorted vegetables; with sugar beets in partnership with [redacted] (3 acres in systematic research trial plots); and across 300 acres of row crops, pastureland, and orchard in Wisconsin and Minnesota. In the Northeast, we are deploying 10 acres on a small farm, with additional acreage in the pipeline. In the Southeast, we are partnering with a farm in [redacted], GA (up to 2,400 acres) to deploy with row-cropped peanuts and sweet corn, with additional trial plots in managed forest acreage; and are in partnership talks with [redacted] and [redacted] for comprehensive deployment across the U.S. South and Southeast. In sum, we have access to 850 acres with a clear path to rapid increase. We are deploying in multiple regions to allow further verification of our process at scale in a diverse range of settings and promote future growth of this process in several regions.

Deployment in the Midwest and Northeast localities will occur in Spring 2022, with initial deployment in the Southeast in Fall 2022. Expanded deployment partnerships and a significant increase in acreage are expected for Spring and Fall 2023.

Technology: maximizing CO_2 removal/acre + cost-effective empirical validation
Our CO_2 removal process is highly efficient, cheap, and scalable. We deploy it using a reactive-transport geochemical model and isotope tracer process along with our in-house soil optimization software (see appendix).

1. Our soil model (SCEPTER) maximizes capture using each farm's soil, crop, and climate conditions.

2. Our novel tracer process empirically measures and validates carbon removal, and is the first cost-effective method to do so. (See documentation in 3e)

Feedstock application rates are optimized for every deployment site using our custom reaction-transport code for soil biogeochemistry (SCEPTER), which takes in local climatology and starting soil characteristics and provides a tailored feedstock application recommendation optimized for crop yield, CO_2 capture, and the target pH needs of crops planted. This approach minimizes the $/ton cost of CDR and reduces CO_2 penalties associated with unutilized feedstock transport or application. The model is predictive, maximizing affordable capture on each farm. Each site's soil data is fed into SCEPTER to generate recommendations and predict capture rates prior to deployment.

Soil sampling for empirical CDR attribution occurs at the beginning and end of each growing season to minimize attribution cost and logistical burden. Soil samples are analyzed for major and trace element composition using our novel isotope dilution "cocktail" technique that allows for extremely high precision analysis, resulting in a transparent and cost-effective quantification of basalt feedstock dissolution and CO_2 capture. We empirically validate CO_2 capture on each site (and compare CO_2 capture results with those of the adjacent control plot). On our largest-scale sites we also complete a series of gridded soil samples to a max depth of 1m, to further increase confidence in our attribution accuracy and representation. Soils are monitored for the loss of reaction products that correlate to trace elements in the basalt, and we have found that the vast majority of this carbon sequestration reaction completes within two growing seasons.

Co-benefits (economic and ecosystem)

- Although basalt has moderately lower CO_2 removal efficiency than olivine, it does not pose a risk of heavy metal contamination in crops and human systems (olivine has high Ni and Cr levels). In addition to being safer, basalt is also rich in macro- and micro-nutrients (incl. Fe, Mg, P, Ca, K, Mo). Basalt thus provides a steady nutrient flow to each field as it decomposes. Our 2021 live field trials demonstrated increases in crop yield between 4-47% dependent on crop type relative to control plots that are regularly limed.

- Studies have projected the economic impacts of basalt amendments: a conservative 5% yield increase in corn could be worth $3B *(Work by our collaborators at [redacted], to be published)*

- America is losing topsoil 10X faster than replenishment rates. Once basalt weathers it can help to reduce erosion, rebuild topsoil, and increase moisture retention.

- Increased crop resistance to pests, drought, and salinity due to dissolved silica (Si) release. Si helps build tougher leaves, stems, and cells, and increases protection against pests (Si is deposited as opaline phytoliths which are an abrasive deterrent). Increased Si uptake can lead to as much as 30% reduction in pupal populations of common crop pests, and also may decrease uptake of heavy metals.

- Silica stripping is a growing issue in croplands worldwide but Si fertilizers are beyond the means of most smallholder farmers; basalt amendments directly address this.

- Basalt addition may also decrease N_2O fluxes by 4-16%, in contrast to approaches aimed at building up soil organic carbon which lead to increased soil N_2O fluxes.

These benefits for yields and ecosystems may be even higher across depleted soils such as those in the rural Southeast (which we are piloting in Fall 2022).

CDR capacity and a path to multigigaton capture

Existing estimates of global CDR capacity through ERW indicate clear potential to achieve gigaton-scale capture in the coming decades. We have enrolled over >800 acres for an upcoming deployment, and our projected total capacity in 2022 is >1,500 tCO_2 captured and stored. We see a long-term path to $50-100/$tCO_2$ removed. By combining the best of engineering, nature, and cutting-edge agronomy, we believe we can offer one of the most cost-effective and scalable CDR solutions in the world, while simultaneously decarbonizing agriculture and addressing food security to meet the needs of a growing population. We are optimistic that by providing clear agronomic benefits and an economic incentive to farmers, there is strong potential for rapid growth in the deployment of this process without the large infrastructural investments required by most other CDR approaches.

By furthering our understanding of feedstock sources, drivers of unit costs, and levers to increase capture/acre, we hope to reach gigaton levels of CDR (Fig 2) in the next decade:

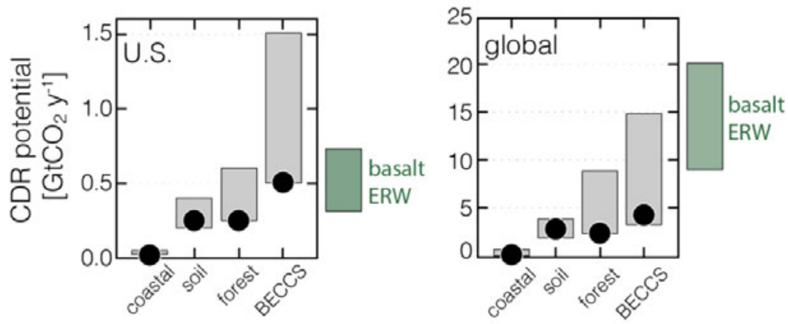


Figure 2. Regional (U.S.) and global estimates of CDR potential of enhanced rock weathering using basalt (green), compared to estimated CDR for a range of other proposed approaches. Other approaches shown include sequestration in coastal "blue" carbon ("coastal"), soil carbon sequestration in agricultural systems ("soil"), carbon sequestration associated with afforestation/reforestation and improved forest management practices ("forest"), and bioenergy with carbon capture and sequestration ("BECCS"). Grey boxes show ranges for estimated CDR potential, while filled circles show values determined to be "safe" — e.g., levels of deployment that would, with high confidence, not be expected to cause adverse societal, economic, and environmental impacts (in review).

Summary

With our in-house soil optimization software + cost-effective empirical attribution technique (MMV), we aim to establish a commercially profitable method that drives down the cost curve of ERW over time and improves crop productivity for growers. We've conducted live field trials to test our approach and have empirically confirmed our ability to sequester carbon: we've already captured 30t of CO_2 over the spring growing season of 2021. We capture ~1tCO_2 for every 3 tons of basalt applied (the vast majority of this max removal occurs over the first two growing seasons) and on average, each acre of farmland in the program captures 2.1tCO_2. This is based on a conservative application rate that we expect to improve with further optimization.

Agriculture and land use change is responsible for 20-25% of worldwide anthropogenic greenhouse gas emissions. Lithos is a compelling approach because it provides permanent, verifiable sequestration of atmospheric CO_2 while decarbonizing agriculture—and transforming the base of our food supply. Managed croplands worldwide are already equipped for frequent rock dust additions to soils, making rapid adoption at scale feasible.

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.)*

Carbon removal verifier and broker: We capture and remove carbon permanently, measure and validate the removal, and sell the carbon offsets.

Interface between source material and field: We source crushed basalt and transport it to field; recommend a custom application rate for each site; and quantify carbon removal and crop yield increases (reporting this back to the farmer and related partners).

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

1. Logistics: Logistics costs vary widely with season, availability of transport (e.g. barges unavailable in the winter), road conditions, trucking demand, and fuel prices.

2. Application rates: We are still fine-tuning our ideal application rate to maximize capture while optimizing crop yield. We are currently applying at conservative customized rates (avg 7t/acre/yr). However, our collaborators at [redacted] and [redacted] have applied high annual rates ([redacted]) in specific systems on long-term (>6 years) study farms with no adverse crop impacts. Our own fieldwork has indicated parabolic behavior where certain crops respond better to higher applications than others; the highest applications (24t/acre) still generate increased yields relative to a control. We expect geographic variation as well: the U.S. Southeast may be primed for higher application rates due to nutrient-stripped and acidic soil conditions.

3. Feedstock supply: We are not currently supply-limited, but might become so at high volumes (see Appendix, part i: we expect this to occur only beyond the ~40 – 60 $MtCO_2$/year scale).

To address issue #1, we hope to develop regional stockpiles and pursue strategic distribution partnerships to minimize inefficiencies.

To address issue #2, further experimentation is underway and we have begun strategic research in partnership with [redacted] and other stakeholders. These experiments will include plant tissue safety tests at harvest and economic assessments for higher application rates.

To address issue #3, in the case of an unexpected material limitation we may require the acquisition of in-house crushing equipment or contracting additional basalt fine production. Beyond the 40 – 60 $MtCO_2$/year scale, if we were to contract for basalt fines as a commodity, we expect that prices might be in the $11-$18/t range (this is the range quoted by our suppliers for their commoditized, salable rock gravel products today).

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

- Zenodo release contains the LICENSE file via which we retain sole copyright.

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?

Our team includes two world-class geochemists who have leveraged their extensive experience to design novel methods to quantify and maximize affordable carbon removal, as well as a former tech founder with experience deploying software at global scale.

Dr. Noah Planavsky is Associate Professor in the Department of Earth and Planetary Sciences at Yale University. He's the Director of the Yale Metal Geochemistry Center and on the steering committee for the Yale Center for Natural Carbon Capture. He's spent 15+ years on the leading edge of carbon cycle research, leveraging field studies, analytical chemistry, and novel

isotope systems to investigate Earth's Carbon cycle, and has published >150 papers in high-impact journals (15,000 citations). He's spent the last 4+ years inventing Lithos' isotope dilution technology to enable cost-effective verifiable carbon extraction in soil. Dr. Chris Reinhard is an Associate Professor in the School of Earth and Atmospheric Sciences at Georgia Tech, with 15+ years of work aimed at understanding global carbon, oxygen, and nutrient cycling, deploying enhanced rock weathering as a CDR strategy, developing novel techniques for solubility trapping of atmospheric CO_2, and evaluating CDR potential and ecological consequences of ocean-based CDR. Chris spent the last 4+ years building Lithos' software for predictive optimization and verification of carbon removal. On the operational side, Mary Yap comes from 6+ years of experience leading product and sales strategy for venture-backed startups (founding team, FamilyLeaf; product director at Tilt (expanded to 8 countries, acq. by Airbnb), both Y Combinator W12). Mary holds a B.S. in Earth and Planetary Sciences from Yale University, where she won the department's top student prize. Her past research focused on developing climate models (published) and urban field research on environmental sustainability, systems of waste, and networked energy usage. Not only have Chris and Noah been building this work over the last decade, but their rigorous geochemical expertise and software expertise give us an edge in finding levers to increase CDR efficiency, as well as rigorous research angles to constrain uncertainties as we deploy in novel conditions. We believe this advantage will help us revolutionize the landscape of certifiable ag carbon capture. Noah's and Mary's families hail from generational crop and vegetable farmers (across the American Midwest and Southeast Asia, respectively), giving the team unique on-the-ground insight and sensitivity to smallholder grower needs as we scale operations. As we work towards decarbonizing food systems and transforming one of the most promising forms of carbon capture, we are urgently looking to recruit a policy specialist who can navigate uncharted territory of federal subsidies and carbon market incentives (which will drive down ERW costs and improve scalability), and a logistics specialist who can help us efficiently deploy to new regions.

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

a. Please fill out the table below.

	Timeline for Offer to Stripe
Project duration *Over what duration will you be actively running your DAC plant, spreading olivine, growing and sinking kelp, etc. to deliver on your offer to Stripe? E.g. Jun 2022 - Jun 2023. The end of this duration determines when Stripe will consider renewing our contract with you based on performance.*	**Delivery:** May 2022 — May 2024 **Renewal evaluation:** December 2023

When does carbon removal occur? *We recognize that some solutions deliver carbon removal during the project duration (e.g. DAC + injection), while others deliver carbon removal gradually after the project duration (e.g. spreading olivine for long-term mineralization). Over what timeframe will carbon removal occur?*	May 2022 — May 2024
Distribution of that carbon removal over time *For the time frame described above, please detail how you anticipate your carbon removal capacity will be distributed. E.g. "50% in year one, 25% each year thereafter" or "Evenly distributed over the whole time frame". We're asking here specifically about the physical carbon removal process here, NOT the "Project duration". Indicate any uncertainties, eg "We anticipate a steady decline in annualized carbon removal from year one into the out-years, but this depends on unknowns re our mineralization kinetics".*	Removal begins immediately after application (Spring 2022), but accrues through multiple growing seasons (up to 2 years, or 3 years conservatively). Based on our ongoing live field trials we anticipate ~70% of removal to occur in the first three growing seasons (Spring/Fall 2022, and Spring 2023), and the remaining ~30% to occur between Fall 2023-Spring 2024.
Durability *Over what duration you can assure durable carbon storage for this offer (e.g, these rocks, this kelp, this injection site)? E.g. 1000 years.*	Oceans (45%): 10,000+ years Sediments (45%): 1,000,000+ years Rivers/estuaries (10%): 5-10 yrs* **Some river leakage will be present across all ERW approaches, regardless of source material/style, and is not unique to our process.*

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

Number/range Sediments — 1,000,000+ years Oceans — 10,000 - 100,000+ years

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.)*

Ocean storage timescales are based on standard estimates of the ocean carbonate compensation response. Sediment storage is based on the residence time of inorganic carbon in Earth's rock cycle.

It is possible that some downstream leakage of bicarbonate back to CO_2 will occur in any ERW deployment, but the magnitude and timescales of this are not well-constrained in today's literature. Our team's ongoing work on riverine bicarbonate transport and downstream degassing in the coastal ocean (e.g., Kanzaki et al., *In review*) includes a novel coupling of USGS gauging station data to catchment alkalinity fluxes within a biogeochemistry model and indicates that only ~10% of initially captured carbon will leak back into the atmosphere. Some of this may occur on timescales of ~5-10 years, but much of it will likely occur on longer timescales including those linked to groundwater storage (up to 10,000+ years).

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?

The principal durability risk for ERW is downstream leakage of carbon captured as bicarbonate back to atmospheric CO_2. This can be considered a "geochemical risk" and our mitigation of this durability risk involves using a data-constrained model to explicitly calculate downstream carbon leakage (see Sec. 3e). By design, our process leverages logistical and management practices and infrastructure already well established in the agricultural system, limiting the fundamental uncertainty in our underlying technological processes.

Physical and socioeconomic risks are minimal for ERW given the minor lifecycle emissions associated with feedstock transport and application (see Sec. 4).

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.)*

End-to-end monitoring of river/stream/estuary carbonate chemistry and CO_2 degassing would be impractical and prohibitively expensive. Our approach toward evaluating overall CDR durability is the development of a novel analytical pipeline that links USGS river/stream monitoring infrastructure (Zhang et al., *In revision*) with an Earth system model (Kanzaki et al., *In review*). A given deployment of ERW is modeled as a catchment-specific alkalinity flux that is incorporated into USGS gauging station data and pushed through a river network to the coastal ocean, and then coupled to a 3-D ocean biogeochemistry model. Carbon fluxes and leakage timescales are tracked explicitly throughout the transport continuum. However, we do not include downstream carbon leakage in the lifecycle of our offer to Stripe because the timescale over which this leakage emerges is longer than the duration of our offer (Sec. 2c).

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	1,024 tCO_2
If applicable, additional avoided emissions e.g. for carbon mineralization in concrete production, removal would be the CO_2 utilized in concrete production and avoided emissions would be the emissions reductions associated with traditional concrete production	563 - 1,126 tCO_2 | Assumes basalt replaces ongoing agricultural liming on the same acreage at twice the tonnage (see Sec. 3b) and a range of emission factors (EF) between 0.5 - 1.0.

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)*

We can use a modified Steinour formula to estimate the CDR potential of our basalt feedstocks (CDR_{pot}, in $kgCO_2$ per ton of feedstock) based on major oxide composition:

$$CDR_{pot} = \frac{M_{CO_2}}{100} \cdot \alpha \frac{CaO}{M_{CaO}} + \beta \frac{MgO}{M_{MgO}} + \varepsilon \frac{Na_2O}{M_{Na_2O}} + \theta \frac{K_2O}{M_{K_2O}} \cdot 10^3 \cdot \eta$$

M_i terms refer to molar masses, while CaO, MgO, Na2O, and K2O refer to abundances of major oxides in the feedstock. Scaling parameters (α, , ε, θ) are pH-dependent and will have a value of 1.0 across the conditions implemented in our process. Our current feedstocks yield values of 300 - 330 $kgCO_2$ per ton of feedstock, which is typical for basalt. We assume a very conservative CDR of 200 $kgCO_2$ per ton of feedstock which together with a planned deployment of 5,120 tons of basalt feedstock yields a total gross CDR of 1,024 tCO_2.

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

We have 5,940 tons of basalt feedstock in the pipeline for the next growing season, of which 5,120 tons are earmarked for this offer. This corresponds to roughly **1,024 tCO_2** of gross CDR according to the assumptions outlined in Sec. 3b.

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.)*

Through prior pilot deployment and empirical measurements of CO_2 capture, we have ground-truthed our capacity for CDR. In 2021, we deployed at farms across the Midwest to further calibrate our predictive models, gain a better understanding of site-specific parameters influencing capture, and empirically measure the amount of captured and sequestered carbon.

We are currently limited by deployment acreage and operating capital rather than feedstock supply. Deployment for this offer will cover ~850 acres, and we hope to expand to ~4,700 acres in 2023 and to 5-10X that coverage in 2024. Combined with the above (conservative) assumptions, this would correspond to ~10,000tCO_2 and ~50,000 - 100,000tCO_2 of gross CDR in 2023 and 2024, respectively. This estimate is in line with empirical results from our field trials in 2021, which yielded CDR rates between 0.4 and 8.1 tCO_2 per acre per year, which are comparable to estimates from our custom soil biogeochemistry model.

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.

Up to 5 links

- Link to brief description of our in-house soil optimization software: [Code release for SCEPTER v0.9]
- Description of our isotope tracer technique for cost-effective empirical attribution:

Technique and demonstrated match between model output and ground-truth data

(Our technology guarantees permanent, empirically verified capture of CO2. We've developed a novel methodology to measure the amount of CO2 captured and sequestered by leveraging trace elements in soils.)

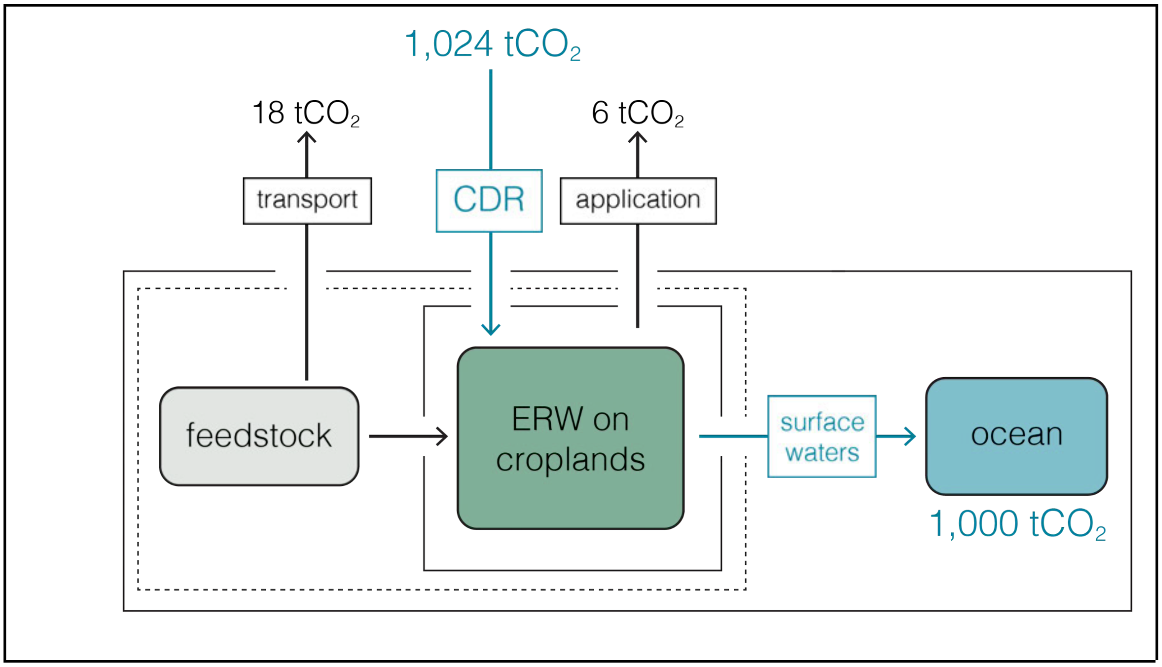
- ERW in cropland background described in Beerling et al. (2018)
- Link to private appendix information for this offer

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	1,024 tCO_2
Gross project emissions	18 tCO_2 (feedstock transport) 6 tCO_2 (feedstock application) = 24 tCO_2
Emissions / removal ratio	0.02 (benchmark, emissions-based)
Net carbon removal	1,000 tCO_2

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?

Our initial life cycle includes CO_2 emissions from feedstock transport (boat/rail/truck) and diesel emissions from feedstock spreading, balanced against gross CDR during ERW on croplands. For managed lands on which we substitute basalt application for ongoing agricultural liming it could be argued that the transport/application emissions do not represent an additional CO_2 burden imposed by our process. However, we include them here to be conservative. We are currently sourcing stockpiled and waste basalt with no additional processing or grinding, so energy/emissions at the point of harvesting are currently negligible.

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.

Last-mile trucking distances and upstream barge and rail transport distances are known definitively for all localities in our deployment, as are tonnages transported in each case. We use rail and truck CO_2 emissions of 0.0121 and 0.0181 $kgCO_2$ per ton per km (see here), and assume CO_2 emissions from barge transport are negligible. We also assume diesel emissions from feedstock spreading are 1 $kgCO_2$ per ton of feedstock (see here). Gross CDR is calculated as described in Sec. 3b based on the chemical composition of our feedstocks and the tonnage deployed.

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.

Our initial life cycle analysis is consistent with existing estimates of the CO_2 penalties associated with feedstock transport and application. However, we will pursue a third-party LCA tailored to our specific deployment conditions with Lifecycle Environmental Impact Footprinting (LEIF).

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)*

Our unit of deployment is tons of crushed basalt. This unit drives logistics planning, deployment cost, and capture volumes. Deployment cost decreases with economies of scale, as we are able to leverage more economical transport methods, procurement volumes, and deployment planning.

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
2022	5,900t basalt (planned this spring)	Material: $0 to $8.90/ton (direct from quarries) Transport: $6.75 to $109/ton (highest end from 2022 fuel surcharges)	0.2 - 0.3tCO_2 removal per 1 ton basalt applied	*<50 words* Deployment and further optimization
2021	151t basalt	$30,442.52/ton (including material and very distant transport)	0.2 - 0.3tCO_2 removal per 1 ton basalt applied	*<50 words* Initial pilots on real farms
2020	0	—	—	—

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.)*

We have reduced feedstock cost by sourcing from quarries rather than third-party suppliers and decreased transport costs by locating quarries/waste fines near our farmland. In moving from pilot-scale to 2022's larger-scale deployment we are able to leverage rail, intermodal, and over-the-water bulk shipping volumes, which are more economical.

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)
5,120	0.3tCO_2 removal per 1 ton basalt applied (to 0.2tCO_2 with inefficiencies)

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?

For 2022 season: $40-$330/t CO_2 *(varies by proximity of field to feedstock, fuel price hikes, and availability of seasonal transport)*

(material + transport cost)/t * unit gross capacity

Variance is transport-driven and includes cost hikes due to Spring 2022 fuel prices and winter shipping bottlenecks. >95% of capture costs come from transport. 1 ton of basalt is needed for ~0.3 tons of CO_2 capture, and at higher regional deployment volumes we are able to take advantage of bulk transport by freighter (5,700t minimum), boat (3,500t min.), and rail (1,500t min.). In future seasons we hope to further reduce expenses by avoiding early spring/late fall shipping peaks. Logistical cost can fall as much as 40% if we ship next year's feedstock during the low seasons, but this requires enough upfront capital and reasonable estimates of the subsequent cycle's feedstock demand.

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.

We include in costs:

- Feedstock costs
- Transportation to field
- Spreading/labor cost for the few farms who rent spreading equipment (vast majority of our farms have their own equipment)
- There are also weather delay surcharges and significant fuel price increases, which are driving up costs in April/May 2022 across the Midwest

We do not include:

- R&D
- Labor for sampling
- Sampling and verification
- Grinding costs (we are not grinding for our 2022 deployment)

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.

Goals:

- <$100/t CO2 removal at the Megaton scale
- Reliable <$50/t CO2 removal at the Gigaton scale (see ag lime note*)

**Note*: As a point of comparison, agricultural limestone dust (which is often also a waste product) regularly goes for $12.25-$25.00/ton *including* transport to the field. This is made possible by federal subsidies and the work of distribution chains that transport limestone at high volume to co-op stockpiles/larger farms. If basalt were to go at similar prices, we could reasonably achieve a ballpark of $40-$75/t CO_2 removal across the USA.

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)

In order to achieve a long-term cost of <$100/t$CO_2$, we need to lock in low commodity prices for basalt and develop our ability to stockpile feedstock at lower transport prices. A primary assumption is that we will be able to continue to use the waste basalt suppliers we have located near farmland (see Appendix) — and that we will be able to optimize transport to reach far-flung aglands in the future. We have begun to explore this and have learned that signing transport contracts at higher volumes (repeat contracts) or intermodal (reduced labor) can slash prices as much as 40%. There are discounts if we can afford to wait and negotiate empty bulkheads or leftover space in long-distance rail cars for later shipment. This year's assessments of safety at high application rates will also help increase efficiency of bulk transport to the field (fewer custom transports + capture more carbon per acre). Working with larger deployments (1,000+ acres/grower) will also decrease one-off transports. Order-of-magnitude increases in volume have nonlinear impacts for lowering unit costs.

Transport becomes a chicken-and-egg problem at some point: due to winter shipping premiums, stockpiles need to be established in advance of the upcoming spring's deployment. But upfront cost of capital is a barrier, and we need to establish demand; preselling offsets to VCM purchasers would help us achieve this. Ongoing purchase agreements could help our prices come down the cost curve and help us achieve an average \$100/tCO2 cost. (For a reliable \$50/tCO_2 cost, we may need federal incentives/subsidies on basalt or avoided liming emissions)

Today's scaling strategy relies on partnering with large farms that can expand their initial ~50-80 acre pilots to 500-2,000 acre deployments in upcoming seasons. Due to significant co-benefits (lime savings, crop yields) and free upfront cost of our program, we are currently receiving inbound farmer interest. However, farmer acquisition will likely become a bottleneck as we try to scale new regions and 5-10X annual deployment volumes.

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

In a worst-case scenario, we would expect a range of \$300/t – \$600/t, driven by:

- Transport: Rising fuel prices, supply chain shortages, or labor shortages
- Disappearance of waste fines: A worst-case scenario would include a sudden halt in demand for basalt construction aggregates, ending business-as-usual basalt waste fine production (in this scenario, after historical waste stockpiles run out Lithos would have to contract quarries/vendors for dedicated crushing) But existing projections of steel/cement production (which are decent proxies for aggregate production) are globally through the roof leading up to 2100, even in the U.S.; thus, we expect that waste fine production is likely to increase significantly in the coming decades.
- Complete saturation of deployment farmland near strategic quarries, and thus higher transport costs to reach distant farmlands (it should be noted that far-flung farms are still able to tap into affordable ag lime prices today, due to regional stockpiles at co-ops and maintained by empty rail cars/freighters loaded in low-seasons)
- If we had to buy and operate our own crushing equipment due to inadequate waste

fine production or to reduce reliance on existing operations (the equipment side could cost $400k USD/crusher, amortized)

In all of these cases, there is a tradeoff where economies of scale and established demand with lead-time enable more efficient production and transport of the material.

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	Deploy ~800 acres covering diverse conditions + new crops; scaling capture to >1,000t CO_2	We've deployed real world pilots (>40 acres in the Midwest in 2021). The 2022 deployment will allow us to analyze behavior across a broader range of crops, soil types, management practices. This vital data will help us tailor implementation rates and processes. We will engage with more partners in this cycle, enabling a deeper understanding of stakeholder concerns and benefits as we scale up capacity. This will include a significant uptick in logistics volume relative to our pilot. This experience is critical if we are to overcome logistical challenges. To start, we will be leveraging more optimal bulk transport. We will be able to calculate LCA as well as ROI/unit costs for the end-to-end commercial process.	Deployment Q2/Q3 2022 *Crop yield data:* *Q3 2022/Q1 2023* *CO_2 removal validation:* *Q3 2022-Q4 2023* *LCA calculation:* *immediately following deployment* *ROI calculation:* *following validation*	Lithos can provide photos of deployment, experimental data from soil samples, ongoing data on yield and CO_2 removal, and descriptions of the LCA/ROI.

2	Scientific report on sampling resolution, estuary/river leakage, and metal content monitoring.	Trustworthiness and attribution confidence are critical to scale up the method. We aim to demonstrate the reliability of our sampling density; demonstrate a constrained understanding of river leakage for LCA calculations; and the safety of this method at high application rates for soils and crop tissues.	Q1 2023	We will gather monitoring data and modeling over Q3/Q4 2022 in partnership with our research institutions and co-op research partners, and provide reports/papers describing our learnings.
3	Land strategic partnerships for feedstock distribution + partnerships for farmer deployment.	Farmers already rely on existing distribution networks for other rock dusts and fertilizers. We've consulted advisors who are deeply embedded with fertilizer distribution networks to confirm that leveraging these systems will drive down our in-house costs and inefficiencies. We also hope to work closely with regional co-ops which conduct [rigorous tests]() of seed strains, new fertilizers, or new management practices (such as [redacted]). The co-ops validate ROI of new practices via rigorous field tests, then recommend/ distribute within a network of growers. This strategy will enhance the rigor of our experiments, build local trust, and accelerate the speed of deployment across strategic regions.	Q1/Q2 2023	Lithos can share documentation of agreed-upon partnerships and trials with local distributors and co-op networks.

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	1,024 tCO_2/year	5,000 tCO_2/year	Knowledge gathering to enable deployment across further crops, systems, soil types, and climates. The data we gather on removal rate and yield increases will improve our ability to onboard additional farmers and partners.
2	1,024 tCO_2/year	>5,000-10,000 tCO_2/year	The scientific investigations will bolster our ability to safely deploy with high safety confidence, and with certainty around ROIs, efficiency, and the lifecycle of carbon removal. Being able to point to a technical assessment of leakage risk should bolster uptake of this ERW offset.
3	5,000-10,000 tCO_2/year	>10,000-100,000 tCO_2/year	By leveraging existing ag distribution networks (e.g. for lime/other rock amendments) we can cut out the bespoke aspect of delivery and hopefully enable more efficient transport. By partnering with co-ops and carbon consultants (trusted sources of management practices), we hope to onboard farmers more quickly and plug into the network effects of regional focus.

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	*Should match 6(a)* ~$40-$330	~$40-$330	No change in expected costs until higher volumes and lead times have been achieved.
2	~$40-$330	~$40-$330	Our refinement of sampling density could help drive down costs (if we are able to prove less need for high-density sampling)–but only marginally. Main cost reduction will need to come from transport.
3	~$40-$330	Target of ~$40-$150 in near-term	Cost reduction is driven by economies of scale, ability to predict next year's feedstock demand, and ability to stockpile accordingly.

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

We would ask the federal government to broaden 45Q to include ERW on croplands and build in incentives similar to biochar today. This would set the stage for high capture volumes and act as a platform for expansion. We would also ask the USDA to consider decreasing the ag lime subsidies (an established CO2 emitter) in favor of basalt (which acts as a direct stand-in for pH balance while generating safe carbon removal).

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

1) Connections to ag distributors to efficiently transport material; 2) introductions to major retailers who are connected to vast farmlands for deployment and are committed to reaching net zero by 2040/2050 (Frito-Lay, PepsiCo, General Mills); 3) media coverage that highlights the potential for high-quality soil carbon offsets through ERW in contrast with poor accounting in other soil carbon practices today.

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.

> In our early stages of scaling this effort, we have proactively gathered input from our farmers as well as a number of regenerative agriculture groups, rural development organizations, and ag think-tanks across the Midwest and Southeast (including [redacted], [redacted], [redacted], [redacted], [redacted], [redacted], [redacted], and growers' co-ops). These collaborators are plugged into the broader community, and our engagement with them focuses on education and gathering opinions or potential concerns from the get-go. This has become a valuable inbound channel of new growers and source of deeper understanding of grassroots practices, conservation management strategies, and regional environmental challenges (such as growing pest populations or water use needs) that Lithos can help address. This has already led to a deeper understanding of localized crop and farmer needs in terms of pH and rotation, which has led us to implement additional optimization packages in our software. We will continue to iterate our software and deployment recommendations through ongoing dialogue. Many of our partner organizations focus on socioeconomic equity for diverse or rural farming communities, which we are eager to engage further with. To speed community input, we openly share crop yield and carbon capture results with each partner and farmer in our program.
>
> On the feedstock end, we focus on suppliers with existing low-carbon-footprint transport. We have dialogues with each supplier/quarry to learn about their waste management practice and any additional overhead needed to excavate their waste fines. We are in contact with the [redacted], and are starting a dialogue about how removal of basalt [redacted] from the [redacted] may address [ecosystem degradation]() and support [redacted].
>
> As we scale we plan to further engage with government entities and partner with strategic ag conservation platforms who may help us scale up adoption and understanding of diverse managed lands.

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

We engage with stakeholders in-house. To further on-the-ground education, transparency, and dialogue, we're also working towards live demonstrations and field days in partnership with [redacted] and [redacted]. Many of our partner farms are on the leading edge of conservation and actively build relationships within the local community, helping to direct input back to us. We have consulted with land grant universities and extension services to keep an ear on the ground with respect to the latest crop/soil science, and to better serve the community. We plan to collaborate with a policy advisor to broaden our advocacy efforts and engage with government entities.

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

We've learned that there's a growing demand for carbon conservation practices as an additional revenue stream. However, growers are hesitant to adopt new practices until there is a way to tap into VCM purchasing. By engaging with the Stripe purchasing program we hope to validate this high-confidence removal method and open up a high-value revenue stream for farmers. **Many soil carbon offsets are conducted with low rigor, posing a challenge to trust in the field.** To this end, we aspire to **rigorous scientific standards (field-wide sampling, sampling fidelity, and novel monitoring of downstream leakage; in addition to models).** To address crop-specific growing needs, we've recently implemented new add-ons in our software to achieve narrow pH ranges for complex growing situations.

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?

As we scale in new regions, we plan to establish long-term collaborations with environmental justice organizations (focused on J40 goals and economic opportunities for rural farmers) and identify co-ops that are strategic centers for education and deployment of conservation practices. Public stakeholders are eager for amendments to improve croplands that degrade ecosystems (i.e. [redacted]) and we are eager to identify synergies. As we deploy with crops that thrive under higher basalt rates (i.e. acidic starting soils coupled with higher target pHs), we will conduct plant tissue and soil sampling to ensure safety and trust every step of the way. This is a small overview of projects in our queue.

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?

All approaches toward CDR have environmental justice dimensions that must be thoughtfully navigated in order for CDR to become a meaningful component of a just transition. In the case of ERW, the primary potential environmental concerns are heavy metal release and the environmental footprint of feedstock harvesting. There is an additional broader social justice issue associated with equitable access and partnership, as our approach will provide a significant source of potential revenue and jobs for rural areas when deployed at scale. Key stakeholders include growers, agricultural co-ops, aggregate producers, government agencies (USDA), and local communities proximate to deployment sites.

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

Our feedstocks have comparatively low metal content and release potential, and we will monitor the potential for metal release throughout our deployment. Because our feedstocks are sourced largely from existing environmentally damaging waste or from waste fine production in existing quarries, the additional environmental footprint of feedstock harvesting for our process is minimal. The harvesting of one of our principal feedstock sources essentially represents a mitigation effort that will restore aquatic habitats [redacted] (see above). We are particularly excited about partnering with the local [redacted] in this effort to turn an existing environmental hazard into megaton-scale CDR.

We envision our approach as providing a significant new source of revenue and jobs for underserved rural communities, and are committed to ensuring that the financial and environmental co-benefits of our approach are equitably distributed. This can only be achieved by staying connected to our grower partners on the ground and the local communities in which they are embedded. As we continue to scale, we plan to engage in partnership with environmental justice organizations that focus on concerns facing rural communities (and with an eye to the J40 goals), and to partner with agricultural co-op organizations and other groups that are striving toward socioeconomic equity and environmental justice for diverse and rural communities (such as the [redacted] initiative).

9. Legal and Regulatory Compliance (Criteria #7)

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

We have not formally engaged specific legal counsel vis-a-vis regulatory compliance.

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.

Deployment of ERW on privately owned cropland and range/pasture lands does not currently require any specific permitting. We will remain in compliance with the National Ambient Air Quality Standards (NAAQS) established by the EPA for for PM2.5 and PM10, and with the

recommendations and stipulated permitting guidelines for heavy metal abundance in the Clean Water Act (CWA). Ground basalt is currently already listed as approved by the Organic Materials Review Institute (OMRI), which regulates products for use in certified organic growing operations under the USDA National Organic Program.

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?

One potentially relevant regulatory framework is the Convention on Biological Diversity (CBD), an international protocol associated with the United Nations Environment Programme (UNEP). Although there is no specific guidance in the convention regarding ERW, there is some rhetoric related to a broader class of practices that might fall under the label of "geoengineering." However, the U.S. is not a formal party to the CBD.

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.

Although there is currently no legal or regulatory framework that is specific to ERW, existing environmental guidelines for air and water in the U.S. provide a useful framework for maintaining minimal negative environmental impact of ERW deployment. One particular area of uncertainty with relevance for deployment of ERW at scale is how waste fines from aggregate production interface with the EPA Resource Conservation and Recovery Act (RCRA), which gives the EPA authority to control the life cycle of hazardous and non-hazardous waste.

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)

N/A

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*	1,000 tCO2

Delivery window *at what point should Stripe consider your contract complete?*	**Delivery:** May 2022 — May 2024 **Renewal evaluation:** December 2023
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.*	*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).* \$500/tCO_2 *We have added a buffer to the costs described in (6) to account for (by priority):* 1. *Splitting revenue with farmers (beyond covering operational costs).* 2. *Additional rigorous research including [1] full cycle alkalinity attribution using downstream DIC monitoring of river network for any leakage (as described in Sec. 2c/2e), [2] additional gridded sampling to further constrain minimum bounds of sampling resolution for high-fidelity empirical verification, [3] additional crop tissue sampling and tests as part of rigorous metal safety assessment.* 3. *Cost of labor and delivery in partnered co-op trials which do not have economies of scale* 4. *Uncertainty in last-mile transport costs (rising fuel prices and labor costs in last-mile transport)*

Application Supplement: Surface Mineralization

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

Source Material and Physical Footprint (Criteria #1 and #8)

1. What source material are you using, and how do you procure it?

Our process uses natural basalt powder as a feedstock. Current feedstock sources include unused (waste) mining [redacted] and waste fines from the production of construction aggregate.

2. Describe the ecological impacts of obtaining your source material. Is there an existing industry that co-produces the minerals required?

Our current feedstock supply chain has minimal ecological impact, as it leverages unused (waste) basalt powder from previous mining efforts and ongoing aggregate production for the construction industry. Our deployment of [redacted] basalt results in an important environmental/ecological co-benefit by mitigating an ongoing sedimentological disruption [redacted].

3. Do you process that source mineral in any way (e.g grinding to increase surface area)? What inputs does this processing require (e.g. water, energy)? You should have already included their associated carbon intensities in your LCA in Section 6.)

We do not currently process our source material, which minimizes energy/water use and associated cost/CO_2 penalties for the overall process (see above). However, we will continue to explore the cost/benefit of additional grinding for future efforts in parallel with deployment during the 2022/2023 growing seasons. In particular, we are currently developing a platform for estimating the energy/water/carbon impacts of grinding feedstock to increase surface area based on regional data for carbon intensity and energy cost.

4. Please fill out the table below regarding your project's physical footprint. If you don't know (e.g. you procure your source material from a mining company who doesn't communicate their physical footprint), indicate that in the square.

	Land area (km^2) in 2021	Competing/existing project area use (if applicable)

Source material mining	N/A (material is waste product from quarries with a total area of 1.6 km^2, and harvested waste from 0.3 km^2 of [redacted])	Non-competitive area — Existing quarries for basalt (waste fines); stockpile of legacy mine waste ([redacted])
Source material processing	The processing of waste fines occurs within the existing footprint of the quarry (see above).	Non-competitive area — Existing quarries for basalt (waste fines); stockpile of legacy mine waste ([redacted])
Deployment	850 acres (~3.4 km^2)	Non-competitive — Will remain agricultural land

5. 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)**
Source material mining	*700 – 1,000 km^2 **Note: Assumes waste fine production and footprint from one of our suppliers, scaled to between 20-30% CDR efficiency; will be less if quarries are established specifically for ERW deployment*	Non-competitive area up to a capacity of roughly 60 – 90 Mt/yr; beyond this will need to either source additional construction waste or establish new quarries exclusively for ERW efforts
Source material processing	Same as quarry footprint	(See above)
Deployment	50 – 100 million acres (~200,000 – 400,000 km^2)	Non-competitive — Will remain agricultural land

6. If you weren't proceeding with this project, what's the alternative use(s) of your source material? What factors would determine this outcome? *(E.g. Alternative uses for olivine include X & Y. It's not clear how X & Y would compete for the olivine we use. OR Olivine would not have been mined but for our project.)*

Our feedstock sources upcycle waste basalt from legacy mining and aggregate quarrying, which would otherwise remain stockpiled *in situ* (as it historically has at these sites). Some quarries currently sink their basalt waste fines in industrial ‘ponds’ for easy storage and compaction. Our project makes better use of this material while reducing the waste footprint.

Measurement and Verification (Criteria #4 and #5)

7. We are aware that the current state of the field may include unknowns about the kinetics of your material. Describe how these unknowns create uncertainties regarding your carbon removal and material, and what you wish you knew.

The maximum CDR capacity of our feedstocks is well-understood and easy to estimate based on standard geochemical characterization (Sec. 3b). However, the extent to which this maximum capacity can be achieved under different deployment regimes and land management styles is a significant unknown. A key uncertainty is whether we can promote significant feedstock dissolution and CDR on lands that are not actively tilled (this changes soil kinetics). For instance, there are currently ~396 million cropland acres in the contiguous U.S., but an even larger area (~474 million acres) is classified as range, pasture, and forested lands (not regularly tilled). Assuming a conservative gross CDR of ~1-2 tCO_2 per acre per year (see above), widespread implementation across both types of managed land could yield total gross CDR between 0.9 – 1.7 $GtCO_2$ per year for the U.S alone. We are currently exploring the CDR capacity of pasture land in new 2022 field trials and model simulations.

8. If your materials are deployed extensively, what measurement approaches will be used to monitor weathering rates across different environments? What modeling approaches will be used, and what data do these models require?

We have developed a novel isotope-dilution technique for cost-effective measurement of feedstock dissolution. This approach reliably and empirically quantifies overall CDR in a given deployment. We combine this with our custom soil biogeochemistry code to definitively allocate carbon throughput in the system between dissolved inorganic carbon species, organic carbon, and secondary mineral phases. Our model pipeline requires standard pre-deployment soil characteristics (e.g., cation exchange capacity, CEC), local climatology (temperature, rainfall), and management practice (e.g., tillage).

Human and Ecosystem Impacts, Toxicity Risk (Criteria #7)

9. What are the estimated environmental release rates of heavy metals (e.g. Cr, Ni, Pb, Hg)? Dust aerosol hazards? P loading to streams? How will this be monitored?

Release rates of heavy metals are potentially a significant problem for olivine and dunite as ERW feedstocks, but are much less likely to be an issue for basalt given much lower native abundances and mobilities of potentially toxic heavy metals. However, we will actively monitor tile drainage waters (from our drainage system that removes excess sub-surface water from fields to allow sufficient air space within the soil) for dissolved chromium (Cr) abundance and speciation. Loading of P to watersheds should be negligible given the low typical P abundance of our feedstocks. Dust aerosol hazard should be similar to that of agricultural liming, but we are actively monitoring airborne particulate abundance at a representative deployment site ([redacted]) and have observed levels below the limit of detection (<0.001 mg m^{-3}) adjacent to plots with relatively high basalt application rates of 12 tons per acre.

10. If minerals are deployed in farmland, what are the estimated effects on crop yields, what's this estimation based on, and how will actual effects be monitored?

Our previous deployment (Spring 2021) resulted in crop yield increases of 4-47%, depending on crop type (across corn, oats, and hay). This is consistent with long-term field experiments at the [redacted] which show yield increases of ~5-15% for corn. However, we expect yield increases to vary by starting soil condition: for instance, there may be even greater improvements for deployments on the nutrient-stripped soils of the Southeast (another study has reported 17-77% increases on rice). We consider robust and reproducible crop yield increases to be central for at-scale deployment ERW on managed lands, and will continue to monitor yields using conventional crop-specific techniques in all deployments.

11. How will you monitor potential impacts on organisms in your deployment environment? (E.g. Health of humans working in agricultural contexts, health of intertidal species, etc. depending on the context of deployment)

We will routinely monitor tissue-specific heavy metal abundance in all crops, and metal dynamics within the soil will be monitored in parallel with our standard CDR attribution protocol (see Sec. 2e). All precautions taken during conventional application of agricultural lime (and fertilizer) translate directly into our deployment strategy. We will also actively monitor airborne particulate abundance and rigorously adhere to all OSHA guidelines for particulate exposure to rock dust.

12. If you detect negative impacts, at what point would you choose to abort the project and how?

A core component of our ethos is leveraging substantive economic and environmental co-benefits for stakeholders on the ground in order to drive ERW to scale. As such, we aim to bring the same rigor to our environmental impact assessment as we do to our CDR lifecycle. Any detectable dissolved heavy metal release above EPA guidelines, tissue metal content in crops significantly above background levels, or adverse impacts on crop yield will result in immediate pause in deployment unless and until a mitigation strategy can be formulated that is agreed to by all stakeholders (including Stripe).