Research Priorities for Enhanced Weathering (EW)

Created by the Enhanced Weathering Policy Working Group

Carbon Removal Alliance

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The enhanced weathering policy working group is composed of the field's leaders, spanning nonprofits, academics, and industry. Led by Cascade Climate and the Carbon Removal Alliance, the working group aims to advance critical research and deployment milestones for this emerging field.

What is enhanced weathering?

Enhanced weathering is a promising land management and carbon removal solution that involves spreading finely crushed rocks–such as basalt and olivine–onto fields. Weathering is a natural process where rocks break down or "weather" after interacting with the environment either through physical, chemical, or biological means. Think about the process of creating sand, or rocky coasts eroding against the ocean. Enhanced weathering (EW) seeks to speed up this natural process, while removing carbon from the air and storing it durably.

Enhanced weathering is a general approach toward soil management that includes the widespread agricultural practice of applying agricultural lime (calcite or dolomite) to fields to counteract soil acidification. It begins with finely crushed rocks, often leftover material at quarries, that are spread onto agricultural fields to accelerate a natural reaction between the minerals, water, and atmospheric carbon dioxide. This interaction converts carbon dioxide from the air to dissolved bicarbonate that can be transported by rivers to the oceans where it can be stored on millennial timescales. Initial research also suggests that EW can reduce on-farm emissions of nitrous oxide, an important and long-lived greenhouse gas that is primarily derived from the agriculture sector.

Enhanced weathering with silicate minerals has potential to provide powerful benefits to farmers managing their fields – adding critical nutrients and countering the acidification of soils from fertilizers. It also has the potential to better position American farmers to mitigate the effects of extreme weather and lead efforts to meet sustainability targets within agricultural supply chains.

To date, federal research agencies and programs have lent early support to the emerging enhanced weathering field. USDA has awarded $4.9M in funding for enhanced weathering projects through the Partnerships for Climate-Smart Commodities Program and DOE has awarded $16M in funding for enhanced weathering pilots through the Carbon Negative Shot Pilot Program in addition to $5M for development of an enhanced weathering modeling framework. The private sector has been active, attracting millions in investments and seeding a dozen companies that are working with farmers across the globe today to put enhanced weathering into practice. Nearly 300,000 tons of carbon dioxide removal have been sold on the voluntary carbon market attributable to enhanced weathering, according to CDR.FYI. These companies are partnering directly with American farmers, who are taking advantage of the potential to reduce soil acidity, improve soil nutrient content, reduce the need for fertilizer application, and boost crop yields.

The funding support needed for enhanced weathering will vary by research area and program. The National Academies of Science has developed a research agenda for carbon mineralization (including but not limited to the potential of enhanced weathering on agricultural lands) and estimated its basic research costs to be around $48,500,000 per year over ten years in typical academic grants and around $21,500,000 per year over ten years in Department of Energy National Lab and USGS projects as shown in Table 6.3. Note, this estimate is over 5 years old and therefore is likely an underestimate of the current needs for the field. Interagency coordination is also essential to align on government research priorities and reduce redundancies.

More research is needed to advance carbon quantification and nitrous oxide emissions reduction methods and tools to accurately quantify net emissions benefits, determine specific site and feedstock conditions where enhanced weathering's agronomic and environmental benefits can be realized, identify any potential environmental risks, and evaluate corresponding approaches to mitigate those risks. There is still much to learn about the soil benefits and rates of carbon uptake across different agricultural systems and mineral feedstock types. The majority of federally-funded enhanced weathering research grants have not taken place on agricultural lands, and very few have sought to quantify the agronomic and environmental benefits and impacts of this practice across soil types, climatic regions, and types of farming operations.

Our recommendations highlight new and existing research programs that could be better utilized and resourced to increase scientific understanding of the environmental, health, and agronomic impacts of enhanced weathering implementation. These public research and demonstration efforts will ultimately support farmers with the tools and resources they need to inform decision-making around adopting these soil amendments. They are also essential for building farmer trust in the practice and its suitability for agronomic applications.

	RESEARCH AREA	JUSTIFICATION
1. INVEST IN MONITORING, REPORTING, AND VERIFYING (MRV) AND CARBON AND EMISSIONS QUANTIFICATION.		
1A	Efficiency of carbon removal and nitrous oxide emissions reduction under different agriculture system conditions and mineral types	Due to the heterogeneity of agricultural systems and the variety of feedstock options, the carbon, nitrous oxide and agronomic benefits of enhanced weathering are highly context-dependent. Deploying EW in research demonstration sites across soil types, climatic settings, crop types, and operations (organic, specialty crop, commodity production, rangelands, etc.) will be necessary to assess the environmental and economic benefits of the practice across U.S. regions.
1B	Data collection and management	Government support is needed for measurement and data collection from EW deployments and field trials that go beyond typical commercial expectations for CDR quantification—for example, measurements of non-GHG fluxes, and measurements of carbon and cation fluxes in deeper soils, critical zones, and rivers and catchments. These additional measurements can help reduce system-level uncertainty and drive continuous improvement of EW MRV over time. Additionally, coordinated support for data management and storage across government data systems is needed.
1C	MRV tools (e.g., novel sensor development) and model development	Due to the early stage of measurement, reporting, and verification (MRV) in the field of EW, MRV costs are relatively high. Government support for MRV tool innovation, monitoring infrastructure, model development and continuous refinement can help drive down costs and scale EW.
1D	Life cycle assessments	Additional life cycle assessment research across a range of scenario feedstock and agricultural system combinations can help move the field towards a model-based netCDR quantification process such as GREET or COMET, and inform policy decision-making around incorporating EW as part of carbon intensity calculations for biofuels tax credits/LCFS.

Relevant USDA programs: Long-Term Agroecosystem Network, Agriculture Food Research Initiative, Rapid Carbon Assessment, Foundation for Food and Agriculture Research OpTIS, Agricultural Research Service Global Change and Photosynthesis Research Unit, ARS GHG Monitoring Network, Conservation Innovation Grants

Relevant other government programs: USGS river monitoring, NASA US Climate Reference Network, NASA Harvest, DOE MMRV Lab Call, DOE Carbon Negative Shot, DOE Bioenergy Technologies Office, NSF National Ecological Observatory Network

	RESEARCH AREA	JUSTIFICATION
2. INVEST IN AGRONOMIC AND ECONOMIC RESEARCH TO UNDERSTAND SOIL AND YIELD IMPACTS AND THE FARMER ROI.		
2A	Yield and soil nutrient impacts, including comparing to lime as a soil pH amendment	For farmers to be interested in applying enhanced weathering soil amendments, research is needed to better understand the agronomic benefits of application including any yield, soil health, nutrient use, input substitution, and pest resistance impacts. It is particularly important to compare these impacts systematically against limed controls.
2B	Techno-economic assessments	For farmers to be interested in applying enhanced weathering soil amendments, research is needed to better understand the costs of deploying EW and how this varies by distance to feedstock source relative to baseline liming practices. Quantification of the revenue streams associated with EW, including carbon payments, practice payments and yield benefits and/or input reductions is also needed to conduct a full farmer return on investment (ROI) analysis.
2C	Tool development for estimating EW application rates under different soil conditions and mineral types	Farmers will need a simplified tool, analogous to existing regulatory assays for aglime and aglime equivalence calculators, that can estimate EW feedstock application rates for a targeted pH change. Research into modeling and protocol development will be crucial to enable local regions to identify appropriate EW feedstocks and rates for their soils.
Relevant USDA programs: Conservation Innovation Grants, Sustainable Agriculture Research and Education, Soil Carbon Demonstration Trials, Agriculture Food Research Initiative, Agricultural Research Service Relevant other government programs: DOE MMRV Lab Call		

	RESEARCH AREA	JUSTIFICATION
3. ADVANCE RESEARCH ON POTENTIAL ENVIRONMENTAL AND COMMUNITY IMPACTS.		
3A	Heavy metals exposure thresholds	Guidelines for cumulative application limits specific to EW feedstocks are needed to ensure the safety of ecosystems, drinking water supplies, and communities near deployments.
3B	Environmental and health impacts	Further research is needed to understand the effects of EW on a broader scale than just the surface soils in which it is applied (including enhanced and expanded mining; compaction from amendment application; and soil health, soil microbe, and biodiversity impacts). This funding could be extrapolated to understanding the effects of increased weathering products in soil, groundwater, and surface water systems on ecosystems and human health.
3C	Social science research	Additional research is needed to engage producers to better understand what their management priorities are, how EW aligns with those priorities, and to educate producers on the potential agronomic risks and benefits. Broader community social science is also needed to determine how communities view EW and their perceptions of the potential risks and benefits.
3D	Large-scale environmental monitoring technology development	Pilot field studies that integrate groundwater, air and other relevant environmental monitoring and establish data coordination effort across private and public research. Support development of affordable, modular Internet of Things devices tailored to EW applications. These could integrate sensors for tracking material composition, GPS for precise location mapping, and connectivity for real-time data upload.
Relevant USDA programs: Climate Hubs, Conservation Innovation Grants, National Institute of Food and Agriculture Relevant other government programs: EPA Soil Screening Levels under Safer Chemicals Research Program, National Science Foundations, U.S. Geological Survey		

Long term research is essential.

Existing and proposed national research networks provide a blueprint for enhanced weathering research. For example, the Agricultural Research Service (ARS) manages the Long-Term Agroecosystem Research (LTAR) network, which operates 18 research sites across the country. Researchers across the network strive to answer questions fundamental to future agricultural sustainability—such as those involving changes in soil carbon, climate, and the long-term effects of land use changes—that take longer than the typical 2-5 year project cycle.

Meanwhile, the Biochar Research Network has been proposed by Representatives Miller-Meeks, Pingree, and Schrier and Sens. Grassley and Thune to test biochar's ability to absorb carbon on a variety of soil types and increase crop production. This offers a model for what a new EW research network could look like.

Both the creation of new and expansion of existing programs for enhanced weathering research should emphasize translating research insights into real agronomic impact.

FOOTNOTES

[1] EW can include both carbonate and silicate feedstocks as long as there is net carbon removal which will be location-specific. Carbonate feedstock (calcite, dolomite) is commonly referred to as agricultural lime ("aglime"), and is already a widespread practice among U.S. farmers to counteract soil acidification. Silicate EW feedstocks are not a 1:1 replacement for agricultural lime. The rate at which silicate feedstocks dissolve is slower than that of aglime, meaning that silicate feedstocks tend to take longer to achieve the same pH benefit as aglime.

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