General Application

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

Company or organization name

RockFarm (brand), NASKA robotics GmbH (company)

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

Schönefeld, Germany

Name of person filling out this application

Dr. Tobias Brett

Email address of person filling out this application

tobias.brett@naska.io

Brief company or organization description

We use carbon removal walls to protect arable land and clean the atmosphere.

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.

Challenge

The geoengineering method of enhanced weathering of natural rock (EW) is one of the most promising solutions to fight the climate crisis [IPCC 5]. Yet, it will require massive governmental subsidies and is not likely to scale to a relevant level of impact before 2040

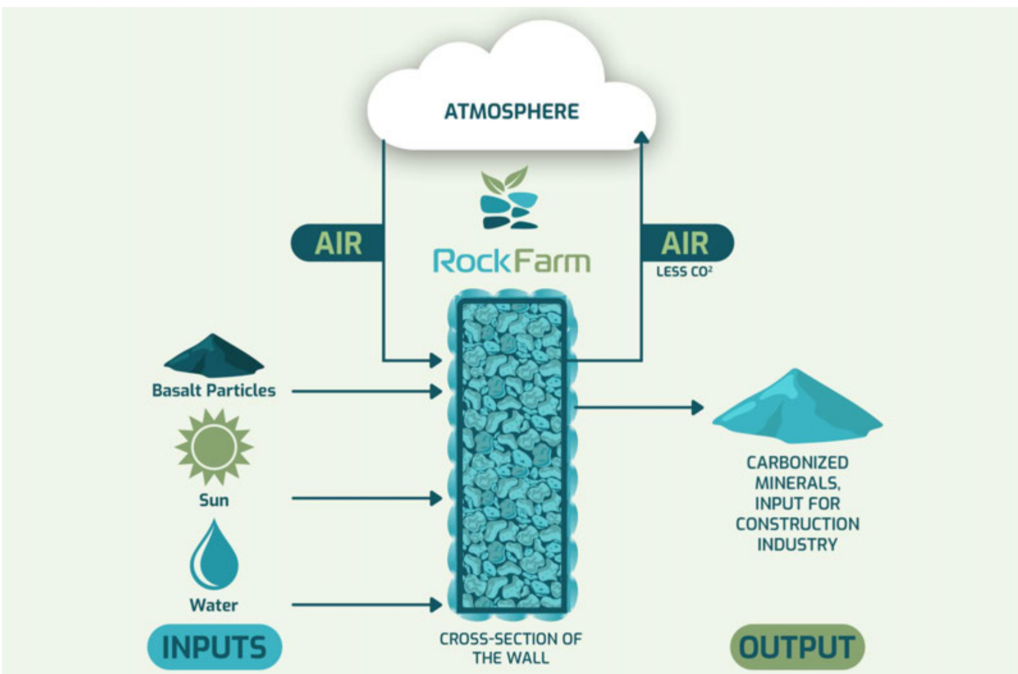
[STR-18]. While this point is valid, we propose an alternative route beyond geoengineering to scale EW within this decade:

- Internalisation of EW to the market and integration into a product.
- Decentralization of EW and and an open ecosystem of industry partners
- Accountability by measurement of both inputs and outputs of minerals
- Zero sink to nature: No spill of rock powder into the environment

Approach

We aim to add value to CDR, cut its cost through an economy of scale and make it available to everyone. Our goal is to remove emissions on the perimeter of customer ground without actually consuming ground. Protective walls offer security as a utility and remove CO2 as a feature. Volcanic rock is cheap, limitless available and capable to permanently lock large amounts of carbon from the atmosphere. Today, metal fencing dominates the market due to a high degree of automation throughout its value chain. But it is limited through high material cost and high cost for anti corrosives. Thus, rock wall prices will decrease by means of autonomous manufacturing. It will eliminate the cost advantage of metal fencing and flip the market towards a climate positive economy of perimeter rock walls.

CDR technology has been a subject to research for the last 20 years. In this project we combine scalable solutions to an overall CDR approach towards the emergence of economic CDR by 2025.



THE INPUTS AND OUTPUTS OF ROCKFARM'S CLIMATE PROTECTION TECHNOLOGY PROCESS

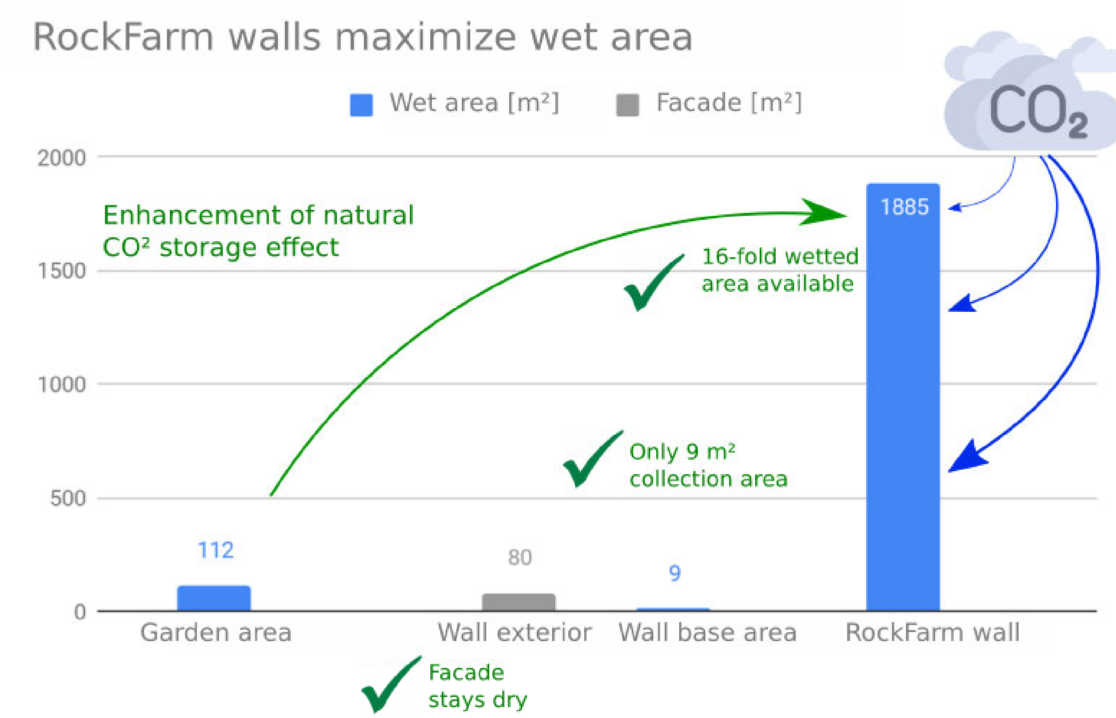
Every domain of this project supports scalability, as shown below.

Scaling wet surface

Weathering of natural rock occurs on the surface of rock in contact with water and air at rather high temperature above 20°C. The surface of rock is maximized through crushing and grinding. At RockFarm, we consider 20 micrometers to be an optimal grain size, as proposed by Dr Thorben Amann from the university of Hamburg. This grain size satisfies cost aspects for commutation. [STR-18]

Wet rock particles behave like a slurry. The ultimate goal of a weathering device is to maximize the surface of that slurry towards air containing CO2. Any structure would generate a carbon footprint itself. Therefore, we use weathering material itself for the structure, but in a much larger granularity of 1.2 cm per particle. Through this, the structure will not be affected by weathering, until it becomes recycled and crushed to much smaller particles.

Packed rock gravel of 1.2 cm contains 50% of air gaps between its particles. This space is being used to contain the rock powder, flush water and circulate air containing CO2. By enclosing an area of 112 m^2 with a rock gravel wall of 1.2 m height, the wet surface of that area is increased by factor 16. Thus, the conditions for weathering are improved, greatly.



Scaling of the weathering rate

Enhanced weathering is missing control. Biology and chemistry inside of soil is complex. Integration of EW to a rock wall reduces that complexity. EW in the wall will be monitored by an autonomous mobile robot. The robot is equipped with sensors to measure humidity and further parameters inside the wall. It submits the values to our cloud. We optimize the parameters and the cloud sends commands to the local vessel system in the rock wall pipes. A closed-loop control is obtained. Our robots will receive frequent updates over the air. Through this, the efficiency of all installed facilities will improve, every year.

Scalable supply

A diversified supply chain with many materials and parts is difficult to scale. Few sorts of materials on the input side lead to large purchase volumes. For our rock wall product, we use only volcanic rock materials and nothing else. The wall consists of volcanic rock powder, volcanic rock gravel and volcanic rock fiber, particularly basalt fiber. Very simple to scale for a purchasing department.

Image: Input material for building a wall. Rock powder, rock gravel and rock fiber.

The second aspect for a scalable supply is a short supply chain. Our automated manufacturing process is able to process raw material with undefined geometry. The gravel is just broken from rock and sorted by size.

Availability is the third aspect for scalability of supply. Olivine and dunite rock is widely available throughout most parts of the world. To keep transport emissions for rock on a low level, the material should not be carried more than 200 km on fuel trucks. Below 200 km, transportation emissions take a low share of the removal potential of the rocks, see [STR-18].

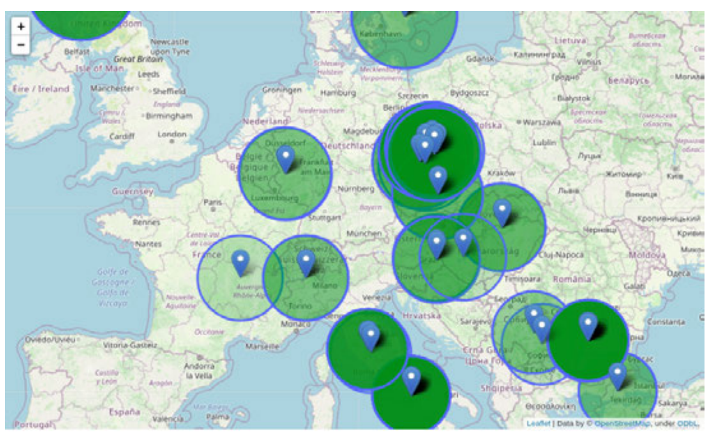


Figure: Map of Europe, showing an incomplete selection of sources of olivine and dunite taken from the georock database.

Production at scale

A main challenge for the production of carbon removal walls is the structural material. If concrete is applied, massive emissions of CO_2 will be associated with the production process. The ETH Zürich has developed an alternative solution to stabilize rock gravel and to keep it in a desired shape. The jamming effect requires only gravel and string to obtain a stable structure. If string is layed loosely into gravel and weight is put onto it, then the string becomes fixed inside the gravel. If gravel is enclosed by string, it is fixed, as well. Thus, the whole structure becomes stable, see images below.

Image: Jamming-Structures as a Pavilion with a massive roof of steel (o.), Building machine (u.l.) and sculpture at Ars Technika in Chicago (u.r.) [LIN-17]

RockFarm applies the idea of the jamming effect to carbon removal walls. Gaps between the gravel make up 50% of the wall volume. In these gaps, powder, water and air can circulate. The sun heats up the rocks. A robot can still penetrate the gravel with adequate sensors and measure the wall condition.

For walls around large farming grounds with several kilometers of perimeter, logistics and transportation will become the most difficult challenge. Several truck loads of rock need to be coordinated and the road condition on the perimeter might be bad. For this purpose, a special construction machine is required, where all input materials are fed through pipes of at least 100 m length from a truck on a road directly to the machine on the perimeter of farming land. Blasting of rock gravel through a pipe is already an established process in industry. A second pipe will be used to feed water, powder and the fiber into our construction machine. Our target is a feed rate of at least 12 m per minute for one layer of wall to be built. Researchers from the ETH Zürich expect a fabrication speed of 11.8 m^3/h [AEJ-20].

A startup will not be able to offer global sales, maintenance and service for a construction machine. Therefore, we will sell licenses to mid-size and large enterprises. VogtlandMobil will distribute the RockFarm service in Germany and ramp up a machine park.

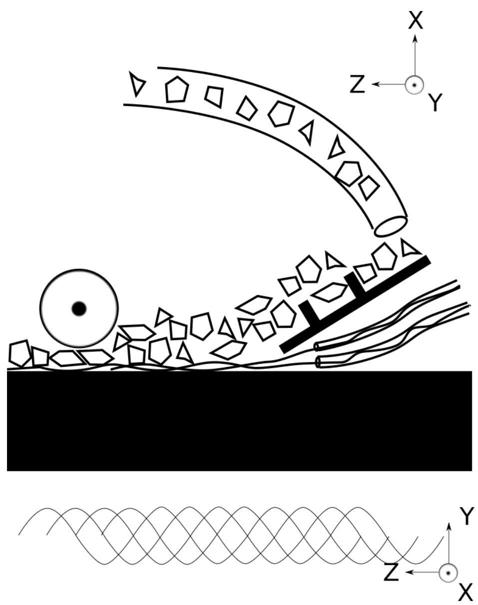


Image: Concept of our high speed manufacturing machine, as taken from our patent application.

The construction machine will be developed and manufactured in Germany in 2021 and delivered in March 2022.

Self-reproduction

The known reaction of Forsterite on EW is

$$Mg_2SiO_4 + 2\ H_2O + 4\ CO_2 => 2\ Mg^{2+} + SiO_2 + 4\ HCO_3^-$$

For the purpose of reproduction, we need dry materials according to this formula:

$$2\ Mg^{2+} + SiO_2 + 4\ HCO_3^- => 2\ MgCO_3 + SiO_2 + 2\ H_2O + 2\ CO_2$$

We release half of the removed CO2 back to the atmosphere but obtain three benefits:

- a solid state of permanence,
- controlled precipitation and
- crystallization as an additive manufacturing process

Carbonates are solid and a well known input material for the construction industry. The natural material obtained from EW is not pure and will therefore likely not achieve a good price on the market. Instead of selling the material, we will build our own input parts for the construction industry by additive manufacturing based on precipitation of carbonates and charge a minimum of USD 100 per ton.

The first generation of construction parts will be simple. We create plates in a shell and apply a robot to crack them into gravel. The gravel will be used to build further wall structures.

Next generations of construction parts will be more complex and we will apply biomineralization to obtain further control on the build process.

CO2 Oases: How we earn money

We use cooperative robots to manufacture carbon storage walls on private ground for business parks and private gardens. We cooperate with outstanding garden and landscaping companies and offer customers to remove all facility emissions on the perimeter to the environment. If facility emissions surpass the removal rate of the garden, the customer stakes a corresponding amount of carbon removal wall on a farming ground. This premium landscaping includes a greenkeeping service.

For private ground, we have developed an autonomous build process, which includes facade structures. We have accomplished semi-automated manufacturing of marble stones with undefined geometries. This process will be improved towards autonomous manufacturing of beautiful carbon removal walls for private gardens and exterior facilities in industry.

Image: A RockFarm prototype of a premium wall with white marble stones and illumination for garden owners replacing a fence. An autonomous wall manufacturing robot in the front.

The robot can accomplish the manufacturing process with a single gripper. Therefore, it is a universal robot system without special adaptations. It can be utilized for any other task and is not turned into a special machine device.

The offering will start as a premium service, but has potential for considerable cost decrease:

- The cost of carbon removal walls will benefit from cost decrease in robotics. Robotics has been an economy of scale through the last decades.
- Germany has introduced a tax on CO2 emissions in Jan`21. In 2025 the tax shall be transformed into a certificate market with carbon at USD 66. There are ideas to extend this for the entire EU. Based on the estimated cost for weathering of olivine and dunite at a particle size of 20 micrometers, the operation of the wall would be covered by the tax advantage, if creditable to taxes by 2025. In other words: operation of the wall

would not generate cost to the stakeholder.

Customers' choices in Germany are clear. More than 50% prefer our natural rock wall design against any other available fencing solution

Scaling the perimeter network

For some green technologies, public acceptance is limited. With an increasing amount of installed systems over land, some people may feel disturbed. Wind mills already face considerable resistance in the public in Germany. Thus, design is an important aspect for scalability of decentralized DAC. If decentralized DAC integrates to the landscape, it will likely be accepted, even at large scale. Building a sustainable future is not sufficient. The future should also be beautiful.

Ireland has a heritage of an estimated 40.000 km of dry rock walls. In relation to its population an avg. of 4.904 million (2019) that is an average of 8 m per person. The same density of rock walls to the population of Europe would enable a yearly weathering rate of 0.6 Gt, if 1 m of wall removes 0.1 tCO_2e. Consequently, public acceptance is likely not a threat to scaling this DAC solution.

This project

In this project, we offer weather capacity from three different locations. In 2022 a wall length of 5 km is planned for installation on a field in Steinhöfel, Brandenburg, Germany. In the third quarter of 2021, a wall length of 50 m is planned for installation on the ground of our partner VogtlandMobil in the city of Adorf, Germany. A pilot wall a length of 1 m has been installed in March 2021 in Schönefeld, Germany.

For the pilot wall, semi-automated manufacturing has been evaluated and the prototype has been filled with 25 kg of Basalt powder. Both for the walls in Adorf and Fürstenwalde, we are still evaluating, which rock material we will utilize.

Source

[LIN-17]	Aejmelaeus-Lindström, P.; Gramazio, A.; Kohler, M.; Kernizan, S.; Sparrman, B.; Laucks, J.; Tibbits, S.	Granular Jamming of Loadbearing and Reversible Structures: Rock Print and Rock Wall, Special Issue:Autonomous Assembly: Designing for a New Era of Collective Construction, Volume 87, Issue 4, https://doi.org/10.1002/ad.2199 , 2017
[STR-18]	Strefler J., Amann T., Bauer N., Kriegler E., Hartmann J.	Potential and costs of carbon dioxide removal by enhanced weathering of rocks, 05.03.2018, in : Environmental research letters. 13, 3, 034010. DOI: 10.1088/1748-9326/aaa9c4
[AEJ-20]	Aejmelaeus-Lindström, P. ; Rusenova, G.;	Rock print Pavilion: robotically fabricating architecture from rock and string. In: Construction Robotics (2020) 4:97–113

Mirjan, A.; et al https://doi.org/10.1007/s41693-020-00027-8

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.)*

RockFarm - NASKA robotics GmbH

Project coordinator, software developer and engineering consultant.

Vogtland Baumaschinen

Distributor, responsible for the installation of the walls on customer ground.

EDAG CityBot

Mobility provider for robots in urban areas.

Fürstenwalder Agrarprodukte GmbH

Ground provider. Farmer.

Nordkalk (purchase request made)

Provider of wollastonite powder.

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

- Based on research data for EW over land, we have good estimates to predict the weathering rate in the wall. However, there is a risk that we do not find the optimal parameter set for operation of the wall within 12 months.
- Risk of extreme weather conditions to flood the wall foundation with rain water and spill minerals into farming land. Risk of strong wind blowing too much dust into the wall.
- Risk, that the manufacturing machine is delivered on delay. In this case, we will start to build the wall with our robot systems. However, we will not achieve the full wall length.

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

The first patent among a series of patents has been published:

- [DE201910125041 20190917]()

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.*	50 m wall: Sep 2021 - Sep 2022 5 km wall: May 2022 - Sep 2023 <10 words
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.*	Sep 2022 - Sep 2023
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*	We expect more than 50% of the weathering to occur in the months of Jun to Sep, due to hot temperatures and our internal irrigation system. <50 words

our mineralization kinetics".	
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.*	We mineralize and obtain dry carbonates. These are permanent.

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

The solid carbonates are used as inputs to the construction industry in the circular economy.

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.)*

Carbonates are permanent, but need some protection against acidic rain.

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?

We will conduct tests to obtain gravel directly from the wall by drying carbonates in shells. If the efficiency of the process is too low and the gravel is not stable, we may use some concrete or other material, which will cause emissions of CO2.

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

We quantify by direct measurement of inputs and outputs. We will send probes to third party laboratories.

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	378 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	Not applicable.

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 use Nordkalk W200 WOLLASTONITE CaSiO3 at a grain size of 17 micrometers from Finland as our prototype material for weathering. We will fill 400 kg of powder per meter wall at a total length of 5 km. Theoretically, 2.64 tonne of wollastonite sequesters 1 tonne of CO2 [HAQ-19]. However, we will use half of the sequestered CO2 during the drying process. That makes 5.28 tonne of wollastonite for our dry material. This sums up to 378,78788 tCO2 per 2.000 t wollastonite.

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).

> 378 metric tonnes CO_2/yr if filled with wollastonite (prototype material).
> 1100 metric tonnes CO_2/yr if filled with dunite (production material).

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.)*

> The fill volume of the wall per meter is based on experiments on our prototype in our headquarter.
> For wollastonite, the weathering equation is taken from [HAQ-19]:
>
> calcium release from wollastonite:
>
> $$CaSiO_{3(s)} + 2H^+ \rightarrow Ca^{2+} + H_2O_{(l)} + SiO_{2(s)}$$
>
> calcium carbonate precipitation:
>
> $$Ca^{2+} + 2HCO_3^- \rightarrow CaCO_{3(s)} \downarrow + H_2O_{(l)} + CO_{2(g)}$$
>
> For dunite [STR-18] concludes that 1 t dunite remove up to 1.1 tCO2.
> We control all parameters for weathering, except the temperatur. Thus, we can entirely weather particles of 17 micrometers within 12 months.

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.

> - RockFarm - new website to launch, soon.

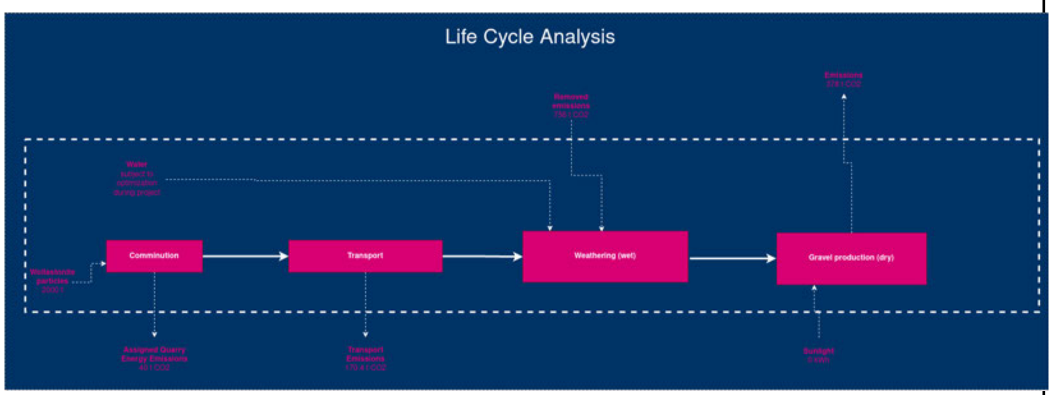
4. Net Capacity / Life Cycle Analysis (Criteria #6 and Criteria #8)

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	378 tCO_2 (weathering minus gravel production)

Gross project emissions	210.4 tCO_2 (without gravel production)
Emissions / removal ratio	0.556
Net carbon removal	167.6 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 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?

Manufacturing of the wall is excluded, as the wall structure is permanent.
Minor emissions excluded: on-site operations like pumps, robot power, etc.
Output transport excluded: Output serves as input to build another wall on the same farm.
Transport from Finland causes much emissions. For production with olivine transport emissions will be much lower.

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.

CO2 emissions wollastonite									2000	t wollastonite
CO2 comminution	20000	g CO2/t				20	kg CO2/t		40	t CO2
CO2 truck	138	g CO2/t	400	km		55.2	kg CO2/t		110.4	t CO2
CO2 ship	30	g CO2/t	1000	km		30	kg CO2/t		60	t CO2

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.)

The comminution emissions are taken from [STR-18] for 20 micrometer particles. This number should be updated by real numbers from the powder provider.

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)*

We measure units of deployment in meters of wall deployed on farm ground.

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	1	0	10 kg CO2	We use basalt powder for this prototype with unknown particle size from a quarry in Germany. This material is free of cost. <50 words

2020	2			Just wall prototypes without EW
2019	1			Just a wall prototype without EW
...				

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.)*

As this project has a focus on scalable technologies rather than improvements of state of the art in EW technology, this project could be carried out without weathering. Science provides mch data on EW, already.

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)
5000	75.75 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?

500 $/ton CO_2 with wollastonite prototype material.

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."

The cost includes manufacturing of the wall and filling with powder and operation during the projected time frame. Depending on the subsequent contracting phase with the ground owner, we should be able to offer the yield of the coming years, as well. The cost will then reduce, as we will sell the gravel at 60$ per ton to customers of "CO2 oases".

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	Installation of the wall in Fürstenwalde <100 words	This will be the major logistics challenge of the project. Many trucks to be coordinated. And we will not be able to excessively test the equipment. Testing would be too expensive, as the machine moves so much material in a short time.	Q2 2022	We will be happy to invite you to visit Fürstenwalde and Berlin. We will submit a drone video. And the ground owner will need to sign a document stating, that the wall is deployed.
2	Drainage testing	We will test all operating modes. 1. Moisturing the wall. 2. Sedimentation of powder. 3. Carbonisation. 4. Removal of powder. We will test for any leakage. <200 words	Q3 2022	If the ground owner is not satisfied, he might not allow us to fill the wall. We would report this to you.
3	Experimental gravel production	We start to dry the mineralized material in shells on top of the wall and expose it to sunlight. We will test different methods to foster precipitation of carbonates to solid parts. <200 words	Q2 2023	We will submit a detailed report on experimental results. If the experiments in shells on top of the wall are not satisfying by Q1 2023, we will switch to a manual method based on

				concrete. This will unfortunately lead to CO2 emissions. This would be part of the report.

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	Installation of the wall in Fürstenwalde	No mineralization without this milestone	<100 words
2	Drainage testing	No significant mineralization without this milestone	<100 words
3	Experimental gravel production	If these experiments fail, we will choose a concrete alternative with very low CO2-emissions.	<100 words

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	500$	500$	<100 words
2	500$	500$	<100 words
3	500$	60$	If gravel production is successful and the market catches up, we will sell the gravel. Also, we will fill the wall in future with dunite or

			olivine and reduce cost dramatically.

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?

I would ask chancellor Angela Merkel to make DAC creditable on CO2 taxes by 2025. Our EW projects would become cash positive for our customers.

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

We need an initial customer, regardless of the amount purchased. For our CO2 oases, we will have complex payment processes and would be happy to solve this with Stripe.

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?

If this project scales, all citizens will become stakeholders. This is an inclusive project. Important voices will be raised by the association of farmers. They could convince politics to make DAC creditable to taxes. And we have the lighthouse project enabled by Stripe.

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 are in good contact with our regional farmer association and expect more intensive discussions on this topic and this project. We will also conduct a clickworker survey to analyze the reactions of the population on our technology and our design.

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 were fascinated by the intense reactions on our natural rock wall design. More than 50% preferred our design among other perimeter solutions like e.g. fencing. Most people want this climate project to be successful. However many people cannot believe that DAC could be so simple in the end. And nobody expected robots to do the job.

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 plan further wall designs to be developed by artists.

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

Our project has no output as we use our material to increase the overall wall length. Currently, I see no negative impacts. The only unknown is the amount of water required for the drainage system. However, there are several technical options to reduce water consumption, if needed.

11. Legal and Regulatory Compliance (Criteria #7)

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

In Germany, we do not need a building permit, if the wall is limited to 1.2 m or lower. Anyway, we are already in contact with our local administration and continue so.

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.

This project could indeed run under the radar of regulation. However, we will keep open communication. E.g. we learned from the farmer association, that "dry wall" is becoming an official legal term by summer of this year in Germany.

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.

We are engineers and not familiar with architecture. But our partners are. We have a good understanding, that perimeter walls are subject to the local administration and that we get good feedback from there.

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)	167.6 tCO_2
Delivery window (at what point should Stripe consider your contract complete?)	Sep 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.*	500 $/ton CO_2. The cost is high because of using wollastenite. Potentially, we can test directly with olivine, but there might be some concerns from stakeholders.

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?

We use wollastenite from Finland. In the future, we will use olivine and dunite.

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

Nordkalk offers an extensive sustainability report.

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.)

Our drainage system requires some water.

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	*Report. We did not validate ourselves.*	E.g. Existing mine for basalt
Source material processing	*Report. We did not validate ourselves.*	E.g. Gravel production facility

Deployment	Deployment only inside of a perimeter wall.	E.g. Agricultural land + beach

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	*Sourcing should not be further than 200 km away from the ground of usage.*	
Source material processing	Unknown	
Deployment	Deployment only inside of a perimeter wall.	

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.)*

The material would stay in stock for another customer, e.g. from Ceramics, metallurgical powders, paints & coatings, thermoplastics and thermosets, gaskets & sealants, elastomers

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.

Product development is not comparable to a research phase. In product development we have many unique unknowns. We will use the method of design of experiments to gather knowledge on many aspects with few experiments.

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?

Autonomous robots will monitor the wall segments and send the data to our cloud. This is a closed-loop control cycle. The cloud controls the vessels of the drainage systems.

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?

No material is spilled over land.

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?

No material is spilled over land.

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)

No material is spilled over land.

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

In case of any leakage, we will immediately close the vessels of that wall section and keep it completely dry. If there is a systematic failure leadiing to leakages alover the walls, will pause the project and stop, if no solution possible.