General Application

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

Company or organization name

The Future Forest Company

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

UK

Name of person filling out this application

Kris Anderson

Email address of person filling out this application

kris@thefutureforestcompany.com

Brief company or organization description

<10 words
We co-deploy enhanced weathering, biochar and reforestation for carbon removal.

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.

<1500 words

Enhanced weathering is a method of removing carbon dioxide from the atmosphere through acceleration of naturally occurring rock mineralisation processes. Rain water contains carbon dioxide in the form of bicarbonate ions, which can react with alkaline minerals to form carbonates. Our company is attempting to accelerate these naturally occurring reactions, by increasing the surface area of basic rocks. We achieve this through various forms of comminution that break apart the rock structure until we achieve a particle diameter <100 microns. This decreases the time required to dissolve the rock from >100,000 years to <1 year. Dissolution of basalt releases magnesium and calcium cations that will subsequently react with bicarbonate ions in rainwater to form carbonate minerals, which will be stable for millions of years.

Whilst there has been considerable and sustained scientific interest in the potential of enhanced weathering as a carbon removal mechanism, there have been no full-scale demonstrations. A 2012 study by Renforth (doi.org/10.1016/j.ijggc.2012.06.011) concluded that the greatest barrier to commercialisation for this technology is in sourcing low cost renewable energy to power the process. If fossil fuel derived energy is used, then this will offset the quantity of carbon that is being removed from the atmosphere. By utilising renewable energy, the net reduction in carbon dioxide can be maximised. We presently own a site on the Isle of Mull that has a source of renewable energy, a basalt mine and ~800 hectares of land. The site receives around 2 metres of rainfall per year and contains full access to several streams and a shore line. This creates an ideal environment for demonstrating enhanced weathering as a financially profitable means of carbon sequestration.

The rock supply for our project will initially be waste material sourced from a basalt mine that is 6.5 km from our site. The mine has the capacity to produce >100 tonnes per day of 2.5 cm diameter rock that will be transferred to our site by truck, where it will undergo further comminution to achieve a particle size of <100 microns. The ground particles will be subsequently spread upon our 800 hectare site, where it will add to the carbon sequestration that is being achieved through our tree planting and biochar production activities. Combining multiple carbon sequestration technologies on the same land, greatly increases the quantity of carbon that can be stored and reduces investment risk through diversification of income streams.

Processing 100 tonnes of basalt rock per day will allow our site to reach full capacity within a year. The enhanced weathering process will then sequester CO2 at a rate of 8,400 tonnes of CO2 per year. Absorption capacity and rates are estimated from modelling studies, where the dissolution rate is extrapolated from studies conducted over several months. There is considerable uncertainty in these estimates, which will be resolved by this work. A study by Kelland *et al*. (doi.org/10.1111/gcb.15089) estimated that around 70% of sequestration potential could be achieved within a year if the particle diameter was in the range of 125 microns. Our comminution equipment will be able to produce particle sizes below this level, thus allowing us to test this calculated estimate.

Our target application rate is 28,000 tonnes of basalt per year, spread across 560 hectares of suitable land (our site has 800 hectares in total). This would require an application rate of around 50 tonnes per hectare. This is lower than many of the lab based academic studies, some of which involved application rates as high as 220 tonnes/hectare. The high rainfall and sloping terrain at our site may allow for intensive application rates that are above our current target. To reach 0.5 gigatonnes of carbon dioxide sequestration per year by 2040 will require <1% of Scotland's surface area. In contrast to many similar projects, we are applying our enhanced weathering activities to land that is targeted for reforestation/afforestation and not agriculture. This goal is in alignment with official Scottish government policy, which aims to increase Scotland's forestry cover from 19% to 21% by 2032.

We have undertaken our own lifecycle analysis and estimated the emissions of our process to be 92 tonnes of CO2, which equates to around 1% of our overall emission reduction potential. We have plans to lower these emissions further as our site has planning permission for the construction of a small hydropower facility. All of our onsite comminution and spreading equipment is electrically powered so that we are able to switch over to renewable energy once our hydropower facility is operational. This will lower our emissions down to 19 tonnes of CO2, which equates to around 0.2% of our total emission reduction potential. Our site also contains an abandoned basalt mine that we will reopen in the future. This will allow us to eliminate the emissions associated with transportation from the mine and lower our production costs to around 70 USD/net tonne of CO2.

The Future Forest Company is the primary instigator and driver of this project. The onsite operator of the facility has a PhD in chemical engineering and has worked on the development of carbon sequestration technology for nearly a decade. John Maclachan Quarries Ltd will supply 100 tonnes per day from their quarry site that is approximately 6.5 km from our location. Dr Phil Renforth is an Associate Professor at Heriot-Watt University and specialises in research relating to enhanced weathering. He will provide expert advice and onsite personnel in the form of a PhD student called Veronica Furey, who will undertake sampling and analysis at the site over a 3 year period. Prof David Beerling is the Director of the Leverhulme Centre for Climate Change Mitigation and provides expertise relating to the effect that enhanced weathering may have on the local ecology.

Our project is targeting a start date of June 1st 2021. An agreement with the local quarry facility is already in place to supply 100 tonnes per day and the comminution equipment for grinding the basalt to <100 microns is already purchased and is currently in transit. Once this equipment has been commissioned and is demonstrated to produce <100 micron particles, we will commence baseline sampling of the soil and waterways. We have chosen a 75 hectare area for the first stage trial and have a 3 m2 site at the corner of our land that is specifically reserved for scientific control experiments. This will allow us to assess large scale application whilst simultaneously undertaking controlled scientific analysis. Once there is confirmation that there are no unforeseen complications, the project will be expanded to include progressively larger areas of our land.

Our long term goal is to incorporate enhanced weathering into the rest of our tree planting sites. We would like to stress that we are not purchasing any land expressly for the purposes of enhanced weathering. As can be seen from our website, our business is primarily centred upon tree planting and all land purchasing is done to achieve this goal. Enhanced weathering will be carried out purely as an addition to this activity. We already own a number of additional sites that offer potential for expansion of our enhanced weathering activities if they are proven to be successful. The long term potential for this methodology in the UK alone is extremely large and has been estimated by Renforth to have a theoretical maximum of 430 $GtCO_2$ (doi.org/10.1016/j.ijggc.2012.06.011)

The majority of studies into enhanced weathering have focused on the application of the olivine class of minerals, as they have high rates of weathering. These materials also contain heavy metals such as Ni and Cr that will be simultaneously released into the environment and are thought to interfere negatively in various complex biological mechanisms (doi.org/10.1515/opag-2020-0016). In contrast to these studies, our project will focus on the application of basalt, which has lower concentrations of both Ni and Cr. As reported by Beerling et al. (doi.org/10.1038/s41477-018-0108-y), flood basalt regions of land are known to be extremely fertile, as the basalt releases elements essential for plant growth, such as P, K, Ca, Mg and Fe. The spreading of basalt on land, therefore has the p otential to promote crop growth whilst simultaneously reducing atmospheric carbon dioxide levels. Successful demonstration of this technology at our site, could potentially lead to worldwide application.

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.)*

<50 words

We are the site owners and operators of the facility. The other actors include Phil Renforth at Heriot Watt University for scientific analysis of the technique's sequestration performance, David Beerling at the University of Sheffield for biological impact assessment and a local mine operator called John Maclachlan Quarries Ltd for the supply of basalt rock.

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

<300 words

- Whilst analysis of our basalt has thus far shown no elements that are harmful to ecological systems, there may be trace quantities that are below the analytical threshold of detection, yet still sufficient to cause ecological problems when deposited at the multi-tonne scale. Controlled scientific analysis of the site will be undertaken over the next three years to determine whether this is the case and to ensure that the issue is mitigated. A potential solution would be to be utilise a different source of basalt that has a different composition.
- Micron size particles can lead to dust inhalation hazard issues. Silicosis is a form of occupational lung disease caused by inhalation of crystalline silica dust. It is marked by inflammation and scarring in the form of nodular lesions in the upper lobes of the lungs. It is a type of pneumoconiosis and is characterized by shortness of breath, cough, fever, and cyanosis. Basalt is typically low in silica, but similar types of issue may be encountered with repeated exposure to the various crystalline components of basalt. A potential solution to this issue is to use particle sizes that are above the threshold where this becomes a problem. Spraying of water to clear the dust particles out of the air may also be a solution.
- Rate data for the mineral weathering process is often measured under controlled laboratory conditions that may not be reflective of what occurs under applied conditions in the field. Reprecipitation of minerals, saturation of stagnant water and

formation of problematic by-products, are all potential issues that can ultimately lead to lower reaction rates. One of the primary aims of this project is to explore these issues and to find ways of overcoming them if they occur. Potential solutions include altering the irrigation pathways to ensure continuous flow of water and varying the application rates.

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

- We have no intellectual property relating to this project.

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 2021 - Jun 2022. The end of this duration determines when Stripe will consider renewing our contract with you based on performance.*	*<10 words* From June 2021 to June 2025.
When does carbon removal occur? *We recognize that some solutions deliver carbon removal during the project duration (e.g. DAC + injection), while others deliver carbon removal gradually after the project duration (e.g. spreading olivine for long-term mineralization). Over what timeframe will carbon removal occur?* *E.g. Jun 2021 - Jun 2022 OR 500 years.*	*<10 words* From June 2021 to June 2030.
Distribution of that carbon removal over time	*<50 words*

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".	Studies suggest that around 70% can be achieved in the first year, with the remaining occurring over the next several years. (doi.org/10.1111/gcb.15089)
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.*	*<10 words* The storage will be >100,000 years.

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

Number/range We estimate 100,000 years with an upper limit of +1,000,000 years and a lower limit of -90,000 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.)*

<200 words

It is our intention to gain a thorough understanding of the pathways and therefore the durability of our enhanced weathering technique over the next 3 years. We are currently reliant upon evidence obtained from the literature as to the efficacy of the carbon cycle in locking up carbon for geological time periods. Examples of historical publications discussing this evidence are as follows:

Berner, R. A., & Berner, R. A. (2004). The Phanerozoic carbon cycle: CO2 and O2. Oxford University Press on Demand.

Arvidson, R. S., F. T. Mackenzie, and M. Guidry (2006), MAGic: A Phanerozoic model for the geochemical cycling of major rock-forming components, Am. J. Sci., 306(3), 135–190.

Ciais, P., Sabine, C., Bala, G., Bopp, L., Brovkin, V., Canadell, J., et al. (2013). “Carbon and other biogeochemical cycles,” in Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, 465–570.

Walker, J., P. B. Hays, and J. F. Kasting (1981), A negative feedback mechanism for the long-term stabilization of Earth's surface temperature, J. Geophys. Res., 86(C10), 9776–9782.

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?

<200 words

A key advantage of enhanced weathering is the certainty with which the carbon is stored once it has been converted into a carbonate mineral. Whilst the carbon cycle is thought to be well understood, we will directly measure the fate of the ions produced by the process through continuous sampling. This will greatly improve the certainty relating to the pathway, and therefore, durability of the process.

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.)*

<200 words

Phil Renforth is a project partner at Heriot-Watt University, as is David Beerling at the University of Sheffield. They have supplied a PhD student called Veronica Furey to work full-time on quantifying the rate of dissolution and fate of the ionic species over time. This will facilitate the creation of a mass balance for all of the materials involved. The land where this project will occur is owned by the company and was purchased with the exclusive purpose of demonstrating various carbon storage solutions. The site has full access to all waterways, including >1 km of coastline.

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	*E.g. XXX tCO_2* We estimate that around 8,400 tonnes of CO2 will be absorbed in total, with around 70% of this occurring within 1 year and the rest over the following 3 years.
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	*E.g. XXX tCO_2* Basalt has soil fertilisation properties that enable it to function as a replacement for fossil fuel derived fertilisers. This can avoid the emissions associated with their production and can also reduce NOx emissions. This is however not applicable to our current project, as no plans were in place to utilise fossil fuel derived fertilizers at our site.

b. Show your work for 2(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)*

<150 words The uncertainty in our estimate varies from 3% to 30% of the rock mass translating into captured carbon dioxide. The upper bound is based upon complete dissolution of the basalt to release all of the cations that are capable of forming bicarbonate compounds. The lower bound is based upon reactive transport modelling studies, details of which can be found in Kelland et al. (doi.org/10.1111/gcb.15089). The authors estimated that for larger particle sizes, around 3% will weather within a 1-4 year period, as the reaction rate will be hindered by a variety of complex equilibria and side reactions. Our project goal is to reduce particle size to the extent that >70% reaction occurs within a year. The application rate is set at 50 tonnes per hectare, which is the upper limit recommended by Strefler et al. (doi.org/10.1088/1748-9326/aaa9c4).

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).

 # metric tonnes CO_2/yr

Current capacity is zero, as the project will not commence until June 2021.

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.)*

<200 words

Our absorption capacity estimates are based on data obtained from small scale field trials where temporal samples were collected and analysed. This data was then projected forward in time through reactive transport modelling. For a detailed explanation of this methodology, see section 2.8 in Kelland *et al.* (doi.org/10.1111/gcb.15089). We are working with the Research Centre for Carbon Solutions at Heriot-Watt University and the Leverhulme Centre for Climate Mitigation at the University of Sheffield. Both of these institutions are actively conducting small scale field trials on this topic (https://lc3m.org/research/theme-3/) and this project aims to expand their capability through participation in our large scale commercial demonstration work. A recent publication by Taylor *et al.* (doi.org/10.5194/bg-18-169-2021) is an example of some of the prior field trials that we are attempting to expand upon.

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*

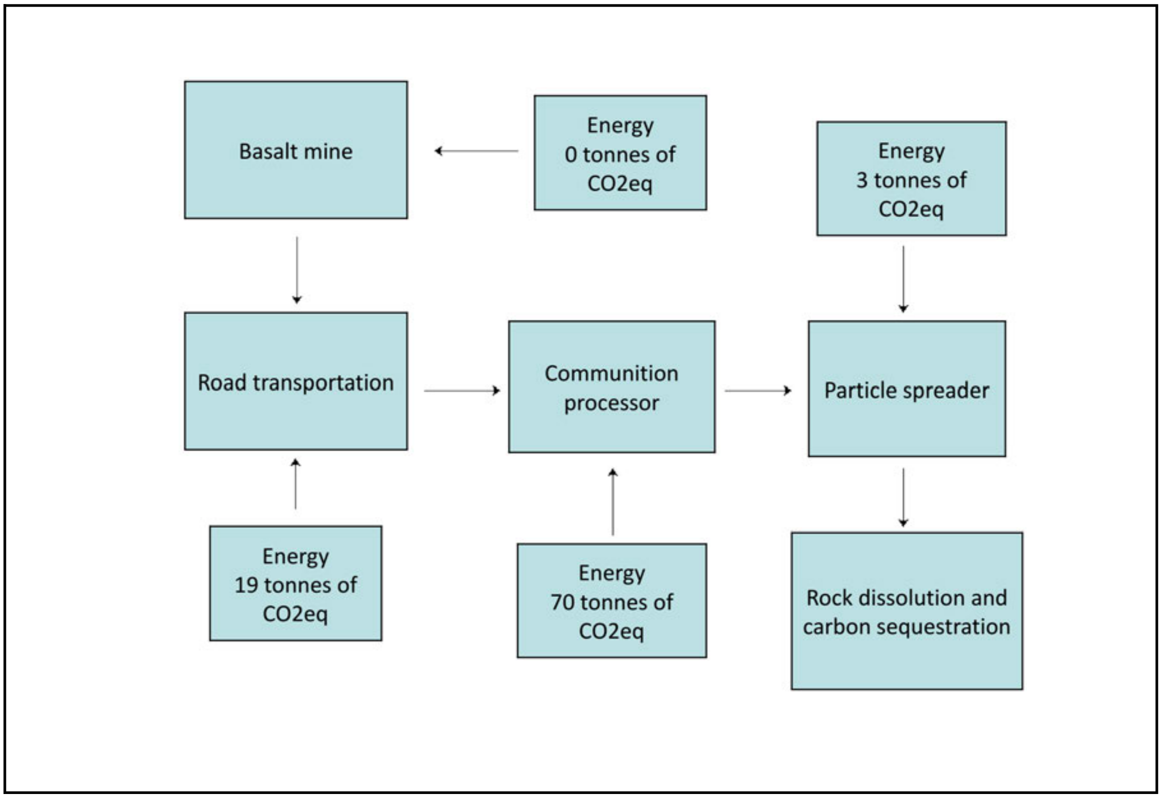
- https://thefutureforestcompany.com/enhanced-weathering
- https://www.youtube.com/watch?v=HnHpLBVJGNc
- Beerling, D. J., Kantzas, E. P., Lomas, M. R., Wade, P., Eufrasio, R. M., Renforth, P., ... & Banwart, S. A. (2020). Potential for large-scale CO 2 removal via enhanced rock weathering with croplands. *Nature*, *583*(7815), 242-248.
- Renforth, P. The potential of enhanced weathering in the UK. Int. J. Greenh. Gas. Cont. 10, 229–243 (2012).
- Hartmann, J. et al. Enhanced chemical weathering as a geoengineering strategy to reduce atmospheric carbon dioxide, supply nutrients, and mitigate ocean acidification. Rev. Geophys. 51, 113–149 (2013).

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	*Should equal the first row in table 3(a)* We estimate that around 8,400 tonnes of CO2 will be absorbed over a time span of between 1 and 4 years.
Gross project emissions	*Should correspond to the boundary conditions described below this table in 4(b) and 4(c)* 92 tonnes of CO2eq
Emissions / removal ratio	*Gross project emissions / gross carbon removal: should be less than one for net-negative carbon removal systems, e.g. the amount emitted is less than the amount removed* 98.9% efficiency.
Net carbon removal	*Gross carbon removal - Gross project emissions* 8,308 tonnes.

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 last year 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?

<100 words

We have not included the embodied energy from any of the equipment or the road infrastructure, as their contribution to the overall emissions is negligible. We have planning permission in place to build a small hydropower facility on our site. This will have the capability to eliminate the emissions associated with the comminution and particle spreading sections of the process. We have not accounted for this, as it may be over a year before the hydropower facility is operational. The basalt mine produces an estimated 196 tonnes of CO2, but we have set this to zero, as they are supplying our site with rock fines which are currently produced as a waste side-product of their normal operations. The mine primarily operates as a supplier of road surfacing material and formerly had no use for the particle size that they are selling to us.

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.

<200 words

The road transportation and particle spreader emissions are modelled using methodology taken from Moosdorf *et al.* (doi.org/10.1021/es4052022). It utilises simple correlations relating to the mass of rock being moved and the fuel efficiency of the vehicles that are moving it. Our comminution emissions are calculated using operational data from our equipment supplier. The comminution process occurs in two stages. The first stage reduces the particle size diameter from around 130 to 30 mm and the second stage reduces it from 30 mm to <50 microns. Around 15% of the total comminution energy is consumed by the first stage and 85% by the second.

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

<100 words

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

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

a. Please define and explain your unit of deployment. (*E.g.* # of plants, # of modules) *(50 words)*

<50 words

We have zero units of deployment at present, as this will be the first year of operation. Stripe's procurement will raise the profile of our activities and will ensure that the facility is funded for its first year of operation. This will give us time to resolve any unforeseen problems and greatly increase the project's long-term prospects for success.

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 if necessary.

Year	Units deployed (#)	Unit cost ($/unit)	Unit gross capacity (tCO_2/unit)	Notes
2021	0			<50 words
2020	0			<50 words
2019	0			<50 words
...				

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

<50 words Our costs have fallen from what we originally estimated, as we now believe that we can utilise larger particle sizes than previously thought. This lowers the communition energy cost and reduces the complexity of spreading low weight particles. We have created a pathway to lower emissions in the future by purchasing electrically powered equipment, as we will be able to switch to renewable energy once our hydropower facility becomes operational in the next year or so.

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)
Number *0*	*# tCO_2/unit*

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

We ask these questions to get a better understanding of your growth trajectory and inflection points, there are no right or wrong answers. If we select you for purchase, we'll expect to work with you to understand your milestones and their verification in more depth.

a. What is your cost per ton CO_2 today?

\$/ton CO_2 £71 per net tonne of CO2 (estimated), which is around 100 USD/tonne.

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."

>100 words The estimate includes labour, comminution, transportation, spreading and purchasing of basalt. At 71% of the total, our primary cost is in purchasing the basalt rock from the local mine. We have agreed a cost of £15 per tonne with our project partner John Maclachlan Quarries Ltd. Our site also contains an abandoned basalt mine that we plan on reopening to reduce our costs. To simplify our activities in the initial stages, we have chosen to partner with a local supplier.

c. 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	Steady state production of 50-100 micron particle size.	A central aspect of our approach is the ability to reduce weathering rates through particle size reduction. It is therefore critical that we are able to produce a target size on demand.	Q2 2021	Independent audit of the site's operations, including sampling and analysis of various sections of the production process.

2	Determination of the actual dissolution rate.	Accurate and fast determination of the weathering rate is critical feedback for adjusting the process parameters.	Q3 2021	Independent audit of the site's operations, including sampling and analysis of various sections of the production process.
3	Attain a mass balance for the basalt.	Attaining evidence as to the fate of the ions that have dissolved from the basalt, is critical to being able to claim carbon credits for the process.	Q4 2021	Independent audit of the site's operations, including sampling and analysis of various sections of the production process.

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

Milestone #	Anticipated total gross capacity prior to achieving milestone (ranges are acceptable)	Anticipated total gross capacity after achieving milestone (ranges are acceptable)	If those numbers are different, why? (100 words)
1	0-830.8 tonnes of CO2	8308 tonnes of CO2	Ability to produce particles sizes below 100 microns, should increase the weathering rate by an order of magnitude.
2	8308 tonnes of CO2	8308 tonnes of CO2	This is an operational milestone for resolving problems and does not affect capacity directly.
3	8308 tonnes of CO2	8308 tonnes of CO2	This is a fundamental aspect of the process that is vital to obtaining carbon credits, but does not affect capacity directly.

d. 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	£787/tonne of CO2 absorbed	£71/tonne of CO2 absorbed	Larger particle size will reduce sequestration levels by at least an order of magnitude, thus increasing the cost per tonne of CO2 absorbed.
2	£71/tonne of CO2 absorbed	£71/tonne of CO2 absorbed	<100 words
3	£71/tonne of CO2 absorbed	£71/tonne of CO2 absorbed	<100 words

e. 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 CEO of Gold Standard/Verra to create a methodology for verifying enhanced weathering as a carbon offset, as this would open up the market for us and give our customers confidence when purchasing carbon credits.

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

<50 words

Help to promote understanding and awareness of enhanced weathering, therefore pushing forward verification.

Make a future commitment to purchasing carbon credits so that we can focus on driving down costs and making it a mass market product, e.g. expansion into the sale of basalt to farmers, as means of displacing fossil fuel derived fertilisers.

7. Public Engagement and Environmental Justice (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 some mechanism 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. There are no right or wrong answers, and we recognize that, for early projects, this work may not yet exist or may be quite nascent.

a. Who are your external stakeholders, where are they, and how did you identify them?

Residents on the Glenaros estate where the project will take place. There are 4 residents (3 are employees). We own the estate and have relationships with all residents. The risks of dust and changes to the ecosystem will be very local (if indeed there is any effect) but these residents will be within this local area.

b. If applicable, how have you engaged with these stakeholders? Has this work been performed in-house, with external consultants, or with independent advisors?

We have discussed with them the details of the project, and have verbal support (we can get letters of support if needs be). We have done this work ourselves, as we know them well.

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?

Not applicable.

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

We are in close and regular contact with the onsite residents and receive feedback on a daily basis. The only issue that we anticipate being a problem, is the spreading activities, as this may produce dust particles that could be harmful if inhaled. We will be ensuring that this is a safe activity for both the workers and the onsite residents. The initial testing area for the project is at a remote section of the site, which is far away from the onsite resident's homes. This allows us to resolve any problems before increasing the scale of operations.

e. What environmental justice concerns apply to your project, if any? How do you intend to consider or address them?

> A 75 hectare area of the site will be used as an initial testing area for the project. This area will be continuously monitored, with controls in place to measure the effect that our project is having on the local ecology. If any issues are discovered, then a mitigation plan will be implemented. The project will be halted if no resolution can be found.

11. Legal and Regulatory Compliance (Criteria #7)

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

> This is an already accepted methodology for fertilising farmland (by the Soil Association), so there is no concern for deploying our solution.

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

> We don't believe we need any at this stage, as we are running our project on land that we own. In the future, we will open our own quarry on site, which will require planning permission. Planning permission for the construction of our hydro power facility is already attained.

c. 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.

> N/A

12. 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)	

	8308 tonnes of CO2
Delivery window (at what point should Stripe consider your contract complete?)	June 2025
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.*	$200/tonne of CO2

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?

<100 words

We are using basalt which is sourced from a mine that is only 6.5 km from our site. We estimated that transportation from the local mine would account for only 5% of our overall emissions, so chose to sub-contract the mining activities to reduce complexity in the first year of operation. We have an abandoned mine on site that we will reopen at some point in the future, as this has the potential to lower transportation emissions and reduce costs to around 70 USD/tonne.

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

<100 words

The local mine primarily sells basalt as road surfacing material. We have an agreement with them to supply a particle size which is deemed a waste material, as it is too small for other applications. As such there is no additional production and no additional ecological impacts.

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.)

<200 words We have already purchased two pieces of comminution equipment that are currently in transit to our site. The comminution process occurs over two stages, with the first reducing particle size from 130 mm to 30 mm and the second going from 30 mm to <0.6 mm. Both of these units run on electrical power, which will come from the grid initially. We have planning permission in place to build a hydropower facility that will provide renewable energy at a later stage.

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	0.0225 km2	Currently operating as a basalt mine supplying road materials to the island's general population.
Source material processing	0.005 km2	None
Deployment	5.6 km2	Currently vacant, but will be utilised as a permanent carbon sink for our reforestation activities.

1. 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	2.7 km2	None, as mines of this size already exist.

Source material processing	0.6 km2	None
Deployment	676 km2	Deer stalking land that currently makes little contribution to the economy and is a poor habitat for wildlife in general.

5. 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.)*

<50 words We are utilising a waste supply of basalt from a mine that is 6.5 km from our site. The supply company has an existing local demand for 5 cm diameter particles for road surfacing, but produces smaller particles as a side-product of its manufacture. This material is currently in large spoil heaps at their location.

Measurement and Verification (Criteria #4 and #5)

6. 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.

<200 words Uncertainties about the dissolution rate could dramatically reduce the quantity of carbon that we are able to sequester during the course of the agreement with Stripe. It is however inevitable that the maximum sequestration potential will be achieved eventually, as we are attempting to accelerate geological processes that occur naturally. We would like to know the exact details of all the mechanisms that are involved in the weathering process. We have already attained a large amount of information relating to this and we are confident that we have the necessary skills within our team to gain deep fundamental insight into the processes involved. Only through applied demonstration can these issues be understood and problems resolved.

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

<100 words

We will monitor the weathering rates by measuring both the strontium isotope ratios and the calcium to strontium elemental ratios. Weathering of basalt will alter these ratios in the water runoff and catchment areas. Temporal sampling will be facilitated by research scientists on site, with quantification being undertaken periodically by transferring the samples to the University of Sheffield for measurement with an analytical instrument called an inductively coupled plasma mass spectrometer. Details about the analytical technique can be found in the methodology section of Peters *et al.* (doi.org/10.1023/B:BIOG.0000015787.44175.3f). We will also monitor the bicarbonate levels in the water on site, using a Fourier transform infrared spectrometer. Details of the methodology can be found in Burt and Rau (doi.org/10.3109/03639049409041960).

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

8. 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?

<100 words

We have purposefully chosen to utilise continental flood basalt, as it can be sourced around the world and has low quantities of heavy metals. As discussed in detail by Beerling *et al.* (doi.org/10.1038/s41477-018-0108-y), flood basalts have low Ni and Cr concentrations relative to ultramafic rocks, that are commonly proposed for enhanced weathering applications due to their high weathering rates. We will monitor the waterways on our site for both of these elements using inductively coupled plasma mass spectrometry. Chemical analysis of our source basalt has shown that it contains 1022 mg/kg of P, 34 mg/kg of Ni and 53 mg/kg of Cr. All of these components will be released at similar rates to the overall weathering process. Dust concentrations will be monitored using an optical particle counter, as real time monitoring will be required to effectively manage dynamic changes in dust particle generation.

9. 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?

<100 words

Our site will ultimately be converted into a permanent woodland for the purposes of carbon sequestration and the rewilding of the environment. As discussed by Taylor *et al.* (doi.org/10.5194/bg-18-169-2021), the application of rock minerals is expected to be beneficial to forest growth. We will monitor this aspect through control trials in a specially designated section of our site. We will calculate the effect on wood production as the difference between the treated and reference watershed mean wood production, over two 5-year periods.

10. 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)

<100 words

The primary human health concern for our process is the potential development of silicosis through inhalation of dust particles. Symptoms only appear once damage has been done to the lungs, so it is imperative that action is taken to avoid exposure from occurring. We will achieve this through avoidance of dust cloud generation by utilising low spreading rates and water sprays. A review by Thomas and Kelley recommends avoidance of dust particle generation and education of workers as to the dangers of exposure (https://doi.org/10.4137/EHI.S4628). Monitoring of the aquatic life in both the intertidal zone and all drainage areas will be undertaken by Veronica Furey, who has a degree in environmental science. Her work will be supervised by Prof Beerling who has a PhD in ecology. The Future Forest Company's CEO Jim Mann, also has a degree in ecology. Our enhanced weathering process is anticipated to take over a year, which reduces the potential for sudden changes in the local environmental conditions. If major issues are discovered in the early stage trials, then mitigation measures can be attempted. If these fail, then the program will be halted.

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

<100 words

The project will begin by utilising a 75 hectare site to carry out controlled scientific studies. This will be the first opportunity to detect any environmental issues before the project is scaled-up. A primary remediation option is to reduce the quantity of basalt that is spread per hectare. If the basalt is found to contain higher levels of heavy metals than analysis has thus far indicated, then an alternative source can be sought out. In the event that these remediation options fail, then depending upon the severity of the issue, the scale-up may be abandoned, but the 75 hectare control study continued to improve scientific understanding of the issues encountered. The site was initially purchased for reforestation and these plans will be unaffected.