⁘ Frontier

Carbon Drawdown Initiative

Carbon Dioxide Removal Purchase Application

Fall 2022

General Application - Prepurchase

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

Company or organization name

Carbon Drawdown Initiative Carbdown GmbH

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

Fürth, Germany

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

Dirk Paessler (CEO), Ralf Steffens (CTO)

Brief company or organization description

We are an independent, privately funded NET-focused startup that invests in existing CDR projects, develops its own CDR projects through targeted science funding and supports EU-wide policy work.

1. Project Overview[1]

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

We propose a ready-to-scale project using enhanced rock weathering (ERW) on agricultural land for carbon removal and long-term storage of inorganic carbon species. Our proof-of-concept-project proposed for a Frontier pre-purchase is however more than just a rock-spreading exercise. Our project has 4 special features:

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

- Our project will be the **world's first third-party certified ERW project** by using a new ERW certification methodology created by our partner Ithaka Institute which can be looked at as a kind of franchise-service for companies and individuals willing to conduct and own ERW-based CDR projects. They may (1) partner with farmers, (2) order rock powder from certified mines for them and (3) put the relevant data and documents into Ithaka's certification system. Through this mechanism, ERW becomes an easily accessible business model.
- **Our project will demonstrate today's economics of the complete value chain** from basalt mine to logistics, farmers, certification and sale/tracking by a dedicated carbon tracking and sales service (Carbonfuture) and it will show that all involved partners will be profitable or break even.

- Our ERW project will capture and permanently store ca. 300 tons of CO_2 with ERW. To shorten the time gap until the actual removal for the customers **we achieve full removal from day 1 through a smart combination with biochar certificates**: we will spread 1,200 tons of basalt on several active agricultural fields scattered across Germany (for long term storage) and cover the time until ERW capture happens with the labile part of biochar applications (which will release a small part of their stored carbon over several years).

- The **resulting CDR credits will formally be issued by our partner Carbonfuture** which will implement the necessary IT infrastructure for tracking and combining ERW-based certificates with other CDR-certificates to bridge the lag-phase of ERW. Still, long-term CDR is 100% guaranteed by conservatively assessed ERW through inorganic carbon species.

Our MRV approach will use in-field measurements and extensive pot/lysimeter experiments to follow up on the actual weathering rates in the cropland fields. The in-field measurements and the greenhouse experiments are performed and funded by our science project, Project Carbdown, which has worked on the science of MRV for ERW since 2020. The actual soil samples from the fields used in this project will be included in a large set of pot/lysimeter experiments using several measurement methods to track each pot's carbon capture.

For this pilot project, Carbon Drawdown Initiative acts as a hub and risk-taker for a group of involved organizations with the goal of demonstrating the economic feasibility of enhanced rock weathering as a method for carbon dioxide removal.

The creation of a new certification methodology is an integral part of this project. During this project, the partners Ithaka Institute and Carbonfuture are developing the necessary (IT-) infrastructure, which will enable the scale-up of ERW globally. Also, the project is a preparation step for the founding of a spin-off company (early 2023) that will scale rock distribution. The certification method applied is based on a very conservative calculation regarding the rate and extent of weathering. All experiments aim at legitimizing more progressive approaches to increase the profitability / reduce the costs of ERW per ton of CDR.

We, that is

- a privately funded, independent NET-focused startup (Carbon Drawdown Initiative),
- a scientific consulting team of 20 scientists from six universities in Europe and the USA (Project Carbdown),
- an independent institute (Ithaka Institute), that has already created a trusted CDR certification methodology for biochar (European Biochar Certificate EBC),
- a basalt company (RPBL),
- a leading platform and marketplace for high-quality and impactful carbon removal credits (Carbonfuture). The Carbonfuture platform provides full digital tracking of carbon sinks, providing verifiable end-to-end carbon removal accounting and flexible trading, and
- eight farmers in Germany.

The ERW field implementation in our pilot project is integrated into our ongoing development/assessment of measurement methodologies of ERW rates which are necessary to optimize ERW on croplands in the future. For the pilot project specifically, we will be using the actual soils from the fields in an extensive greenhouse experiment in winter 2022/2023 where the weathering kinetics will be assessed using several measurement methods to quantify captured CO_2. These will include analyses of weathering products in leachate (alkalinity), quantification of remaining rock in the soil, measurements of soil air/respiration, measurements of precipitation of secondary minerals (which can potentially reduce the amount of captured CO_2 by 50%) using e.g. PIC and Li isotope analyses, isotope analyses of carbon and rocks-in-teabag-analyses. The experiments are planned for 24 months or more and will involve hundreds of pots/lysimeters allowing us to better understand the uncertainty range in realized CDR-potential.

The new certification methodology by the Ithaka Institute considers the specific nutrient and trace-element content of the deployed rock dust, as well as the field's soil characteristics, to ensure application rates that are safe and beneficial for the agricultural system and in accordance with all relevant European regulations. It is imperative that cropland-based ERW applications are carried out in a framework, have only positive effects to the agronomic system and thus can fully be acknowledged as a beneficial agricultural practice – not as a CDR-focused burden to be carried by the farmers and the food system. This foundation is crucial for acceptance and scalability.

The certification will apply a conservative model for the calculation of ERW-based CDR, with adequate security margins to guarantee reasonable carbon drawdown rates with high confidence. Process emissions during rock powder production and transport/spreading are considered in the LCA based carbon budget.

ERW-based carbon sinks build up over a considerable time horizon. To fully monetize the future value of a steadily accumulating carbon sink in an ex-ante, yet risk-free manner, the certification scheme will introduce the novel concept of carbon sink portfolios. Such a financial tool deploys the combination of sequestration curves originating from different types of carbon sinks. Herein e.g. decreasing sequestration curves from biochar-based carbon sinks and increasing sequestration curves from ERW-based carbon sinks cancel out to grant a constant and persistent carbon sink value of the portfolio at any time.

Carbonfuture will be instrumental for developing the appropriate mechanisms and systems to implement this novel portfolio approach.

For this initial pilot project, we are solely focused on demonstrating a working project with all involved parties without accepting any slow-down for cost-reduction optimizations. This results in a sale price of about €300 per tonne of CO_2 – many parameters that can however be optimized. We are using off-the-shelf Eifelgold “Brechsand” with grain sizes up to 2,000 microns supplied by RPBL at a special discounted price per ton. Rock cost could be lowered substantially in future e.g. by using cheap, pelletized waste basalt dusts.

The main cost drivers remain the logistics: our fields are 300-450 km away from the mine (where our scientists are). By choosing fields closer to the mine or by using ships and trains instead of trucks, transport costs (and CO_2 emissions) could be substantially lowered, especially for larger amounts of rock. A mid-term plan for further development of costs still needs to be made, and will also require some input data currently being investigated through our scientific work. Finally, we should be able to progressively lower the carbon removal security margins in the future, through data being collected as we speak, which will have a strong effect on pricing.

In our financial plans at €300/ton of CO_2, all involved parties will be at least minimally profitable while the farmers receive €100 per 40 tons of rock spread for the usage of their fields (plus, reimbursement for their spreading costs).

We can confidently say that this project is safe since we use a rock that has been certified for fertilizer use in the EU for decades, but still we are monitoring for heavy metals, etc. The verification is being followed up by parallel lab-work and in-situ measurements.

A successful demonstration of the full value chain from basalt mine to carbon-sink certificate will lay the foundation for rapid scaling. All required resources, machinery and physical infrastructure already exist today as part of day-to-day mining, logistics and agronomic operations.

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

TRL 7

We are demonstrating this via a trial with 1,200 tons of basalt this fall. All the required technology/machinery for logistics and application of basalt is already existing (we do not buy/build any new machinery), the rock supply is ordered off-the-shelf from well-functioning basalt supplier RPBL (https://www.rpbl.de/) in Germany and is delivered as part of their day-to-day business. Pre-application and post-application measurements are being done by standard lab work.

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

Key performance parameter	**Current observed value (units)**	**Value assumed in NOAK TEA (units)**	**Why is it feasible to reach the NOAK value?**
n/a			
[add rows as needed)			

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

For Carbon Drawdown Initiative: Dirk Paessler, CEO, entrepreneur, founder/chairman of www.paessler.com (software company), co-founder and VP of Negative Emissions Platform (NET lobby organization at the EU in Brussels), and co-founder of 11 other companies/organizations; Ralf Steffens, CTO, long-time technical prototyping engineer

For Ithaka Institute: Johannes Meyer zu Drewer, lead author of the guidelines for ERW certification and Dr. Nikolas Hagemann, CEO and scientific director, co-author of the EBC-guidelines. Long term experience in basic- and applied research in the field of terrestrial carbon dioxide removal.

For Carbon Future: Dr Hannes Junginger-Gestrich, Co-Founder and CEO with a PhD in mathematics and broad professional background in Financial Engineering and risk management; Dr Matthias Ansorge, Co-Founder and CTO with a PhD in mathematics and more than a decade experience as software architect.

The specialized scientists of Project Carbdown, our MRV science project, include Prof. Jens Hartmann (University Hamburg), Prof. Jelle Bijma (AWI), Dr. Mathilde Hagens (University Wageningen), Dr. Ingrid Smet (Fieldcode), Dr. Maria-Elena Vorrath (University Hamburg)

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

Partner	Role in the Project	Level of Commitment
Ithaka Institute	Compilation of methodology and IT infrastructure for ERW carbon sink certification, scientific consultation and field trial coordination incl. sampling	Confirmed project partner
Carbonfuture	Certificate tracking Providing the MRV platform infrastructure for tracking carbon removal and generating carbon removal certificates. Certificates issued will be sold through the Carbonfuture platform and listed on their registry.	Confirmed project partner
RPBL	Supplier of basalt incl. logistics, offering special pricing for this project.	Confirmed project partner
Project Carbdown	Science advisors, involved in all steps of the program	Confirmed project partner
Eighth self-employed farmers in Germany, each managing 20-200 ha	Spreading basalt on fields in property	Confirmed project partner

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

The application of the basalt rock powder (1200t pilot) will be executed in October 2022.

Publication of the certification methodology is anticipated for Q4 2022, thus the certification of the ERW based carbon sink can take place soon after rock powder application.

The full value chain demonstration from mine, to field, to tradable carbon sinks will be accomplished before the end of 2022.

In the following years, research projects nested into the pilot projects will generate new knowledge and serve methodology refinement.

Building onto the established methodology and IT infrastructure, a substantial upscaling can already take place 2023 onwards.

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

The physical CDR, as facilitated through ERW, will take place from the day the rock powder enters the soil until the full CDR potential (complete weathering) is achieved. Depending on environmental factors this can occur on timescales between 10+ and 100+ years. Along this trajectory the weathering speed slows down with time, reaching a plateau state at full CDR potential.

- *Gudbrandsson, S., Wolff-Boenisch, D., Gislason, S. R., & Oelkers, E. H. (2011). An experimental study of crystalline basalt dissolution from 2⩽ pH⩽ 11 and temperatures from 5 to 75 C. Geochimica et Cosmochimica Acta, 75(19), 5496-5509*
- *Rinder, T., & von Hagke, C. (2021). The influence of particle size on the potential of enhanced basalt weathering for carbon dioxide removal-Insights from a regional assessment. Journal of Cleaner Production, 315, 128178.*
- *Lewis, A. L., Sarkar, B., Wade, P., Kemp, S. J., Hodson, M. E., Taylor, L. L., & Beerling, D. J. (2021). Effects of mineralogy, chemistry and physical properties of basalts on carbon capture potential and plant-nutrient element release via enhanced weathering. Applied Geochemistry, 132, 105023.*
- *Renforth, P., & Campbell, J. S. (2021). The role of soils in the regulation of ocean acidification. Philosophical Transactions of the Royal Society B, 376(1834), 20200174.*

Through the combination of such increasing, ERW- based sequestration curves with equivalent certified short-term carbon sinks in a carbon sink portfolio, the net CDR is occurring immediately.

Carbon sink portfolios enable a risk free ex-ante monetization of future ERW carbon sinks (called carbon sink options). Following portfolio principles, ERW based CDR, will be part of a carbon sink product of high flexibility and unprecedented quality, granting for an immediate, constant and persistent climate service from year 1 until year 100+.

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

Year	Estimated gross CDR capacity (tonnes)
2023	300 t from this pilot project
2024	3,000 t from our own follow-up projects

	Plus: After our demonstration project we (and other organizations) will be able to use the knowledge, certification method and (IT-) infrastructure created in our project to scale ERW. This will easily scale into many thousands of tons of CO_2 over the next few years, but we have not created a mid-term planning for this.
2025	20,000 t from our own follow-up projects Plus: To be honest: We can't predict how fast other people/organizations will pick up ERW in general and the infrastructure we have developed in this project in particular. The potential of ERW is in the order of 1-4 Gt per year (Köhler at al., 2010; Streffler at al., 2018, Beerling at al., 2020) so the theoretical scalability is huge and our project will help to get closer to this number.
2026	...
2027	
2028	
2029	
2030	

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

	Milestone description	**Target completion date** (eg Q4 2024)
1	Definition of Certification Methodology (Ithaka Institute)	Q4/2022
2	Spreading basalt	Q3-Q4/2022
3	Implementation of tracking/bookkeeping (Carbon Future)	Q4/2022

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

N/A

k. How are you going to finance this project?

Pre-payments (e.g. for the basalt) were done by Carbon Drawdown Initiative.

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

Not yet, sale is planned on the Carbonfuture platform/website.

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

None.

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

Risk	**Mitigation Strategy**
Financial	Any financial risk associated is sufficiently backed by the Carbon Drawdown Initiative
Ecosystem	Deploying unsuitable rock powder to unsuitable land units may result in soil pH values undesirable for agriculture or introduce critical amounts of trace elements into the agroecosystem. Both such risks are mitigated through rigorous precaution measures embedded in the project (and carbon sink certification-) guidelines. Herein, geo-chemical thresholds for several parameters are defined and must be met by the rock powder product and the soil being subject to rock powder application. Such thresholds/ limit values cover i.a. heavy metal concentrations in both rock and soil as well as the baseline soil pH. Limit values are set more conservatively than dictated by European law (fertilizer regulation/ soil protection act).
[add rows as needed]	

2. Durability

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

The developed CDR accounting methodology aims for the certification of carbon sinks created through the sequestration of atmospheric CO2 as dissolved inorganic carbon (DIC), in the form of bicarbonate, being the product of weathering reactions.

Ultimately these weathering products will reach the ocean, where it can be attributed a mean residence time in the order of 10.000 years.

Parts of the oceanic DIC may be subject to biotic calcification (shell formation by marine biota). Debris of such lifeforms may enter the ocean sediment as particulate inorganic matter, sequestering the embedded carbon for geological timescales.

- Rau, G. H. (2011). CO2 mitigation via capture and chemical conversion in seawater. *Environmental Science & Technology*, *45*(3), 1088-1092.
- Renforth, P., & Henderson, G. (2017). Assessing ocean alkalinity for carbon sequestration. *Reviews of Geophysics*, *55*(3), 636-674.
- Campbell, J. S., Foteinis, S., Furey, V., Hawrot, O., Pike, D., Aeschlimann, S. & Renforth, P. (2022). Geochemical Negative Emissions Technologies: Part I. Review. *Frontiers in Climate*, *4*, 879133.

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

Once a landowner commits to the project and applies rock powder to their soil, the process is irreversible. There is no socioeconomic risk associated with basalt rock application to soil, it follows the same process as the addition of any other soil amendment in agricultural fields.

Fundamental uncertainties remain with the prediction of site-specific, in-situ weathering rates of multi-mineral rocks. The deployed method is conservatively estimating a minimum weathering rate under consideration of relevant environmental predictors.

Only combinations of rock material and land units suitable to facilitate successful and effective weathering reactions will be admitted in the project, thereby guaranteeing the occurrence of CDR. Potential carbon losses may be faced downstream. The reaction product of dissolved bicarbonate is following a soil solution - groundwater - river - pathway towards its final reservoir, the ocean.

Along this pathway, bicarbonate may be converted into carbonate if unfavorable chemical conditions occur (strong pH changes or supersaturation of the carrier solution). Such a reaction is generally reversible, however if no back-reaction takes place one mole CO_2 is lost per two moles of bicarbonate being transformed to carbonate minerals.

The methodology used in the present project is evaluating the likelihood of the formation of persistent carbonate minerals along the field to ocean pathway and addresses potential losses with a generic, yet adequate security margin.

3. Gross Removal & Life Cycle Analysis (LCA)

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

Gross tonnes of CDR over project lifetime	300 t
Describe how you calculated that value	This calculation is the result of the certification method that is being developed with this pilot project. Major steps are the calculation of the rock specific CDR potential and the deployment of a highly conservative model, estimating the extent to which the CDR potential will be realized in year 1 to 100.

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

In our previous field-based experimental science projects we used 110 tons of basalt (10 tons in 2021, 100 tons in 2022) which we expect to draw down 30-35 tons of CO_2 over time, based on our geochemical analysis to identify the optimal CDR-potential.

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

No explicit avoided emissions at this pilot stage.

A future prospect is the substitution of agricultural amendments like fertilizers and especially lime by basalt rock powder. Similar to lime, basalt and other silicate rocks release alkalinity and can be deployed for soil pH adjustments.

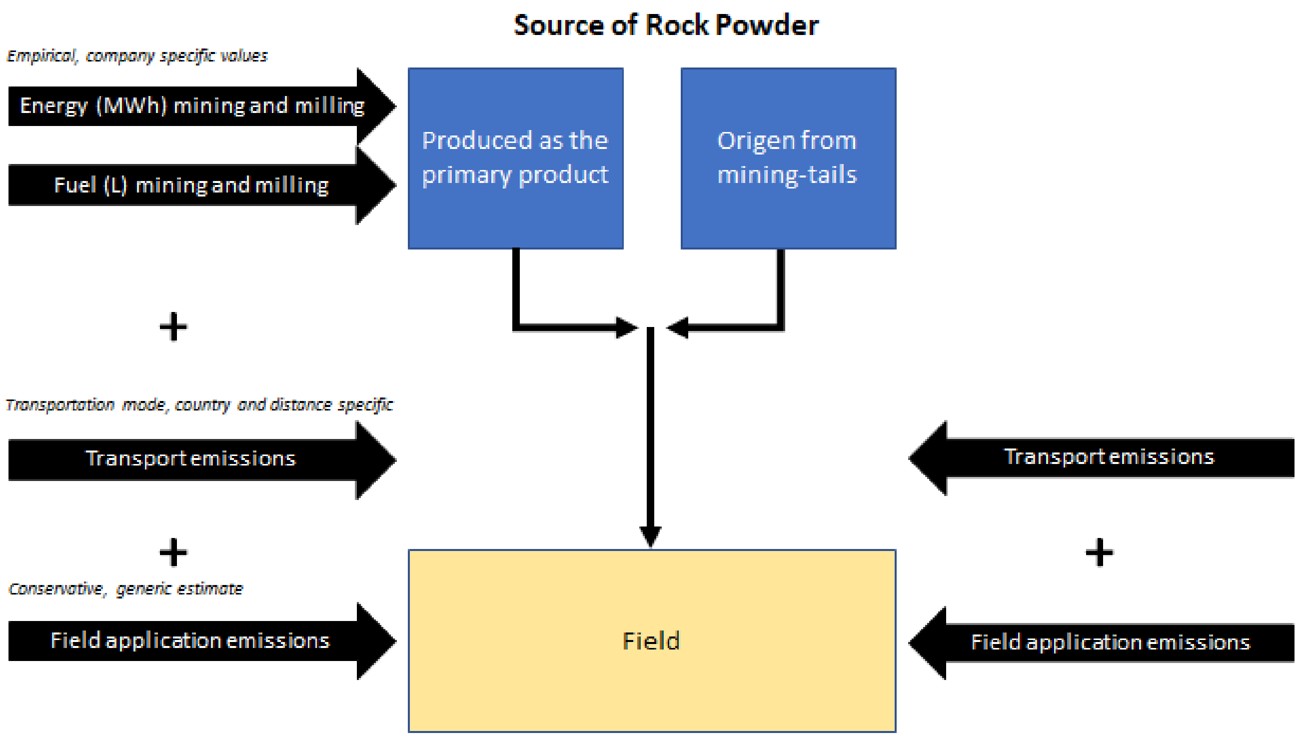
The industrial production of lime is associated with substantial emissions which could not only be abated, but replaced through a carbon negative product providing liming effects and other versatile co-benefits.

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

Gross project emissions over the project timeline *(should correspond to the boundary conditions described below this table)*	If rock powder was produced exclusively for ERW applications, a proportional share of the scope 1-3 emissions of the mining facility will be attributed. The attribution of emissions will be carried out according to the developed carbon sink certification guidelines. At present the project is exclusively deploying basalt rock powder originating from mining-tails (by-products of past mining activities). No additional emissions occur from such

	a scenario. To be considered are emissions from transport and field application, sketched below - to be calculated on a case-by-case basis. Considering mean transport distances of 250km, a mean transport emission factor of 111g CO_2 tkm^{-1} (truck, Germany) and 4 kg CO_2 t^{-1} for field application,each delivered t of rock powder will be attributed with carbon expenditures equivalent to: 250* 0.111 + 4 = 31.75 kg CO_2 1200 t * 0.03175 t = 38.1 t CO_2 In a conservative scenario (described above) 1 t of basalt will sequester ~250 kg CO2. Thus 1200 t basalt sequestering 300 t CO2. In a medium range scenario 1 t of basalt may sequester 300 kg CO2. Thus 1200 t basalt sequestering 360 t CO2 - to be calculated on a case-by-case basis. (CDR potential = 430 kg CO2)
Emissions / removal ratio *(gross project emissions / gross CDR–must be less than one for net-negative CDR systems)*	**Conservative assumption:** 38.1 t CO_2 / 300 t CO_2 = 0.127 **Mid-range assumption:** 38.1 t CO_2 /360 t CO_2 = 0.106
Net CDR over the project timeline *(gross CDR - gross project emissions)*	**Conservative assumption:** 300 t CO_2 - 38.1 t CO_2= 261,9 t CO_2 **Mid-range assumption:** 360 t CO_2 - 38.1 t CO_2 = 321,9 t CO_2

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



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

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

The present project and prospective scale up defines two different applicable boundary conditions, which apply depending on the source of the rock powder. For a fair attribution of product emissions a distinction must take place. The boundaries are set in a way covering all relevant emissions while providing simplicity and comprehensibility- thus real life applicability.

1. Rock powder from mining tails (unintentionally produced rock powder, originating as a by-product from other mining operations which already took place in the baseline scenario) and **2. rock powder exclusively produced for EW purpose** (representing an additionality to the baseline production of the company i.e. not being a waste product of the business as usual scenario).

At the present stage of the project only scenario one applies.

Emission attribution to mining tails:

For a transition period of 3 years past the publication of these guidelines, a mining company has the option to plausibly declare to the certifier that the sold rock powder originates exclusively from a storage of mining tails. If this is made plausible, the carbon expenditures per ton of rock powder must only cover emissions originating from material transport (factory gate to field) and emissions originating from rock powder field applications (diesel usage farm machinery)

Past this transition period, mining tails must additionally be attributed with a share of the scope one – scope three emissions as described below. The share of attributable emissions is equivalent to the share of annual revenue generated from rock powder sale, from the total annual revenue generated from the mining activities. (E.g. If 5% of the revenue is generated from sale of rock powder, 5% of the companies scope 1 – scope 3 emissions must be attributed to the rock powder product).

Emission attribution to rock powder exclusively produced for ERW purpose:

Carbon expenditures per ton of rock powder must cover 100% of relevant scope 1-2 emissions originating from mining and milling operations. Scope 3 emissions are approximated throu a 10 % margin.

$$Ex = ((E_{mining} + E_{milling}) \times EF + (F_{mining} + F_{milling}) \times 3.2 \text{ kg } CO_2eq) \times 1.1$$

E is energy usage in MWh t rock^{-1}

F *is the fuels (diesel) usage in L*

Ex *is the emission factor in kg CO_2e t^{-1} rock powder.*

EF *is the national emission factor for the electricity generation in kg CO_2e MWh^{-1}.*

Further, the material transport (factory gate to field) and emissions originating from rock powder field applications (diesel usage farm machinery)

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

Process Step	CO_2(eq) emissions over the project lifetime (metric tonnes)	Describe how you calculated that number. Include references where appropriate.
Energy Mining	*Not applicable at this stage*	The data will be identified and verified for each certified mining facility
Energy Milling	*Not applicable at this stage*	The data will be identified and verified for each certified mining facility

Mining company fuel use	*Not applicable at this stage*	The data will be identified and verified for each certified mining facility
Transport emissions	111g CO_2 t-km^{-1}	Emission factor for ton-kilometers of trucks in Germany *(Worldwatchers, 2019)*
Field application emissions	4000 g CO_2 t-km^{-1}	High estimate for emissions from field applications (*Moosdorf et al., 2014)*

4. Measurement, Reporting, and Verification (MRV)

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

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

> The rock powder used is very well characterized; all soils will be analyzed for basic parameters. This data is used to feed the model described in Ithaka's guidelines for the certification of ERW-based CDR.
>
> Additionally, there will be field measurements (soil samples sent to lab) and we will take several hundred kg of soil from each field and use them in our extensive pod/lysimeters experiments in the greenhouse mentioned above with lots of measurements/analysis.

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

> ERW transforms CO2 into dissolved inorganic carbon (bicarbonate) that is stabilized by the cations released from the rock during weathering. Bicarbonate will leach from the soil to groundwater, rivers and will eventually reach the ocean. On this journey, partial losses of carbon by precipitation of solid carbonate resulting in CO2 emissions is possible. Based on the geochemical conditions in these compartments, Ithaka's methodology accounts for possible losses by including adequate margins of security.

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

- In the first column, list the quantification components from the Quantification Tool relevant to your project (e.g., risk of secondary mineral formation for enhanced weathering, uncertainty in the mass of kelp grown, variability in air-sea gas exchange efficiency for ocean alkalinity enhancement, etc.).
- In the second column, please discuss the magnitude of this uncertainty related to your project and what percentage of the net CDR should be discounted to appropriately reflect these uncertainties. Your estimates should be based on field measurements, modeling, or scientific literature. The magnitude for some of these factors relies on your operational choices (i.e., methodology, deployment site), while others stem from broader field questions, and in some cases, may not be well constrained. We are not looking for precise figures at this stage, but rather to understand how your project is thinking about these questions.
- See this post for details on Frontier's MRV approach and a sample uncertainty discount calculation and this Supplier Measurement & Verification Q&A document for additional guidance.

Quantification component Include each component from the Quantification Tool relevant to your project	**Discuss the uncertainty impact related to your project** Estimate the impact of this component as a percentage of net CDR. Include assumptions and scientific references if possible.
Ex: storage leakage	*Ex: Based on historical monitoring data from well operator*
(include additional rows as needed)	

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

<50 words

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

> As described in the overview the main targets of our project are
> A) show the value chain already works from the mine to the field without having optimized the costs and
> B) work on MRV after application with extensive laboratory/greenhouse and open field experiments with our team of scientists to narrow down the corridors for future certificates.

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

We want to emphasize that our approach distinguishes us very much from other competitors:
In our view it is vital for the credibility of that purchased certificate that the company who executes the CDR method is not the one which measures and validates the actual CDR and/or the one that then creates the certificate and sells it.
Therefore our process involves independent partners that we have described in 1B.

5. Cost

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

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

300 $/tonne CO_2

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

Component	Levelized price of net CDR for this project ($/tonne)
Capex	$0 (no machinery etc. is being purchased)
Opex (excluding measurement)	$300 (rocks, biochar, logistics, spreading, share for farmer)
Quantification of net removal (field measurements, modeling, etc.)[2]	$0 (quantification/lab/greenhouse work covered by Project Carbdown)
Third party verification and registry fees (if applicable)	$0
Total	$300

c. Describe the parameters that have the greatest sensitivity to cost (e.g., manufacturing efficiencies, material cost, material lifetime, etc.). For each parameter you identify, tell us what the current value is, and what value you are assuming for your NOAK commercial-scale TEA. If this includes parameters you

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

already identified in 1(c), please repeat them here (if applicable). Broadly, what would need to be true for your approach to achieve a cost of $100/tonne?

Parameter with high impact on cost	**Current value (units)**	**Value assumed in NOAK TEA (units)**	**Why is it feasible to reach the NOAK value?**
Logistics	\$150/t CO_2	<\$30-50/t CO_2	The fields we use in this project are scattered over Germany, some are 400km away from the Eifelgold mine (due to speed and logistical reasons). Because only a few truck loads were sent to each farmer, other means of transport (train/ship) weren‘t available. In a scaled up process distance and means of transport would be optimized and thus could be lowered massively.
Biochar	\$60/t CO_2	\$0/t CO_2	In our demonstration project we wanted to show an immediate CO_2 storage effect, this involved buying biochar removal credits. In future, the speed of the ERW could be considered „fast enough“ and this cost block could be avoided.
Rock	\$60/t CO_2	<\$30/t CO_2	We are using off-the-shelf „Eifelgold“ with grain size up to 2,000 microns for a special price offered by RPBL for this project. In the future cheaper waste basalts could be used which could lower cost.
“Negative cost”: co-benefits for the farmer	unknown	unknown	Adding basalt to fields will change fertilizer requirements, which will likely result in cost savings for the farmer. Also, several studies have shown an increase in crop yield and plant health due to basalt spreading. Both effects as well as other co-benefits have not been assessed yet. They are not part of our current calculations yet and will change the calculations for the farmers’ revenue shares.

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

The financial impacts of the co-benefits will need more scientific and experimental work.

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

<200 words

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

Public support and/or financial incentives for farmers to do ERW on their fields.

6. Public Engagement

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

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

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

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

> Through personal contacts, Carbon Drawdown has been able to build a growing network of scientists (Project Carbdown). Direct supplementary funding of research and practical support allows these scientists to use their public funding with more impact. Those scientists partly engage in the funding schemes "CDRterra" as well as "CDRmare" by the Federal Ministry for Research and Education of Germany .
>
> We have been working with a growing group of farmers for over 2 years now during our preparation projects (10 tons in 2021 and 100 tons of basalt in spring 2022) and found that the farmers are very interested in improving their soil, replacing fertilizer with basalt and potentially make additional income from the sale of CO_2 certificates generated on their fields. In our social media channels farmers are approaching us to ask if they can be a part of the project.
>
> Ithaka then introduced ERW to the think-and-do-tank "Landwirtschaft 5.0" (German only, "Agriculture 5.0") that aims at the combined research and implementation of CDR (mainly biochar), agri-photovoltaics, electrification of farm vehicles, promotion of biodiversity of farm and agro-forestry for biomass production (for CDR, for fiber, etc) into the common practices of agriculture. Via

Landwirtschaft 5.0, we could connect with more farmers and this platform helps to gain interest e.g. by the media.

Carbon Drawdown Initiative is co-founder of Negative Emissions Platform (our CEO Dirk Paessler is also a board member), a lobby organization at the EU in Brussels, whose mission it is to support legislators in implementing rules for NETs properly and with deep understanding of the technologies.

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

<300 words

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?

Scaling up our pilot projects over >2 years and working with farmers has resulted in a permanent learning curve (on both sides) and these learnings are being fed back into out current work.

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

<100 words

7. Environmental Justice[3]

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

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

Until now all of our experiment/field work has been carried out in Europe because here we have fast and direct access to materials, machinery, labs, scientists -- the primary objective was learning-speed. But: The beauty of our proposed method of spreading rock dust on croplands is that it will be possible anywhere on the planet where suitable soils and rocks are available. Many of these areas are in the

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

global south (depleted/heavily-weathered soils in the tropics) and the necessary technology is very simple. Some test projects are being considered by our group, but nothing has been confirmed yet.

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

<300 words

8. Legal and Regulatory Compliance

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

There is no need for legal opinions as our project follows the legal framework (Germany/EU) for adding basalt rock dust as fertilizer on agricultural fields in Germany.

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

None. (In the still distant future for megaton/gigaton scale basalt mines will need permits to open new mines).
Application of rock powder is performed in agreement with the German Fertilizer Ordenance, that explicitly allows the use of rock powder as a soil amendment. The farmer does account for the additional rock-derived nutrients (P) supplied to the soil in their mandatory fertilizer planning and reporting.

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?

Not to our knowledge.

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.

The Certification Methodology provided by the Ithaka Institut will make sure that our project complies with all applicable legal or regulatory frameworks.

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

No, we don't.

9. Offer to Frontier

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

Proposed CDR over the project lifetime (tonnes) *(should be net volume after taking into account the uncertainty discount proposed in 4(c))*	300 t
Delivery window *(at what point should Frontier consider your contract complete? Should match 1(f))*	Early 2023
Levelized Price (\$/metric tonne CO_2) *(This is the price per tonne of your offer to us for the tonnage described above)*	US\$ 300

Application Supplement: Surface Mineralization and/or Enhanced Weathering

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

Source Material and Physical Footprint

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

> We use a standard, off-the-shelf product, "Eifelgold" from RPBL, with grain sizes up to 2,000 microns. We order directly from the supplier RPBL (www.rpbl.de). It is also approved for use in organic agriculture according to EU regulations.

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

> The basalt dust ("Brechsand") is produced in large amounts by RPBL, e.g. for the construction projects. For our pilot project we got deliveries via truck. Emissions for grinding and transport are factored in by the certification methodology.
>
> The material contains a certain amount of sand up to 2 mm grain size, which enables open storage, loose transport and spreading without significant dust formation.

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 3.

> No, the basalt as it comes on the truck is spread using lime spreaders.

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 table below.

	Land area (km^2) in 2021	**Competing/existing project area use (if applicable)**
Source material mining	unknown	
Source material		

processing		
Deployment		

5. How much CDR is feasible globally per year using this approach? Please include a reference to support this potential capacity.

The exact extent is unknown, but current basalt mining is in the megatons per year annually just in Germany alone.

Real-world deployment of ERW depends on many factors, including availability of suitable rocks, suitable arable land, and, last but not least, logistics. To this end, our project follows a bottom-up approach: Instead of an overarching, e.g. national modeling of transport routes etc., we focus on the concrete implementation of ERW. Thus, e.g., the rock has so far been transported exclusively by truck. In the coming year, larger quantities will be applied, with the aim of e.g. implementing long-distance transport by inland waterway vessel/train.

If such approach is successfully and globally integrated, the proposed technology may facilitate CDR in the order of 1-4 Gt CO_2 $year^{-1}$.

- Strefler, J., Amann, T., Bauer, N., Kriegler, E., & Hartmann, J. (2018). Potential and costs of carbon dioxide removal by enhanced weathering of rocks. *Environmental Research Letters*, *13*(3), 034010x
- Beerling, D. J., Kantzas, E. P., Lomas, M. R., Wade, P., Eufrasio, R. M., Renforth, P. & Banwart, S. A. (2020). Potential for large-scale CO2 removal via enhanced rock weathering with croplands. Nature, 583(7815), 242-248.

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?

Generally basalt is being used for construction (e.g. in concrete).
However, fine rock powders being most suitable for ERW applications are often considered a by-product of other mining activities, with little value addition in the baseline scenario. In many mining facilities rock powders (mining tails) are stored on a megaton scale.

Human and Ecosystem Impacts, Toxicity Risk

7. 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?

The material contains a certain amount of sand up to 2 mm grain size, which enables open storage, loose transport and spreading without significant dust formation. When rock powder might be dry, e.g.

during mining and processing, adequate personal protective equipment (PPE) is used, this includes respiratory protection.

The deployed rock powder is being analyzed for its heavy metal content and only rock feedstock adhering to the limit and precaution values of given German Fertilizer Ordinance is admitted. Generally the release of these (minor) quantities of heavy metals is much slower than those embedded in industrial fertilizers.

Parallel greenhouse, mesocosm and field-lysimeter trials will monitor potential heavy metal release in a circa-situm manner.

Undesired P-loads entering water bodies are not expected. Any farmer participating in the project needs to declare the field specific demand for P2O5 (according to common practice estimating the agricultural P requirements for the following 3 cropping seasons).
The project guidelines (same as the ERW carbon sink certification guidelines) define a maximum allowable rock powder application rate, equivalent to 50% of the agricultural P requirements.

If the maximal application rate is maxed out in a particular field, no further rock powder application is admitted for at least two years.

8. If minerals are deployed on croplands, what are the estimated effects on crop yields? Include citations to support this claim. How will actual effects be monitored?

In our field/lysimeter tests and pot experiments (greenhouse) done with the Eifelgold basalt before the pilot project we did not yet see conclusive proof that crop yields are improved, but they are expected to improve.

9. 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.)

We do not plan an explicit monitoring. Our basalt, Eifelgold, has been used and has been certified by the EU as fertilizer for decades. Even the organic farming association “Demeter” allows for unlimited use of Eifelgold on their fields, so we do not expect any adverse effects.