OPENAIR   Cornell University

Carbon Gardener

A Project Proposal and Funding Request

Submitted to DrawDAO

May 2022

1. Project Name: Carbon Gardener

2. Project Location(s): United States, multiple locations.

3. Team member names and roles (including advisors):

- **Garrett Boudinot, PhD - Science Lead, Cornell University**
- **Christopher Neidl - Lead Network Organizer, OpenAir**
- **Ben Houlton, PhD - Science advisor, Cornell University (Advisor)**
- **TBD - Volunteer Outreach & Support Coordinator, Cornell University**

- **TBD - Research Technical Project Manager, Cornell University**
- **TBD - Cornell Cooperative Extension Climate Smart Support Specialist (landscape design advisor)**

OpenAir supports a global volunteer community of nearly 1,000 members, adding between 20-30 new people to its Discord server every week. Nearly half of current membership is located in the United States. OpenAir's network will be directly engaged to promote and recruit participants for this initiative.

4. Email address for point of contact:

Dr. Garrett Boudinot - fgb44@cornell.edu

5. Project type:

- Research project that either may or may not physically deploy a working CDRS solution in the future

6. Project / research institution affiliation (if any):

Cornell University, College of Agriculture and Life Sciences (CALS).

7. Method(s) of Carbon Dioxide Removal and/or storage (can choose multiple, Choose from)

- Mineralization / Enhanced Weathering

8. The question(s) being investigated

The application of pulverized basalt ("rock dust") on agricultural soils has been studied as a means to drive permanent and scalable carbon sequestration on farmland through a process known as *enhanced weathering*. Previous trials conducted by Cornell University and University of California Davis researchers have demonstrated upwards of 1 ton CO_2/acre can be removed with practical amounts of basalt, with additional benefits for crop performance and soil health.[1]

Carbon Gardener team members Dr. Benjamin Houlton and Dr. Garrett Boudinot are leading a widespread consortium of field trials across soil and climate conditions in California, New York State, and Canada, applying geologically diverse basalt rock dusts to fields for a wide range of agricultural crops, including soy, corn, clover, hemp, potato, tomato, and even perennials such as alfalfa, almonds, and turf grasses. The detailed monitoring of these trials is generating data that is critical to effectively scale up enhanced weathering as a gigaton-scale carbon dioxide removal technology, being both practical for the farmers and land managers who apply it, and bankable as a CDR pathway with accepted standards for monitoring, reporting, and verification under globally-accepted carbon trading registries.

For the proposed initiative, a large sample of testing data will be derived from a diverse range of soil types and climate conditions from testing locations located throughout all regions of the United States. The primary research question that will be pursued through this initiative concerns the degree and variation of rock dust efficacy - as a CDR pathway and as co-beneficial soil amendment - across these differing physical contexts.

A secondary question relates to the efficacy of distributed, volunteer networks as drivers of accelerated scientific knowledge creation essential to validating rock dust as a viable, gigaton-scale CDR pathway.

9. Working hypotheses

1. The rate and level of carbon dioxide removal resulting from the application of basaltic rock dust to agricultural soil and other soil-rich landscaped areas will demonstrate variation across a range of dynamically linked soil chemistry and climate conditions.

[1] Holzer, I., Noccco, S., and Houlton, B.Z., Enhanced weathering during a historic drought in California (in preparation); Boudinot, F.G., Nasrallah, S., and Houlton, B.Z., Soil carbon and crop performance in response to mineral and microbial soil amendments: A field-scale corn trial (in preparation)

2. Distributed, volunteer-based, citizen science networks, operating under clear, science-aligned protocols, are capable of generating high quality data related to rock dust performance at a rate and scale that can be attributed to the unique properties of such networks, and which are not easily replicated by conventional institutions.

10. Brief description of project (less than 500 words)

The inputs required to scale rock dust-based enhanced weathering in the agricultural sector in the United States are all in place, and supply can be activated rapidly using existing, well-established, and low-cost methods, materials and supply chains.

What remains critically absent, and stands as the single greatest barrier to adoption at scale, is a refined understanding of the efficacy of rock dust for carbon dioxide removal across a diverse range of soil types and climate conditions. Further, the rate of expansion across the diversity of soil and climatic conditions - those that determine the efficacy of enhanced weathering - is limited under the centralized, acres-scale approach led by the existing consortium. A new model for assimilating data on the efficacy of enhanced weathering across geographies and application settings is required to scale up this technology at the rate needed to achieve maximum climate benefits.

Carbon Gardener, a joint mission of Cornell University's College of Agriculture and Life Sciences (CALS) and OpenAir, aims to fill this need by expanding and accelerating data creation/assimilation with the aim of graduating rock dust from the domain of academic research to real world, mainstream practice.

The initiative will activate a distributed citizen science network to generate specific, rock dust performance data across different soil types and climate conditions at locations throughout the United States. *Carbon Gardener* will leverage OpenAir's existing, highly active volunteer base to recruit volunteer teams anchored in high schools in all regions of the country, accounting for considerable soil and climate variation. Teacher-led student teams will perform and report rock dust testing and data collection at easy to construct, standardized garden test beds on school premises following a low-cost, easy to perform protocol developed by CALS researchers (see below).

A distributed network of this kind will bring unique scope, scale and speed to this critical research need; capabilities that even the most well-resourced, institution-led efforts would be hard pressed to replicate as extensively, if at all.

Following the completion of the testing and review phase the CALS team will prepare a scientific report synthesizing results and outcomes. The report will be submitted for peer review and publication at leading journals, such as *Frontiers in Climate*, *Nature,* and *Science*, and presented to leading carbon dioxide removal and citizen science communities, including at the 2023 Gordon Conference for Carbon Capture, Utilization and Storage, and the American Geophysical Union 2023 Fall Meeting. Successful publication at a peer-reviewed journal will foster greater acceptance of rock dust as a valid, CDR pathway among leading voluntary and compliance-based carbon removal and carbon credit registries and programs.

In addition to the direct value of data generation, the Carbon Gardener network will be activated to raise awareness about rock dust, and accelerate acceptance for those poised to deploy this climate solution. In contexts where positive viable results have been demonstrated network nodes consisting of both school teams and OpenAir members will promote rock dust directly to potential adopters in the local agricultural sector, guided by Climate-Smart Agricultural Extension expertise at CALS.

9. Detailed description of methodology

i. The Carbon Gardener Preparation, Testing and Data Collection Protocol.

The following methodology derives from one that has been developed by Dr. Boudinot and his team at Cornell University, and is rooted in well-established experimental practices and equipment.

- Recruited school teams, advised by a designated science faculty lead, will apply rock dust to either a) new raised bed with compost at 50:50 mix, or b) existing bed, then mix into top 3 inches of bed. A minimum of 3 beds will recieve rock dust applications., and for every rock dust bed, a non-amended “control” bed with the same characteristics otherwise (same soil/compost, planting, watering, etc) will also be monitored. A small sample of the rock dust used will be set aside and sent to Cornell for particle size and chemistry analysis to assess the role of specific basalt chemistries and properties on CDR potential.

- Following bed-construction, teams will install suction lysimeters, a small device allowing the sampling of soil water, into each bed (both with rock dust and non-amended). Throughout the growing season (i.e., from last frost to first frost), school teams will collect water samples from the lysimeters (lysimeter vacuum set to -60kPa, left for 24-72 hrs, then sampled with a syringe), place the water samples into 50 mL tubes, and refrigerate. Each month the refrigerated samples will be analyzed for dissolved inorganic carbon by the designated faculty point person at the school (ideally the science instructor). The recorded data tables from the analysis will be uploaded on an online platform hosted on the project website, and uploaded by the Cornell University lab for data processing and integration.
- At least once a year (i.e., at the end of the growing season), lysimeters will be removed, and soils sampled with the soil knife at 0-3 and 3-6 inch depth. Soil samples will be sent to the Cornell lab
- The Research Technician Project Manager (“Project Manager'') on the Cornell team will analyze soil samples for inorganic mineral carbonate, pH, and organic carbon. The project manager will record the results on the Carbon Gardener website, which will be represented geospatially using the google maps API.

ii. Network-Building & Material Logistics.

As a global network with deep penetration in the United States, OpenAir is uniquely positioned to drive recruitment and promotion of this initiative using its proven peer-to-peer outreach methods and *mission* structure. A small committed steering group within OpenAir’s Discord-based community has already formed to plan and execute research, recruitment and communications functions for the Carbon Gardener mission.

OpenAir members, distributed throughout all regions of the United States, will assist the Network Success Coordinator in engaging local high schools and securing participation. Building the Carbon Gardener network around high school nodes and science classrooms will deliver several practical advantages supportive of project success. First, there is a generally high level of demand among science teachers for supplemental curricular resources that augment classroom learning; and, in particular, resources that relate to real world subjects of interest to students such as climate change[2]. This creates generally conducive conditions for recruitment and retention.

Second, the high school environment furnishes a strong, built-in rationale for participation because the activities proposed relate directly to science learning objectives already present in existing curriculum and most local, state and national standards. Third, science teachers and classrooms already possess a baseline of knowledge and materials that Carbon Gardener activities can leverage to reduce time, effort and costs. Finally, schools are centralized locations that deliver participants and activity space within a structured, supervised and mission-oriented institutional context; factors which are generally conducive to quality control and continuity.

The growing number of high school science teachers, and parents of children in high school within the OpenAir community will be assigned special status as outreach peer ambassadors. Further, OpenAir will leverage its existing program and communications assets to promote and enlist participation, including:

- A 100% opted-in, 4,000 person + newsletter and subscriber list.
- Popular regular webinar series including *This Is CDR* and *CDR Horizons*, and other special programming.
- 1000+ followers on twitter (50% growth in last 3 months).

OpenAir and the CALS team will facilitate standard test kit delivery to participating schools (lysimeters, vacuum pump, syringe, ziploc bags, soil knife, 50 mL bottles, as well as analytical kit with pH meter, 100 mL beaker, pipette, and 10N HCl), including rock dust delivery.

[2] Chris Neidl, project lead network organizer, is a former environmental educator with several years of experience providing in-school climate change and energy related education services. In this capacity he has observed a very high degree of interest and willingness among educators to incorporate climate-related curricular activities into educational planning, provided that such resources are funded and standards-aligned. Carbon Gardener fulfills both of the latter conditions.

Kit materials will be fully paid for with funds secured through DrawDAO. To avoid unnecessary expenditure, the Network Success Coordinator will engage with faculty point persons to inventorize materials that the school already possesses or has ready access to, and exclude these materials from kit orders. Further, the mission partners will explore reduced cost rock dust supply through Cornell University's mining and material supply partners, including Maryland-based SGI**,** and bulk or wholesale reduced pricing for other materials and equipment in exchange for exclusivity and promotional/sponsorship opportunities.

10. For projects that are looking to scale their operations, please describe the CDRS project in detail using the below criteria. Feel encouraged to use visuals where applicable.

10.1. Process description: A step-by-step, scientifically verifiable methodology used for the CO2 sequestration/storage

- A comprehensive methodology developed by the Cornell Houlton Group at CALS to monitor CDR via enhanced weathering will be leveraged to monitor and verify CDR efficacy of rock dust. The comprehensive protocol integrates soil moisture, a full suite of soil chemistry (macro/micro nutrients, etc), soil carbon (organic and mineral inorganic), soil water bicarbonate, greenhouse gas flux from soil (CO_2, CH_4, N_2O), and crop productivity (yield, nutrient content).
- A streamlined version will be used for this project, targeting soil water bicarbonate and soil organic and inorganic carbon specifically, to compare changes in soil carbon, derived from atmospheric carbon, in response to rock dust application.
- The measured bicarbonate and carbonate fluxes will be extrapolated by precipitation and area of rock dust application to estimate carbon dioxide removal.
- In raised bed/modified soil studies of 50:50 basalt + compost, >7 tons CO_2/acre/yr sequestration estimated from mineral carbonate alone (e.g., Manning et al., 2013; https://www.sciencedirect.com/science/article/pii/S1750583613002156?via%3Dihub) - integration of lysimeters here will enable more robust assessment of carbon fluxes and CDR potential

10.2. Potential CO2 sequestered at scale

Assuming 1.5 - 3.5 tons of CO_2/acre/yr at 50:50 mix; a typical bed of 6X3'; 3 beds equals 54 ft2, or 0.0012 acres; at between 200 - 500 high school locations of that scale will yield approximately 1.5 - 3.5 tons of CO_2 removal. **However, it should be stressed that the impact value of the proposed initiative does not center on the CO2 that will be removed via the cumulative rock dust disbursal occurring during the course of the testing exercise. Rather the intended impact is to rapidly unlock annual gigaton CDR potential through the generation of soil and climate specific data, made completely public and open source, and subjected to peer review.**

With adequate data generation, acceptance, and optimization, including that achieved through this project, successfully scaled up enhanced weathering could achieve up to tens of gigatons of CDR globally leveraging agricultural lands alone (Fig. 1).

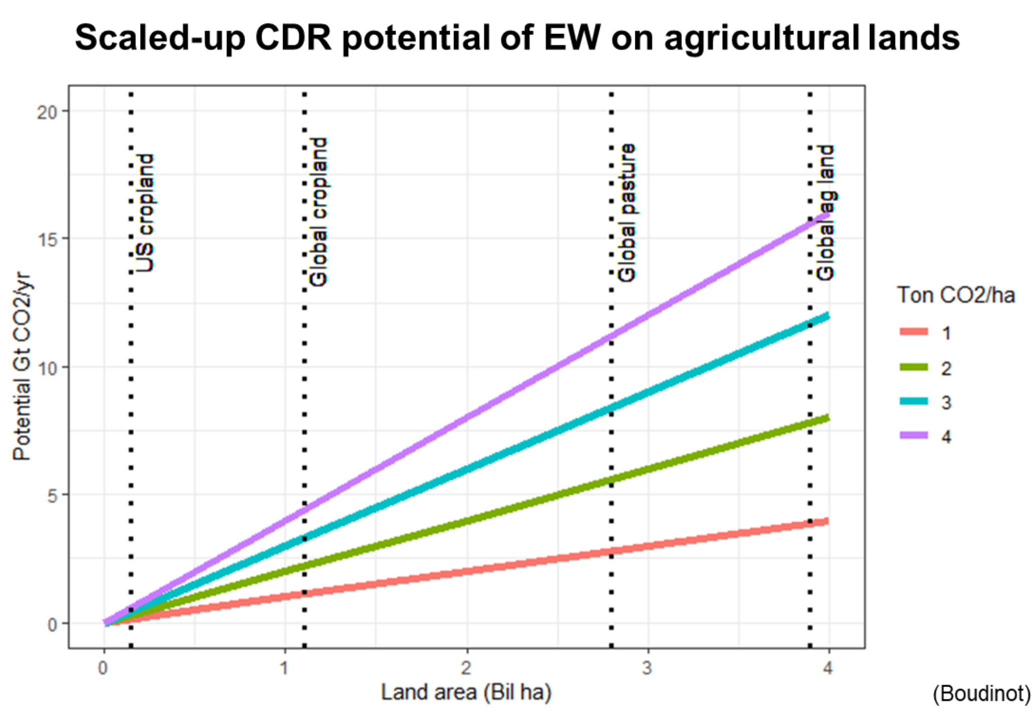

Fig. 1: Potential CDR (in gigatons CO2/year) of enhanced weathering across available agricultural land (in billion hectares) at a range of 1-4 tons CO2 removed per hectare.

10.3. *Permanence of the sequestered carbon in years*

Mineral preicipiated carbonate in soils stable for thousands to millions of years(Renforth and Henderson, 2017; Blattler et al., 2018).[3] If beds are removed/distrubed, much of the carbonate will remain as mineral carbonate, though some may be dissolved by rain over hundreds of years. Most CDR through bicarbonate in water, which enters groundwater, is stable for tens of thousands of years.

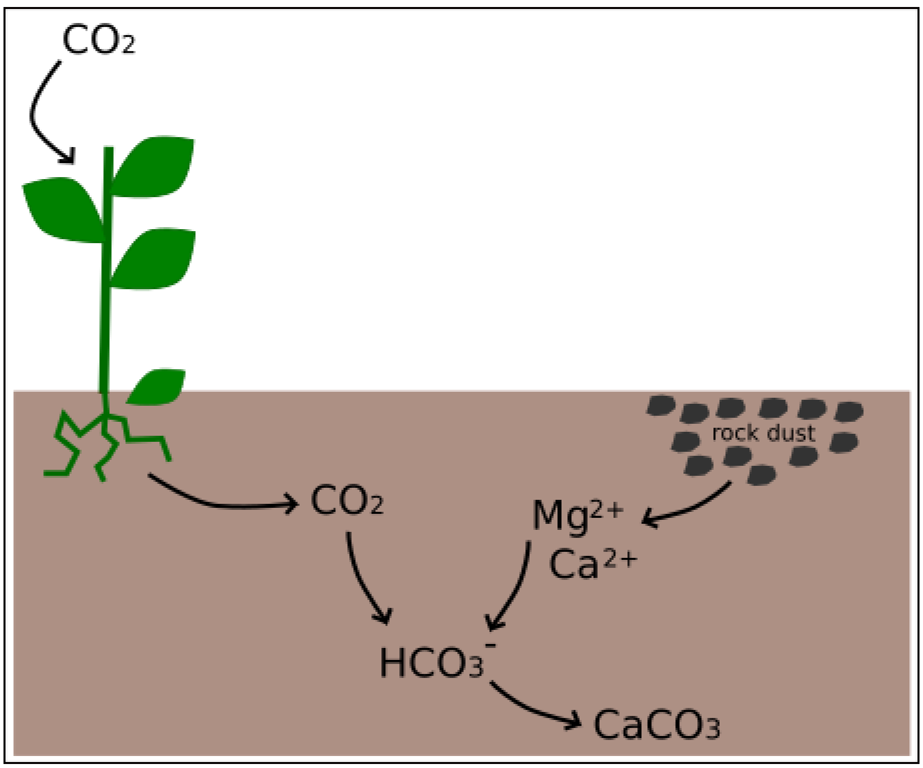

Figure 2: Schematic of the pathway of carbon dioxide removal through enhanced weathering, with end-products of bicarbonate (HCO3) in water and carbonate (CaCO3) minerals in soils.

[3] Renforth, P., and Henderson, , G., 2017. Assessing ocean alkalinity for carbon sequestration. Reviews of Geophysics, 55, 636-674. doi:10.1002/2016RG000533.

Blattler, C.L., Claire, M.W., Prave, A.R., Krsimae, K., Higgins, J.A., Medvedev, P.V., Romashkin, A.E., Rychanchik, D.V., Zerkle, A.L., Paiste, K., Kreitsmann, T., Millar, I.L., Hayles, J.A., Bao, H., Turchyn, A.V., Warke, M.R., and Lepland, A., 2018. Two-billion-year-old evaporates capture Earth's great oxidation. Science, 360, 6386. 320-323. DOI: 10.1126/science.aar2687

10.4. Justification for the additionality of the project (Why is this important now? Would it have happened without your intervention?)

Enhanced weathering offers promise as a CDR pathway, already shown to work at >1 ton/acre, but needs scale up. School facilities have sufficient capability, resources and space to ultimately site thousands of tons of CDR; which is a compelling program opportunity to consider in the future. But, first and foremost, efficacy must be demonstrated definitively through testing to justify large-scale adoption for this use case, and that's what the proposed school-based network is designed to realize at an accelerated pace.

This initiative will closely monitor how basaltic rock dust performs across varied climates and soil types, revealing which conditions and locations are most optimal for implementation. As some input emissions are required to transport rock dust to application sites, such detailed monitoring across conditions will ensure that larger scale-up achieves maximum net negative emissions through this additional soil amendment application.

10.5. Verifiability (how will you verify the sequestered carbon?)

The protocol involves the direct measurement of soil water bicarbonate and soil mineral carbonate and organic carbon. These results will be integrated within the more detailed data framework of the other trials hosted by the Cornell group to inform overall changes in emissions and carbon dioxide removal potential.

10.6. How is your project net-negative? i.e. How does your project result in a net decrease in atmospheric CO2, as opposed to simply avoiding the addition of further emissions? For this step, please take into account the estimated emissions of operating the project itself. It helps to diagram the flow of the process and include the gross emissions and gross removal at each stage.

Project activity	*Approximate resulting emissions, per unit*
Shipping test kit, avg 100 miles, 5 lb package.	0.4 kg CO_2
Shipping rock material, average 200 lb over 50 miles	1.4 kg CO_2.
Shipping soil once a year to the Cornell lab, avg 5 lb over 100 miles	0.4 kg CO_2
Total **Assumption: removal rate of 7 ton CO_2/acre at 0.0012 acres total from 3 beds = ~7 kg CO_2 sequestered. Net ~5 kg CO_2 sequestered.**	2.2 kgCO_2 emissions.

10.7. Rate of sequestration. At what point in time does the sequestration occur? (i.e. 10 years after planting the tree, 1 year after mineral dispersion, etc. Feel free to be more general in your answer, or give caveats as needed)

Sequestration begins immediately with rock weathering (measured with bicarbonate analysis of lysimeter samples,within weeks of rock dust application), and continues as rock weathers over time.

10.8. Potential leakage points

Sequestration efficacy will not be the same across all soils/climate conditions. Further, the distance of rock dust shipping can increase emissions, but the project will target school locations within 50-100 miles of basalt availability. This project will use the cornell groups' partnerships with mines across the country to leverage already-pulverized basalt rock dust that exists as byproduct of mining operations, ensuring that no additional emissions from mining accrue for this project. While this project will drive real, measurable removal of carbon dioxide and storage of carbon in soils, the primary purpose of this initiative is to rapidly generate diverse, in situ performance data on a granular level in order to optimize this technology and verification for large scale adoption, including identifying and mitigating against observed leakage points.

10.9 Co-benefits & potential negative externalities (feel free to use the UN SDGs as guidance, if applicable)

- Forming partnerships with schools (SDG 17, partnerships for the goals) as infrastructure/community hubs to be part of optimizing CDR in a grassroots manner
- Assessing the impact of rock dust on crop performance, with the potential for rock dust to generate food security benefits through soil chemistry and nutrient improvement (e.g., Beerling et al., 2018; https://www.nature.com/articles/s41477-018-0108-y) (SDG 2, zero hunger)
- Sustainable cities and communities (SDG 11) by leveraging common community infrastructure (school gardens) for CDR testbed
- Partnering with and leveraging existing mining industry by products and networks (SDG 9, industry, innovation, and infrastructure) to drive scalable CDR.

10.10. Estimated cost per tonne of CO2, with justification

- The value of CO2 removal currently scales with its permanence, with less stable organic carbon in soils generally priced at $20/ton CO2 (https://www.foodprocessing.com/industrynews/2021/cargill-to-pay-farmers-for-co2-reduction/#:~:text=Cargill%20is%20planning%20to%20pay,sequestered%20through%20regenerative%20agricultural%20practices.) , and million-year-scale belowground basalt rock injection mineralization priced at $1200 (https://www.datacenterdynamics.com/en/news/climeworks-opens-the-worlds-largest-carbon-capture-facility-in-iceland/#:~:text=%241200%20per%20ton%20of%20CO2,-The%20United%20Nation's) . Enhanced weathering generates durable carbon diioxide removal that is stable belowground for thousands to millions of years.

- Furthermore, it is achieved through a decentralized method that is deployed by individuals with land of any scale, from 1 to millions of acres, providing pathways for increased equity of CDR deployment compared to other DAC and subsurface storage pathways. The uniquely decentralized and verifiable nature of this “set it and forget it” technology, able to be deployed on farmland and landscaped areas using existing application equipment, with additional benefits for soil health and agricultural production, will make it the most socially equitable carbon dioxide technology in the market. Whereas existing solutions require enormous capital and specific geographic conditions, this technology is available for farmers of all scales and geographies to benefit from, creating equitable carbon capital for farmers and rural communities.
- These climate and social benefits add value to the price of CO2 tonnage through enhanced weathering, making costs from $100 to $600 appealing for a wide range of offsets consumers, while also opening premium pricing opportunities for agricultural commodities grown in enhanced weathering sois.

10.11. Mathematically verifiable and relevant calculations/methodologies for estimation for any of the above criteria.

The project team used Consumer Ecology’s emissions calculator to estimate shipping emissions projected in section 10.6
https://consumerecology.com/carbon-footprint-of-package-shipping-transport/

10.12. A timeline/roadmap for the various project stages, including where you are currently.

Pending receipt of DrawDAO, Carbon Gardener will commence immediately in Summer 2022 with OpenAir Mission launch, staff hiring, protocol training materials development, website development, and network recruitment, with the objective of confirming all participating school teams by October 1, 2022. Over the remainder of the fall and winter of 2022, rock dust and test kits will be prepared and shipped to participating school teams. In the early spring of 2023, teams will receive virtual training on deploying and verifying enhanced weathering, to be prepared in the spring of 2023 to deploy this project in their school garden for monitoring over the 2023 gardening season. By the winter of 2023, soil samples will be analyzed and the full data integration and CDR accounting will be complete for final reports and dissemination to commence before 2024.

10.13. Current blockers

Part of the core appeal of the proposed project is the high degree of readiness that characterizes all elements, from material and equipment supply, to network participation. This mission is *ready to go*. The following represent barriers that the proposed mission will aim to eliminate.

- TRAINING AND SUPPLIES IN SCHOOLS overcome by us sending kits, having video training for setup installation and sampling, having a dedicated project manager to assist - but we need resources to support that all, hence this application

- LACK OF PLACES TO DEPLOY ACROSS CLIMATE/SOIL CONDITIONS overcome by openair network, track record of grassroots mobilization

- DIFFICULTY VERIFYING BELOWGROUND SOIL CARBON DYNAMICS will be overcome by the Cornell CALS group's leveraging of lysimeters to capture soil water

10.14. Any outstanding research or experimentation to be done

No, excluding the core activities proposed in this application.

10.15. Any current or in-progress LCA's, credit verifications, patents, peer-reviewed papers, or supporting documents that verify the methodology

There are several published and in-progress peer reviewed papers and directly support the assumptions that this project is based on. The following sample includes several, along with other media and public-facing resources relevant to the subject.

- Holzer, I., Noccco, S., and Houlton, B.Z., Enhanced weathering during a historic drought in California (in preparation);
- Boudinot, F.G., Nasrallah, S., and Houlton, B.Z., Soil carbon and crop performance in response to mineral and microbial soil amendments: A field-scale corn trial (in preparation)
- https://cpb-us-e1.wpmucdn.com/blogs.cornell.edu/dist/a/7491/files/2022/02/2021-Hemp-Soil-Weathering-Trial-handout-20220218.pdf
- Demonstration of raised bed/modified soil studies of 50:50 basalt + compost yielding >7 tons CO2/acre/yr sequestration estimated from mineral carbonate alone (e.g., Manning et al., 2013; https://www.sciencedirect.com/science/article/pii/S1750583613002156?via%3Dihub)
- https://thehill.com/opinion/energy-environment/573084-rock-dust-could-put-a-drain-on-atmospheric-carbon-will-this/
- https://e360.yale.edu/features/how-adding-rock-dust-to-soil-can-help-get-carbon-into-the-ground

10.16. Whether or not you would be interested in/able to provide future carbon credits.

A central aim of the proposed project is to help validate rock dust amendment practices as a carbon credit eligible CDR pathway through data generation. Neither OpenAir nor Cornell University intend to assume a position as a carbon credit provider, but it is our hope that this revenue opportunity will be made available to farmers and/or their rock dust suppliers.

11.17. Target amount of funding

A notable advantage of this proposal is its modular, distributed nature, which allows for high value implementation on a variety of participation scales. The mission goal is to recruit 100 participating school teams throughout the United States; However, even a participating cohort of 25 sites, located across a diverse soil and climate spectrum, would deliver a large enough sample to ensure significant value in line with the core mission objectives.

To fully fund the material, logistical and staffing needs for 100 sites, Carbon Gardner would require a maximum award of approximately $340,000. However, an award as low as $124,000 (i.e. @25 participating sites) would make this mission viable.

12.18. Any current or in-progress LCA's, credit verifications, patents, peer-reviewed papers, or supporting documents that verify the methodology

- Holzer, I., Noccco, S., and Houlton, B.Z., Enhanced weathering during a historic drought in California (in preparation);
- Boudinot, F.G., Nasrallah, S., and Houlton, B.Z., Soil carbon and crop performance in response to mineral and microbial soil amendments: A field-scale corn trial (in preparation)
- https://pubs.acs.org/doi/pdf/10.1021/acs.est.1c04111 this paper argues the need for testing of urban garden enhanced weathering
- https://cpb-us-e1.wpmucdn.com/blogs.cornell.edu/dist/a/7491/files/2022/02/2021-Hemp-Soil-Weathering-Trial-handout-20220218.pdf
- Demonstration of raised bed/modified soil studies of 50:50 basalt + compost yielding >7 tons CO_2/acre/yr sequestration estimated from mineral carbonate alone (e.g., Manning et al., 2013; https://www.sciencedirect.com/science/article/pii/S1750583613002156?via%3Dihub)
- Rock dust op-ed by Dr. Houlton and Dr. Boudinot, The Hill https://thehill.com/opinion/energy-environment/573084-rock-dust-could-put-a-drain-on-atmospheric-carbon-will-this/
- "How Adding Rock Dust to Soil Could Help Get Carbon into the Ground." Yale E360. https://e360.yale.edu/features/how-adding-rock-dust-to-soil-can-help-get-carbon-into-the-ground
- *Rock Dust! With Dr. Garrett Boudinot, This Is CDR [OpenAir webinar]* *https://www.youtube.com/watch?v=q-MFy08wD5g*

Rate ton CO_2/ac/yr	*Paper*	*Description*
0.3	*Taylor, L.L., Quirk, J., Thorley, R.M.S., Kharecha, P.A., Hansen, J., Ridgwell, A., Lomas, M.R., Banwart, S.A., and Beerling, D.J. 2015. Enhanced weathering strategies for stabilizing climate and averting ocean acidification. Nature Climate Change, 6, 402- 406. DOI: 10.1038/NCLIMATE2882.*	*Model, basalt*
0.8-1.6	*Kelland, M.E., Wade, P.W., Lewis, A.L., Taylor, L.L., Sarkar, B., Andrews, M.G., Lomas, M.R., Cotton, T.E.A., Kemp, S.J., James, R.H., Pearce, C.R., Hartley, S.E., Hodson, M.E., Leake, J.R., Banwart, S.A., and Beerling, D.J., 2020. Increased yield and CO2 sequestration potential with the C4 cereal Sorghum bicolor cultivated in basaltic rock dust-amended agricultural soil. Global Change Biology, 26, 3658-3676.*	*Mesocosm, basalt*
2.5	*Strefler, J., Amann, T., Bauer, N., Kriegler, E., and Hartmann, J. 2018. Potential and costs of carbon dioxide removal by enhanced weathering of rocks. Environmental Research Letters, 12, 034010 https://doi.org/10.1088/1748-9326/aaa9c4.*	*Model, basalt*
0.4-4	*Lefebvre, D., Goglio, P., Williams, A., Manning, D.A.C., Carlos de Azevedo, A., Bergmann, M., Meersman, J., Smith, P. 2019. Assessing the potential of soil carbonation and enhanced weathering through Life Cycle Assessment: A case study for Sao Paulo State, Brazil. Journal of Cleaner Production, 233, 468-481. https://doi.org/10.1016/j.jclepro.2019.06.099.*	*Model, basalt*

0.2-4.4	*Beerling, D.j., Leake, J.R., Long, S.P., Scholes, J.D., Ton, J., Nelson, P.N., Bird, M., Kantzas, E., Taylor, L.L., Sarkar, B., Kelland, M., DeLucia, E., Kantola, I., Muller, C., Rau, G.H., and Hansen, J. 2018. Farming with crops and rocks to address global climate, food and soil security. Nature Plants, 4, 138-147. https://doi.org/10.1038/s41477-018-0108-y.*	*Model, basalt*
6	*Strefler, J., Amann, T., Bauer, N., Kriegler, E., and Hartmann, J. 2018. Potential and costs of carbon dioxide removal by enhanced weathering of rocks. Environmental Research Letters, 12, 034010 https://doi.org/10.1088/1748-9326/aaa9c4.*	*Model, basalt*
7.1	*Manning, D.A.C., Renforth, P., Lopez-Capel, E., Robertson, S., and Ghazireh, N. 2013. Carbonate precipitation in artificial soils produced from basaltic quarry fines and composts: An opportunity for passive carbon sequestration. International Journal of Greenhouse Gas Control, 12, 309-317. http://dx.doi.org/10.1016/j.ijggc.2013.05.012.*	*Plot, basalt + compost*

13.19. Breakdown of planned use of funds, if received.

Please refer to this google spreadsheet for an itemized budget breakdown, including fixed and variable costs (see rows 34-36 for adjusted expenditures based on level of participating sites.)

14.20. Safety concerns

- Titrations performed by school teacher requires controlled use of 10N HCl; protocol and kit will include safety precautions and equipment
- Potential soil contamination mitigated by testing materials prior to application and use of only basalt / metabasalt (a geographically ubiquitous and harmless rock type)

- Potential inhalation of silicate particles during application mitigated by safety protocol and kit that includes safety equipment (eyewear, face mask)

15.21. Regulatory/compliance concerns (what permits are needed, who needs to approve the project, etc.)

- *School teams will be determined based in part on availability of garden beds, which will require approval at the school garden and from school administrators.*
- *Because school partners will all be located in the US, no permits will be required for the shipping of soils or materials to and from OpenAir/schools/Cornell*
- *For scaled-up deployment, proper shipping contracts/infrastructure is required to transport rock dust in large volumes to acre-scale application sites, and contract work with commercial shipping companies satisfies regulatory compliance.*