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Enhanced Weathering and Working Lands

Opportunities for carbon removal
integration into agricultural subsidies
using the Find-Match-Measure framework



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Contents

04 Executive summary

05 Introduction

06 Find

09 Match

16 Measure

20 Conclusion

21 Appendix



Executive summary

To scale embedded carbon removal pathways, it is necessary to *find* opportunities where carbon removal naturally integrates into existing processes or activities, *match* those opportunities with the policies and regulatory frameworks that could be adjusted to facilitate these integrations, and *measure* removals in ways that are customized to each pathway, application, jurisdiction, and timescale.

This white paper illustrates this Find-Match-Measure framework by exploring its application to enhanced weathering, specifically:

- how we identify soil pH management as an avenue for carbon removal,
- what kinds of policy mechanisms can support agronomic goals and carbon removal in parallel, and
- approaches to quantification that will build trust and scale.

We review the agronomic benefits of enhanced weathering, focusing on soil pH management and its role in addressing widespread soil acidification and improving crop yield. We analyze the prevalence of liming subsidies globally and present two illustrative case studies: the Nova Scotia Liming Trucking Assistance Program, which predates interest in carbon removal, and the Kingston Wollastonite Rebate, a recent public–private partnership supporting commercial enhanced weathering trials. Together, these examples demonstrate the variation of subsidy design across jurisdictions and contexts.

This paper also explores how study design and quantification methods developed within agricultural policy frameworks could complement market-based carbon removal protocols to support scientific learning over time, which is critical for open system pathways at early stages of development.

By mapping research and deployment needs onto existing policy vehicles, this work contributes to the foundation for embedding enhanced weathering within policy. Leveraging public infrastructure, larger spatial scales, and longer time horizons may provide opportunities for improved precision and accuracy of estimates, stronger public empirical datasets, iterative learning, and cost reduction through economies of scale.

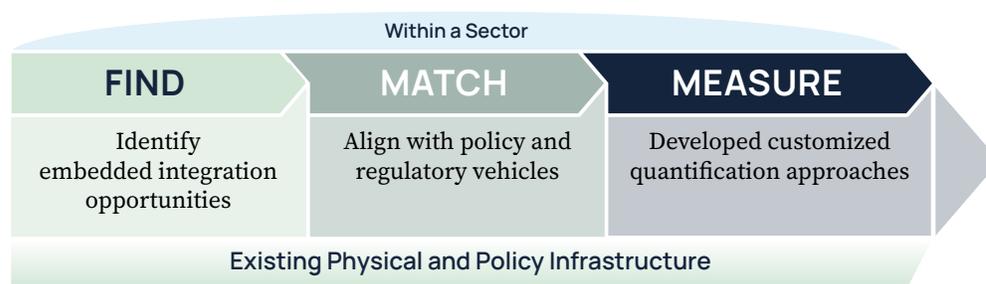
The Find-Match-Measure framework outlined in this paper is a template for myriad other integration opportunities across society. We hope that by exploring our process and questions for one particular integration, the potential of this framework, as well as clear next steps to advance enhanced weathering integrations, will become actionable to the field.

Introduction

Limiting the increase in global temperature and subsequent climate damage will require carbon removal as a supplement to emissions reductions.¹ To meet this need, a suite of carbon removal pathways at various stages of development is being explored.² No single pathway is sufficient; instead, we will need an array of solutions that collectively reach the requisite scale, globally. In addition to dedicated facilities and projects that serve the singular purpose of removing carbon from the atmosphere, carbon removal solutions must be embedded into a range of sectors through a broad portfolio of policy and regulatory mechanisms.^{3,4}

Specifically, to scale carbon removal via embedded pathways, it is necessary to **find** opportunities where carbon removal naturally integrates into processes or activities, **match** those opportunities with the existing policies and regulatory frameworks that could be adjusted to facilitate these integrations, and **measure** removals in ways that are customized to each pathway, application, jurisdiction, and timescale.

The Find-Match-Measure Framework



This white paper explores enhanced weathering through the Find-Match-Measure framework to showcase its practical application. In particular, we focus on understanding the scope and structure of existing liming subsidies and exploring the potential for fit-for-purpose quantification within the context of these policies.

¹ Intergovernmental Panel on Climate Change. (2023). Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H. Lee & J. Romero (Eds.)]. IPCC. <https://doi.org/10.59327/IPCC/AR6-9789291691647>

² Smith, S. M., Geden, O., Gidden, M. J., Lamb, W. F., Nemet, G. F., Minx, J. C., Buck, H., Burke, J., Cox, E., Edwards, M. R., Fuss, S., Johnstone, I., Müller-Hansen, F., Pongratz, J., Probst, B. S., Roe, S., Schenuit, F., Schulte, I., Vaughan, N. E. (eds.)

The State of Carbon Dioxide Removal 2024 - 2nd Edition. <https://www.stateofcdr.org/edition-2-resources-1>

³ Maesano, C., Mitchell-Larson, E., Clark-Sutton, K., Pike, D. Seizing the Industrial Carbon Removal Opportunity. RMI. <https://rmi.org/seizing-the-industrial-carbon-removal-opportunity/>

⁴ Bryce, T., Rubin, B., Corpora, I. Demand-Side Support for Scaling Carbon Dioxide Removal. Carbon Business Council. <http://carbonbusinesscouncil.org/news/demandside>

Find

“Find” is the first step of the Find-Match-Measure framework. To find carbon removal opportunities embedded inside diverse sectors of the economy, the carbon removal community needs to: (1) map carbon flows and sinks, (2) assess carbon removal potential where carbon fluxes and industrial processes intersect, and (3) identify barriers, risks, and opportunities to scaling a given carbon removal integration. In this section, we explore the intersection of soil pH management and carbon removal via enhanced weathering in the agriculture sector.

Overly acidic agricultural land is a persistent problem worldwide. Many common crops require neutral to slightly acidic soil pH to thrive.^{5,6} When grown in more acidic conditions, yields can decrease substantially. In turn, lower yields can lessen food supplies and cut into farmers’ bottom lines. The relationship between pH and yield is well documented, yet large percentages of cropland remain below optimal pH. Globally, 50–60% of agricultural lands are estimated to be below a pH range of 6.5–7.0.⁷ In the United States, approximately 50% of croplands were found to be below crop-specific ideal pH values.⁸ The causes of acidic soils vary geographically and include factors like climate, soil parent material,⁹ and land management practices such as the use of nitrogen-based fertilizers.¹⁰

Acidic croplands are not a new problem. Since the mid-20th century, and much longer in certain regions, spreading crushed limestone, dolomite, and other feedstocks has been a well-established strategy to increase soil pH.¹¹ This process, often called liming, first involves crushing the feedstock (lime) into granules. These granules are often the size of a grain of sand or smaller. They are sometimes a waste product of other limestone materials produced by quarries. After purchase, the lime is transported to farms, where it is spread at rates commonly ranging from under 1 to 3 tons per acre.^{5,12,13} Once deployed, water from irrigation or rainfall reacts with the lime, causing it to dissolve. This dissolution process raises soil pH by neutralizing H⁺ cations and removing them from exchange sites. The soil pH increase from liming can benefit crops within the same or following growing seasons.¹⁴ Lime is used in many countries and the spreading process is relatively straightforward, but higher adoption rates are needed to deacidify working lands around the world.

⁵ Warncke, D., Dahl, J., & Jacobs, L. (2009). Nutrient Recommendations for Field Crops in Michigan (Extension Bulletin No. E2904; pp. 6–7). Michigan State University Extension. <https://www.canr.msu.edu/fertrec/uploads/E-2904-MSU-Nutrient-recomdms-field-crops.pdf>

⁶ Kaiser, D., & Rosen, C. (2023). Lime needs in Minnesota. University of Minnesota Extension. <https://extension.umn.edu/liming/lime-needs-minnesota>

⁷ Levy, C. R., Almaraz, M., Beerling, D. J., Raymond, P., Reinhard, C. T., Suhrhoff, T. J., & Taylor, L. (2024). Enhanced Rock Weathering for Carbon Removal—Monitoring and Mitigating Potential Environmental Impacts on Agricultural Land. *Environmental Science & Technology*, 58(39), 17215–17226. <https://doi.org/10.1021/acs.est.4c02368>

⁸ Beck Woollen & Cella Schnabel. (2024, December). Estimating Soil pH on Agricultural Lands as a Constraint on Enhanced Weathering Potential [Poster]. <https://ui.adsabs.harvard.edu/abs/2024AGUFMGC13Q0427W/abstract>

⁹ US Department of Agriculture. (2014). Soil pH (Guides for Educators, pp. 1–6). <https://www.nrcs.usda.gov/sites/default/files/2022-10/Soil%20PH.pdf>

¹⁰ Barak, P., Jobe, B. O., Krueger, A. R., Peterson, L. A., & Laird, D. A. (1997). Effects of long-term soil acidification due to nitrogen fertilizer inputs in Wisconsin. *Plant and Soil*, 197(1), 61–69. <https://doi.org/10.1023/A:1004297607070>

¹¹ West, T. O., & McBride, A. C. (2005). The contribution of agricultural lime to carbon dioxide emissions in the United States: Dissolution, transport, and net emissions. *Agriculture, Ecosystems & Environment*, 108(2), 145–154. <https://doi.org/10.1016/j.agee.2005.01.002>

¹² Luke Gatiboni & David Hardy. (2023). Soil Acidity and Liming: Basic Information for Farmers and Gardeners (AG-439-51; SoilFacts). North Carolina State University. <https://content.ces.ncsu.edu/soil-acidity-and-liming-basic-information-for-farmers-and-gardeners>

¹³ Ed Rayburn & Bruce Loyd. (2024, July). Low-rate Application of Pelleted Lime. <https://extension.wvu.edu/natural-resources/soil-water/low-rate-application-of-pelleted-lime>

¹⁴ Bast, L., Warncke, D., & Christenson, D. (2011). Facts About Soil Acidity and Lime (Extension Bulletin E-1566; pp. 1–4). Michigan State University Extension. https://www.canr.msu.edu/uploads/resources/pdfs/facts_about_soil_e1566.pdf

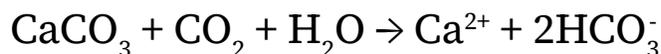
Find

In the last several years, the carbon removal potential of amending soils with rock feedstocks has come into focus. Liming is an example of this process, generally referred to as enhanced weathering. The dissolution of lime removes a maximum of one unit of carbon dioxide per unit of calcium carbonate (the main component of lime, Equation 1).¹⁵ If the process is reversed through the formation of calcium carbonate, for example in waters downstream of the field, one unit of carbon dioxide can eventually be released (Equation 3).^{15,16}

Silicate minerals—most commonly basalt, wollastonite, and olivine—can also be used for enhanced weathering. Silicates have received more attention for their climate benefits because the dissolution of silicates may remove up to two units of carbon dioxide for every one unit re-released by a potential downstream reaction (Equations 2 and 3, respectively).^{15,16}

Equation 1

Dissolution of limestone:



Equation 2

Dissolution of silicates:



Equation 3

One avenue for re-release of carbon dioxide:



The relative net negativity of either type of feedstock can depend on temporal considerations, lifecycle emissions (e.g., mining, rock grinding, transportation), and variable geochemical and agronomic conditions (e.g., soil type, fertilizer application), but both feedstock categories have potential to deliver removals.¹⁷ Additionally, raising soil pH with either type of feedstock can decrease nitrous oxide (N₂O) emissions from soils.^{18,19}

¹⁵ Zhang, S., Planavsky, N. J., Katchinoff, J., Raymond, P. A., Kanzaki, Y., Reershemius, T., & Reinhard, C. T. (2022). River chemistry constraints on the carbon capture potential of surficial enhanced rock weathering. *Limnology and Oceanography*, 67(S2). <https://doi.org/10.1002/lno.12244>

¹⁶ Beerling, D. J., Kantzas, E. P., Lomas, M. R., Wade, P., Eufrazio, R. M., Renforth, P., Sarkar, B., Andrews, M. G., James, R. H., Pearce, C. R., Mercure, J.-F., Pollitt, H., Holden, P. B., Edwards, N. R., Khanna, M., Koh, L., Quegan, S., Pidgeon, N. F., Janssens, I. A., ... Banwart, S. A. (2020). Potential for large-scale CO₂ removal via enhanced rock weathering with croplands. *Nature*, 583(7815), 242–248. <https://doi.org/10.1038/s41586-020-2448-9>

¹⁷ Kukla, T., Kanzaki, Y., Chay, F., Planavsky, N., & Reinhard, C. (2025). Swapping carbonate for silicate in agricultural enhanced rock weathering. CDRXIV. <https://doi.org/10.70212/cdrxiv.2025304.v1>

¹⁸ Chiaravalloti, I., Theunissen, N., Zhang, S., Wang, J., Sun, F., Ahmed, A. A., Pihlap, E., Reinhard, C. T., & Planavsky, N. J. (2023). Mitigation of soil nitrous oxide emissions during maize production with basalt amendments. *Frontiers in Climate*, 5, 1203043. <https://doi.org/10.3389/fclim.2023.1203043>

¹⁹ Vázquez, E., Teutscherova, N., Pastorelli, R., Lagomarsino, A., Giagnoni, L., & Renella, G. (2020). Liming reduces N₂O emissions from Mediterranean soil after-rewetting and affects the size, structure and transcription of microbial communities. *Soil Biology and Biochemistry*, 147, 107839. <https://doi.org/10.1016/j.soilbio.2020.107839>

Find

Agricultural emissions, including N₂O, are expected to be consistently hard to abate in national emissions reduction plans.²⁰ Enhanced weathering could be an important avenue to reduce net emissions across the agriculture sector.

In addition to removing carbon dioxide from the atmosphere, both types of enhanced weathering feedstock can provide similar agronomic benefits. Like conventional lime, silicates can also increase soil pH.²¹ Silicates can additionally be deployed using the same equipment at comparable times to lime in the growing season. Though grain size and application rates may differ, the general processes of spreading silicates and conventional lime are often similar.

Scaling enhanced weathering to deliver climate and agronomic benefits will require policies that support deployment of the appropriate feedstock at the right time and under the correct conditions. One key consideration is the availability of mineral inputs. Lime and silicate feedstocks are not generally available in the same place.^{22,23} Another key consideration is fertilizer use and the availability of micro- and macronutrients. For instance, basalt can deliver valuable macro- and micronutrients, like phosphorus, potassium, manganese, zinc, and silicon to soils at higher rates than lime, offering an additional agronomic benefit to increased pH.^{24,25,26} Lastly, timing and duration of pH changes must be assessed. The time required for certain silicates like basalt to dissolve is often longer than limestone, and higher volumes may need to be spread to achieve the same increase in pH in the same timeframe.¹⁵

Policies that incentivize context-specific, data-driven soil pH management may offer a replicable, effective path toward deacidifying soils and increasing carbon removal. The following section of this white paper explores the network of existing pH management policies, which often include liming but do not all yet include silicate spreading.

²⁰ Smith, H. B., Vaughan, N. E., & Forster, J. (2024). Residual emissions in long-term national climate strategies show limited climate ambition. *One Earth*, 7(5), 867–884. <https://doi.org/10.1016/j.oneear.2024.04.009>

²¹ Beerling, D. J., Kantzas, E. P., Lomas, M. R., Taylor, L. L., Zhang, S., Kanzaki, Y., Eufrazio, R. M., Renforth, P., Mecure, J.-F., Pollitt, H., Holden, P. B., Edwards, N. R., Koh, L., Epihov, D. Z., Wolf, A., Hansen, J. E., Banwart, S. A., Pidgeon, N. F., Reinhard, C. T., ... Val Martin, M. (2025). Transforming US agriculture for carbon removal with enhanced weathering. *Nature*, 638(8050), 425–434. <https://doi.org/10.1038/s41586-024-08429-2>

²² William H. Langer. (2011). Aggregate Resource Availability in the Conterminous United States, Including Suggestions for Addressing Shortages, Quality, and Environmental Concerns (Open-File Report 2011–1119). US Geological Survey. https://pubs.usgs.gov/of/2011/1119/pdf/OF11-1119_report_508.pdf

²³ Amiotte Suchet, P., Probst, J., & Ludwig, W. (2003). Worldwide distribution of continental rock lithology: Implications for the atmospheric/soil CO₂ uptake by continental weathering and alkalinity river transport to the oceans. *Global Biogeochemical Cycles*, 17(2), 2002GB001891. <https://doi.org/10.1029/2002GB001891>

²⁴ Beerling, D. J., Reinhard, C. T., James, R. H., Khan, A., Pidgeon, N., & Planavsky, N. J. (2025). Challenges and opportunities in scaling enhanced weathering for carbon dioxide removal. *Nature Reviews Earth & Environment*, 6(10), 672–686. <https://doi.org/10.1038/s43017-025-00713-7>

²⁵ Swoboda, P., Döring, T. F., & Hamer, M. (2022). Remineralizing soils? The agricultural usage of silicate rock powders: A review. *Science of The Total Environment*, 807, 150976. <https://doi.org/10.1016/j.scitotenv.2021.150976>

²⁶ Beerling, D. J., Epihov, D. Z., Kantola, I. B., Masters, M. D., Reershemius, T., Planavsky, N. J., Reinhard, C. T., Jordan, J. S., Thorne, S. J., Weber, J., Val Martin, M., Freckleton, R. P., Hartley, S. E., James, R. H., Pearce, C. R., DeLucia, E. H., & Banwart, S. A. (2024). Enhanced weathering in the US Corn Belt delivers carbon removal with agronomic benefits. *Proceedings of the National Academy of Sciences*, 121(9), e2319436121. <https://doi.org/10.1073/pnas.2319436121>

Match

The second step is to “Match” carbon removal processes to a jurisdiction’s existing sectoral policies. To create enabling environments, the carbon removal community needs to: (1) understand the policy and regulatory environment governing the relevant sector and (2) modify or expand existing policies and/or regulations to support carbon removal activities. In this section, we lay the foundation for understanding the policy and regulatory environment for soil pH management by learning more about the structure of existing agricultural liming subsidies.

Payments for ecosystem services, cost-share incentives, or pay-for-practice subsidies are policy mechanisms that provide financial support based on the implementation of a service or practice rather than the result.²⁷ Within the agriculture sector, such policies are commonly employed to encourage sustainable land management and enhance soil health. For example, many governments and regional authorities already offer subsidies to reduce the cost of spreading agricultural limestone and other amendments, helping farmers adjust soil pH and improve crop yields.²⁸ [Figure 1](#) presents examples of pH management subsidies or cost-share programs worldwide. The details of these initiatives vary, but they share the goal of improving soil health. For details about these subsidies, see [Table A1](#).

Expanding these policies to more areas with suboptimal soil pH, considering broader categories of feedstock, linking to other soil health policies ([Table A2](#)), and recognizing and quantifying carbon removal as a co-benefit could broaden the set of politically resilient opportunities for enhanced weathering deployment through mechanisms tailored to the needs, realities, and scales of the agriculture sector. As a first step, we begin by describing the structure of two existing pH subsidy policies in more detail.²⁹

²⁷ Lin, Chung-Li, et al. “Pay-for-Practice or Pay-for-Performance? A Coupled Agent-Based Evaluation Tool for Assessing Sediment Management Incentive Policies.” *Journal of Hydrology*, vol. 624, Sept. 2023. <https://www.sciencedirect.com/science/article/abs/pii/S0022169423009010>

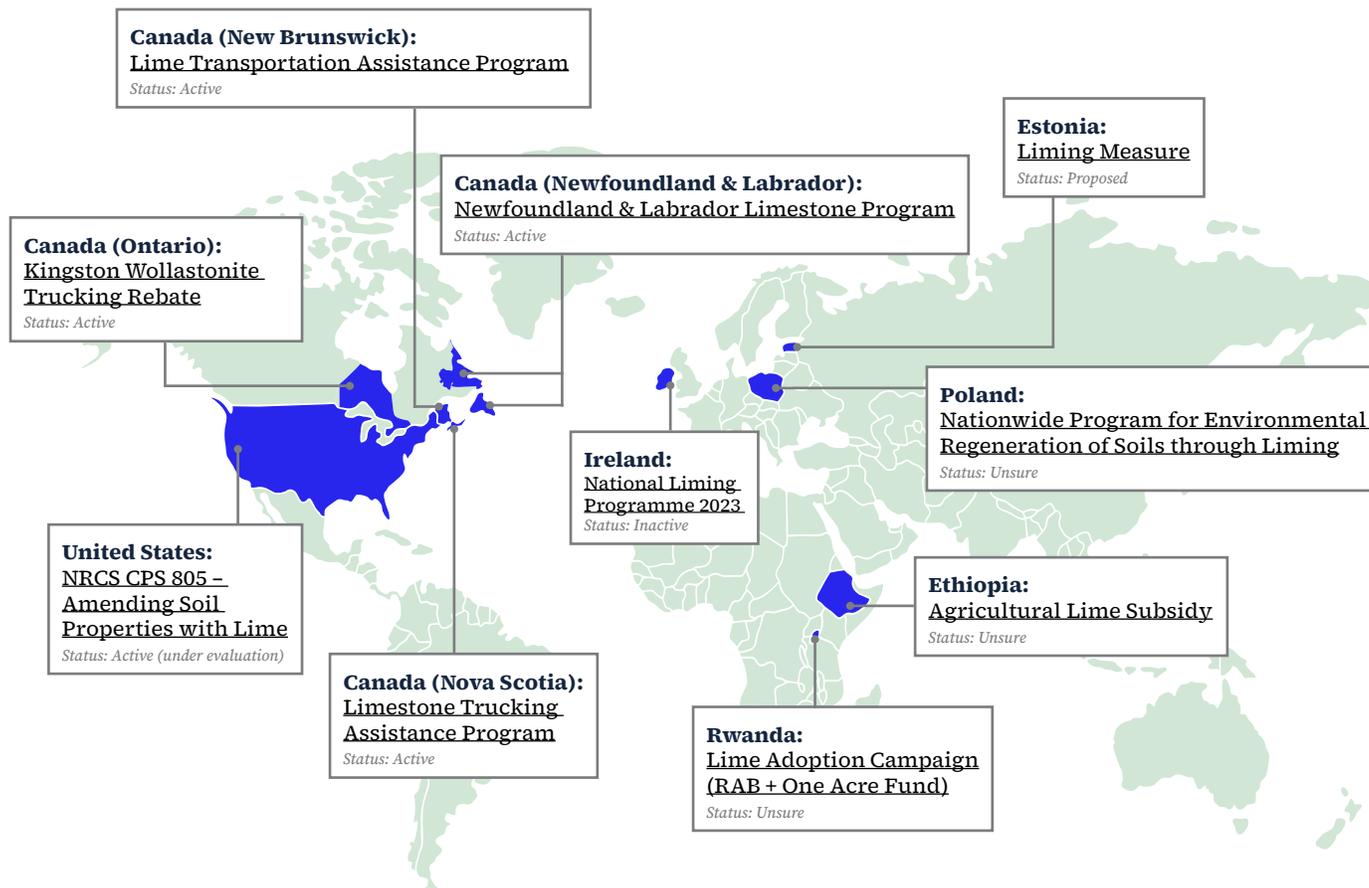
²⁸ Enesi, R. O., Dyck, M., Chang, S., Thilakarathna, M. S., Fan, X., Strelkov, S., & Gorim, L. Y. (2023). Liming remediates soil

acidity and improves crop yield and profitability - a meta-analysis. *Frontiers in Agronomy*, 5, 1194896. <https://doi.org/10.3389/fagro.2023.1194896>

²⁹ The selection of these two policies was based on availability of information and does not reflect a prioritization or preference. CRSI intends to build out further case studies representative of more geographical and political diversity.

Match

Figure 1:
Examples of liming policies ³⁰



³⁰ See [Table A1](#) for more details.

Match

Case Study 1

Nova Scotia's Limestone Trucking Assistance Program

Key Actor:

- Nova Scotia Department of Agriculture

Anecdotally, the practice of liming soils and rivers in Nova Scotia was a response to counter the effects of acid rain that had drifted north from industrial centers along the east coast of the U.S. Acid rain has substantially lowered soil pH levels across Atlantic Canada, where soils are already naturally acidic, negatively impacting crop yields and aquatic life.

The Limestone Trucking Assistance Program (LTAP) has been an enduring feature of Nova Scotia's farm policy for at least 35 years. Over time, the program's structure and name have evolved, but its essential purpose to help farmers improve productivity by defraying the cost of transporting agricultural limestone has remained consistent.³¹

LTAP helps registered farms and industry associations offset limestone delivery costs by covering up to 80% of approved transportation expenses, capped at \$32,000 CAD per applicant per year. Eligibility requirements include a soil analysis lab report or a Nutrient Management Plan no more than three years old.³²

Program governance rests with the Nova Scotia Department of Agriculture, which administers LTAP alongside its other cost-share programs. The Nova Scotia Federation of Agriculture serves as a key consultative partner; the Federation of Agriculture provides annual feedback on the Department of Agriculture's suite of funding programs on behalf of its members, which are considered in light of government objectives and resource availability.

Liming practices are actively encouraged by the provincial extension services and Perennia Food and Agriculture Corporation, a government-owned business providing technical expertise to farmers. The Department of Agriculture operates a subsidized analytical laboratory where farmers can submit soil samples for pH analysis and receive recommendations for liming application. Soil samples can be dropped off at regional offices, which facilitate delivery to the lab.

The program's broader agronomic framework connects to Nova Scotia's nutrient management and environmental planning systems. Anyone offering

³¹ Canada Info (CKJM Radio). (2022). Department of Agriculture adds \$200,000 to cover farmers' limestone trucking costs. <https://canada-info.ca/en/department-of-agriculture-adds-200000-to-cover-farmers-limestone-trucking-costs/>

³² Limestone Trucking Assistance Program Guidelines, 2025-2026. <https://novascotia.ca/programs/limestone-trucking-assistance/docs/ltg-guidelines.pdf>

Match

nutrient management advice must be a professional agrologist, registered with the Nova Scotia Institute of Agrologists. Although there is no provincially enforced template for a Nutrient Management Plan, the Dalhousie University Faculty of Agriculture's Extended Learning program offers recognized training in this area. Most farms, particularly those with livestock, incorporate nutrient management into their Environmental Farm Plans, a free and voluntary program to help farmers assess environmental risks.

Overall demand for LTAP has risen over the past two years, both in terms of the number of applications and in requested funding. The increase in requested funding amounts appears to be mainly driven by increasing fuel prices.

Public transparency is maintained through Nova Scotia's Open Data Portal, which lists funding recipients and amounts disbursed each year.³³ These records document the program's duration and changes over time in response to agricultural requirements. The program's inclusion in successive provincial budgets indicates its ongoing role in supporting soil health within the province's agricultural framework.

The Limestone Trucking Assistance Program serves as an example of a sustained, iterative approach to agricultural support that relies on transparency, an interconnected system of public services, and multiple touch points with the local farming community.

This case study was informed through correspondence with Rebecca Sooksom, Program Director at the Nova Scotia Department of Agriculture.



Alejandro Barron via unsplash

³³ Government of Nova Scotia. (n.d.). Agriculture Funding Program Details: Total Funding by Year. <https://data.novascotia.ca>

Match

Case Study 2

I The Kingston Wollastonite Transportation Rebate

Key Actors:

- City of Kingston, Ontario
- Canadian Wollastonite
- UNDO Carbon

The City of Kingston, Ontario, launched the Wollastonite Transportation Rebate for local farms in January 2025, following demonstration projects in late 2024. The policy was developed in partnership with Canadian Wollastonite, a local mining company, and UNDO Carbon, a carbon removal developer, to scale enhanced weathering deployment at a low cost to farmers and help expand the city's existing climate action framework to include carbon removal.

With an overall cap of \$250,000 CAD, the program offers rebates directly from the City of Kingston of up to \$5 CAD per tonne of wollastonite delivered, paid directly to farmers, covering roughly half of the total transportation costs. The feedstock, spreading, and measurement, monitoring, reporting, and verification (MMRV) are financed through the support of corporate buyers of carbon removal credits.

Eligible farms must be located within the municipal boundary of Kingston. UNDO leads implementation, including quantification, soil measurement, and spreading operations. The mineral wollastonite is applied using standard lime-spreading equipment, enabling integration into existing farming practices. Participating farms also receive free soil pH testing to ensure the pH range of their fields meets UNDO's project deployment requirements.

No municipal, provincial, or national agency regulates the program. Instead, the City of Kingston relies on UNDO's data collection, transparency commitments, and submissions to third-party evaluators for verification. Kingston reports removals resulting from this rebate program in a ledger alongside emissions reduction efforts.

While some farmers are open to trialing wollastonite, others remain cautious, citing fatigue from an inundation of climate initiatives or lack of familiarity with mineral amendments. Lingering skepticism despite low costs underscores the critical importance of quantifying agronomic impacts. The

Match

program aims to achieve a 10% adoption rate across two million acres of land in the surrounding region in order to generate evidence of soil health benefits, such as yield increases. Demonstrating that the agronomic return on investment is both significant and quantifiable can strengthen stakeholder support and open new, resilient revenue streams.



Photo credit: Canadian Wollastonite

Alongside the implementation of this program, Canadian Wollastonite and the City of Kingston are actively exploring expansion opportunities with neighbouring municipalities to replicate the transportation rebate structure. Canadian Wollastonite has also begun to fully electrify its mine and develop a solar generation facility to offset electricity demand through Ontario's net metering program, reducing the footprint of upstream emissions.

The Kingston Transportation Rebate serves as an early example of carbon removal integration into municipal-scale resource management policy, highlights the importance of continued work to demonstrate and quantify agronomic benefits, and illustrates how public-private partnerships can catalyze important learning and unlock new policy pathways to scale.

This case study was informed through correspondence with Bob Vasily, CEO of Canadian Wollastonite.

Match

These case studies demonstrate that even when the purpose or type of subsidy is similar, the realities of each policy and jurisdiction may differ significantly. We do not make any claims about which structure is more suitable for enhanced weathering integration, and note that considerations such as transparency, regulatory oversight, reporting and accounting clarity, and longevity are critical.

Effective integration of enhanced weathering into policies such as liming subsidies will depend on many factors, including the availability of local feedstock, existing requirements and practices for soil data and analyses, the capacities of and coordination between regulating entities, farmers' perspectives and histories, and the ability to quantify and convey the agronomic benefits. Because these are all context-dependent, methods to quantify the carbon may be as well. Ultimately, we aim to understand how and when to tailor enhanced weathering quantification to specific jurisdictions and policy opportunities. In the next section, we take a first step by investigating how incentive structures could support learning and long-term monitoring goals for national greenhouse gas accounting.

Measure

The final step is to “Measure” carbon removal processes inside sectors using fit-for-purpose quantification and accounting standards. To measure carbon removal, the CDR community needs to: (1) drive the science needed for effective, fit-for-purpose standards, emphasizing foundational learning and data collection, and (2) leverage existing public and private infrastructure where possible to decrease cost and increase speed of adoption by regulators and industry experts. We define fit-for-purpose standards as scientifically sound, logically consistent with existing standards and regulations, and administratively feasible.

In this section, we focus on enabling conditions to drive the science needed for fit-for-purpose standards for enhanced weathering in the agriculture sector. We anchor this work toward a future accounting scenario that enables the inclusion of enhanced weathering on croplands in national greenhouse gas inventories.^{34,35} We examine how incentive structures and policy mechanisms can interact to create conditions that enable learning and incrementally incorporate this learning into inventories over time.

The IPCC Guidelines for National Greenhouse Gas Inventories are standards designed for use by countries with varying administrative capacities to produce conservative estimates of emissions and removals. The guidelines require, at a minimum, information about the scope of an activity to estimate emissions (or removals) using tables of emissions factors, with the expectation that estimates can be improved and reporting requirements will be refined over time.³⁶

Given that we currently lack the scientific evidence base to estimate carbon removal rates from activity data with sufficient certainty, our near-term goal is to better understand how rock amendments affect carbon and alkalinity fluxes in soils. In designing studies to fill this knowledge gap, we must consider both precision and accuracy.

Precision, quantified by standard error (SE), is a measure of sampling variability, i.e., random error.

Accuracy refers to the proximity of an estimate to the true value, affected by systematic biases that can include the use of non-representative covariates or suboptimal control design.

³⁴ Inherent in this framing is a choice of boundary condition that looks different than a carbon market LCA; in particular, we do not explicitly discuss upstream emissions. We also note that any future projection for accounting requires assumptions about the future state of decarbonization across sectors, a calculus we do not explore in this paper.

³⁵ Scoping of the Methodology Report on Carbon Dioxide Removal Technologies, Carbon Capture Utilization and

Storage. <https://www.ipcc.ch/report/2027-ipcc-methodology-report-on-carbon-dioxide-removal-technologies-carbon-capture-utilization-and-storage-for-national-greenhouse-gas-inventories-additional-guidance/>

³⁶ The IPCC is in the process of developing a 2027 report on carbon removal technologies, as of publication of this white paper, lead authors have been selected and the outlining process has begun.

Measure

Current crediting approaches provide partial incentives for precision. Enhanced weathering protocols credit carbon removal based on a lower confidence bound on estimated net removal at either 84% or 90%.^{37,38,39} Under these approaches, when net removal is positive, tighter confidence intervals yield a larger lower confidence bound and thus more credits, penalizing undersampling and rewarding measurement intensity.

The lower confidence bound, however, does not capture the effect of other aspects of study design, such as control area sizes or structures. Revenue increases as more land is allocated to treatment areas and less to control areas, while practical constraints can lead to more clustered control designs. Consequently, the incentive structure of crediting mechanisms may disincentivize distributed, cumulatively larger, and more representative controls in commercial deployments. Consider that best-in-class scientific trials have control plots as large as 20–50% of the total project area, and academic modeling exercises use similarly large controls, while commercial projects are trending toward smaller control sizes (<5%).^{40,41,42,43}

In Table 1, we compare revenue and standard error across study designs with different sampling allocations and control area sizes to illustrate this point.

Table 1:

*Summary of design scenarios computed from field-anchored variability*⁴⁴

Design	Control Size	Number of Samples (Treatment:Control)	Standard Error	90% Lower Confidence Bound	Revenue
1. Smaller control area; suboptimal sampling allocation	5%	90:10	0.380	1.59	\$604,000
2. Smaller control area; improved sampling allocation	5%	67:33	0.300	1.70	\$646,000
3. Larger control area; improved sampling allocation	20%	67:33	0.300	1.70	\$544,00
4. Larger control area; more sampling	20%	100:50	0.245	1.77	\$566,400

³⁷ Isometric HQ Ltd. (2026). The Isometric Standard (Version 1.9). <https://registry.isometric.com/standard/1.9/1.9.0>

³⁸ Puro.earth. (2025). Enhanced Rock Weathering Methodology for CO₂ Removal (Edition 2025, v.1). Puro Standard. <https://7518557.fs1.hubspotusercontent-na1.net/hubfs/7518557/ERW%20Standards/ERW%202025/ERW%20Edition%202025%20v1.pdf>

³⁹ Rainbow. (2025). Enhanced Rock Weathering Methodology (V1.0, RBW-ERW-V1.0). Rainbow Standard. <https://docs.rainbowstandard.io/methodologies/enhanced-rock-weathering>

⁴⁰ Beerling, D. J., Epihov, D. Z., Kantola, I. B., Masters, M. D., Reershemius, T., Planavsky, N. J., ... & Banwart, S. A. (2024). Enhanced weathering in the US Corn Belt delivers carbon removal with agronomic benefits. *Proceedings of the National Academy of Sciences*, 121(9), e2319436121. <https://pubmed.ncbi.nlm.nih.gov/38386712/>

⁴¹ Bradford, M. A., et al. "Testing the Feasibility of Quantifying Change in Agricultural Soil Carbon Stocks through Empirical Sampling." *Geoderma*, vol. 440, Dec. 2023, p. 116719. <https://doi.org/10.1016/j.geoderma.2023.116719>.

⁴² Potash, E., Bradford, M. A., Oldfield, E. E., & Guan, K. (2025). Measure-and-remeasure as an economically feasible

approach to crediting soil organic carbon at scale. *Environmental Research Letters*, 20(2), 024025. <https://iopscience.iop.org/article/10.1088/1748-9326/ada16c>

⁴³ Suhrhoff, T. J., Khan, A., Zhang, S., Woollen, B. J., Reershemius, T., Bradford, M. A., ... & Planavsky, N. (2025). Aggregated monitoring of enhanced weathering on agricultural lands. <https://doi.org/10.70212/cdrxiv.2025394.v2>

⁴⁴ The results are based on the following assumptions. (i) 2,000 hectares divided into two soil pH strata (40% acidic, 60% neutral). (ii) Treatment effects: 2.5 tCO₂/ha/yr (more acidic soils), 1.8 tCO₂/ha/yr (neutral soils). (iii) Spatial variability: treatment standard deviation (SD) is 2 × control SD (typical for open-system interventions). (iv) Absolute variability scale anchored to field data: With cumulative carbon removal SD of 3.8 tCO₂/ha over 4 years, we take annual control SD to be ~1.0 tCO₂/ha/yr (assuming independence across years) and annual treatment SD to be ~2.0 tCO₂/ha/yr. (v) Sampling budgets: We assume a cost of \$800 per sample. The first three scenarios use 100 total samples; the fourth uses 150. (vi) Credit price: \$200/tCO₂

Measure

The integration of enhanced weathering into pH management subsidies and large-scale soil health policies could provide alternative incentive structures to enhance learning through a different set of measurement designs and practices.



First, and most simply, additional public funding streams, like the Kingston Wollastonite Rebate, can help to reduce economic pressure on projects, a driver of land allocation decisions such as control size and structure. Strong control design, a component of strong study design, is important for ensuring the accuracy of weathering estimates based on in-field data.



Second, public funding through subsidies brings additional stakeholders with a clear interest in establishing the long-term climate and agronomic benefits, like local governments and publicly funded laboratories and agronomic experts, to the project.



Third, time-tested public financing mechanisms may also reduce barriers to land manager participation and create opportunities for harmonized deployments. The Nova Scotia Limestone Trucking Assistance Program is an example of an annually iterative incentive structure within which a regulatory authority oversees implementation and coordinates and subsidizes soil analyses through a public laboratory.



Fourth, integration in large-scale soil health policies can help build strong baseline and deployment data. These will be integral to understanding the efficacy of enhanced weathering practices. The Nova Scotia Open Data Portal and India's Soil Health Card Scheme are examples of ways that public policies can support data collection and sharing. In the interim, philanthropically supported efforts like [Cascade's Data Quarry](#) are helping to fill the data gap.



Fifth, recent work has shown that the precision of carbon removal estimates can be improved through aggregation of soil measurements over many fields, and this approach may, at sufficiently large scales, reduce overall measurement costs.^{41,43} For example, with modest shared systematic error from common measurement methods, the standard error of 50 aggregated Design 4 projects, each with a standard error of 0.245, is reduced significantly:

Measure

$$SE_{\text{aggregated}} = \sqrt{\frac{0.245^2}{50} + 0.05^2} = 0.061 \text{ tCO}_2/\text{ha}$$

The spatial and temporal scales of agricultural policies, which cover millions of acres and reach many farmers over decades, can enable such aggregation.

Although agricultural incentives cannot, in the near term, displace the need for sustained private sector and philanthropic investment in enhanced weathering projects, they can help align incentives and achieve near-term learning goals. They also serve as useful examples of ubiquitous subsidy mechanisms that present politically resilient pathways to the deployment of enhanced weathering.



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Conclusion

Enhanced weathering is a promising carbon removal solution that needs policy to scale. This paper focused on the opportunity to integrate enhanced weathering into agricultural subsidy schemes. Such an approach provides a politically resilient support mechanism for enhanced weathering projects on croplands and demonstrates a promising framework for integrated carbon removal policy development, which we call Find-Match-Measure.

First, we described the agronomic benefits of enhanced weathering, with an emphasis on soil pH management. Second, we explored the use of liming subsidies to defray the cost of soil pH management for farmers. We presented case studies on the Nova Scotia Limestone Trucking Assistance, which predates current interest in enhanced weathering, and the Kingston Wollastonite Rebate, a recent public-private partnership to fund commercial enhanced weathering trials, demonstrating that the structure of these subsidies can vary widely across jurisdictions and contexts. Third, we described the role that liming subsidies could play in improving study design and quantification methods for near-term enhanced weathering field trials, as a complement to market-based protocols.

Putting the pieces together, we find that soil pH management subsidies could play an important role in the research and development of enhanced weathering as a climate and agricultural intervention, both through the expansion of subsidies to new geographies and the inclusion of a broader range of feedstocks in liming subsidies. In the near term, subsidies can support early learning and evidence-building for enhanced weathering, especially if data are openly shared.⁴⁵ Over time, leveraging agricultural policies and the regulatory architecture that accompanies them can enable methodological improvements, public data collection frameworks, and ultimately, better carbon removal estimates.

We hope this paper is a foundational first step towards embedding enhanced weathering within global agricultural policy. While coordination over larger spatial areas and longer timelines will not be without challenges, the benefits of robust and aggregated data, strong study designs, and iterative learning are essential to scale carbon removal via enhanced weathering and achieve global agricultural decarbonization targets.

Agriculture is just one industry that can benefit from embedded carbon removal, but early momentum indicates it will pave the way for myriad others. How we approach early integration projects, and what we learn from them, will help scale carbon removal across society and ultimately contribute towards a resilient future for all.

⁴⁵ Reinhard, C. T., & Planavsky, N. J. (2026). The importance of radical transparency for responsible carbon dioxide removal. *npj Climate Action*, 5(1), 7. <https://www.nature.com/articles/s44168-025-00324-4>

Appendix

Table A1:
Examples of liming policies (expanded)

Jurisdiction	Policy	Phase/Description	Eligibility	Soil Analysis	Regulatory Authority
Canada (New Brunswick)	<u>Lime Transportation Assistance Program</u>	<i>Implementation.</i> The program provides funding for New Brunswick landowners to transport lime from the nearest quarry that matches the eligible lime characteristics. It encourages consultation with local agronomists to determine optimal lime type and application rate.	Eligibility requirements for the program include a starting field soil pH below 6.2 (additional funding available for farmers with a pH below 5).	Yes. A soil test report from the current or previous year is required to confirm both the need for and the appropriate type of lime. At a minimum, one soil analysis must be provided for every 25 acres of land.	Department of Agriculture, Aquaculture and Fisheries
Canada (Newfoundland & Labrador)	<u>Newfoundland & Labrador Limestone Program</u>	<i>Implementation.</i> The program provides \$25 CAD per tonne (minimum purchase of 32 tonnes) of limestone for eligible farmers within the province.	The applicant must be an eligible agricultural producer and purchase at least 32 tonnes of qualifying limestone to access the subsidy.	Yes. Soil samples are required and must be submitted to the Soil, Plant, and Feed Laboratory after October 1 annually to qualify for the subsidy in the corresponding year.	Department of Fisheries, Forestry, and Agriculture
Canada (Nova Scotia)	<u>Limestone Trucking</u>	<i>Implementation.</i> The program covers up to 80% of the eligible transportation costs for agricultural limestone.	Eligible participants include farmers, not-for-profit agriculture industry associations, and the Mi'kmaq people.	Yes. Soil analysis or a nutrient plan is required.	Department of Agriculture
Canada (Ontario)	<u>Kingston Wollastonite Trucking Rebate</u>	<i>Implementation.</i> The rebate offers up to \$5 CAD per tonne of wollastonite spread on eligible lands and is available on a first-come, first-served basis.	Farmers and landowners within the municipal boundary of Kingston who apply wollastonite within one of the designated rebate periods, provide verifiable land parcel details and haulage receipts, and use wollastonite as a soil amendment within their agricultural operations are eligible for the rebate.	Yes. Eligibility includes demonstrating soil pH between 6.0 and 7.0.	N/A

Appendix

Jurisdiction	Policy	Phase/Description	Eligibility	Soil Analysis	Regulatory Authority
Estonia	<u>Liming Measure</u>	<i>Development.</i> This liming policy, initially proposed as a results-based payment, is planned as an activity-based subsidy in Estonia. It falls under the broader EU Common Agricultural Policy. To minimize CO ₂ emissions, the use of ash or a mixture of ash and limestone will be required. Applicants are required to participate in a training on liming during the first commitment year.	The policy specifically focuses on soils that have a pH _{KCl} below 5.5, or between 5.5 and 6.5 with calcium content less than 1,500 mg/kg.	Yes. To ensure that liming has been conducted, soil samples taken before the commitment period will be compared to soil samples taken after liming.	Ministry of Rural Affairs
Ethiopia	<u>Agricultural Lime Subsidy</u>	<i>Status unsure.</i> The structure of the subsidy varies by region. Some regional governments fully subsidize the production and distribution of lime, where farmers get lime free of charge through the district Bureau of Agriculture.	Farmers in high-acidity soils with a pH below 5.5.	Yes. Regional and national soil laboratories in Ethiopia test both soil acidity and lime quality to guide lime use. The National Soil Laboratory evaluates lime from factories—mainly its calcium carbonate equivalence (CaCO ₃)—and may restrict deposits with low quality. Meanwhile, regional labs provide free acidity testing for local farmers, processing samples sent through woredas and returning results promptly.	Ministry of Agriculture and the Bureaus of Agriculture in the major regional states
Ireland	<u>National Liming Programme 2023</u>	<i>Post-implementation.</i> Approved applicants received a financial contribution of €16 per tonne of lime spread to offset part of the cost of applying calcium- or magnesium-ground limestone. Subject to budget availability, payment was made for a minimum of 10 tonnes of ground limestone and a maximum of 200 tonnes.	Farmers who submitted a Basic Payment Scheme (BPS) or Basic Income Support for Sustainability (BISS) application in previous years. The maximum eligible application rate is 7.5 tonnes of ground limestone per hectare.	Yes. Applicants must have soil test reports for the land (within the last four years from the date of purchase) that indicate a lime requirement.	Department of Food, Agriculture, and the Marine

Appendix

Jurisdiction	Policy	Phase/Description	Eligibility	Soil Analysis	Regulatory Authority
Poland	<u>Nationwide Program for Environmental Regeneration of Soils through Liming</u>	<i>Status unsure.</i> The program provides financial support through subsidies that offset the cost of agricultural lime. The subsidy level depends on farm size and the amount of active deacidifying material applied. Small farms of up to 25 hectares can receive as much as 300 PLN per ton of lime, with proportionally lower rates available for larger operations.	Each application must be supported by appropriate documents, such as confirmation of the size of agricultural land, the right to manage the land, and soil pH levels of less than or equal to 5.5.	Yes. Soil pH analysis is required.	Provincial Fund for Environmental Protection and Water Management, Regional Chemical and Agricultural Stations
Rwanda	<u>Lime Adoption Campaign (RAB + One Acre Fund)</u>	<i>Implementation.</i> This lime adoption campaign is a partnership between the Government of Rwanda and a social enterprise, the One Acre Fund, to improve soil fertility and crop productivity. As one data point, in 2020–2021, about 1.6 billion RWF was allocated specifically for lime procurement. The funding covered the purchase of 20,500 tonnes of lime, enough to treat approximately 8,200 hectares of land.	Eligible farmers were determined by targeted acid soil districts (e.g., Gicumbi).	No. Soil pH analysis is not required.	Rwanda Agriculture and Animal Resources Development Board
United States	<u>NRCS CPS 805 – Amending Soil Properties with Lime</u>	<i>Implementation.</i> CPS 805 is an interim federal conservation practice standard supporting liming for soil pH correction. It is currently under evaluation and has not yet been adopted at the national level.	Lime application rates must be based on soil test analysis for the planned cropping/tillage system and follow local Land Grant University (LGU) recommendations.	Yes. Soil tests no older than three years are required. Soil test results must provide a recommendation for how much lime in the calcium carbonate equivalent (CCE) material is needed to adjust the soil pH to the optimal range for the planned cropping system.	Department of Agriculture

Appendix

Table A2:

This table provides examples of jurisdictions that either require soil testing or maintain public soil health card/data programs.

Jurisdiction	Policy/ Instrument	Summary	Data Management
EU	<u>Soil Monitoring Directive</u>	Under the directive, member states will set up monitoring systems to assess the physical, chemical, and biological condition of soils on their territory, based on a common EU methodology.	The directive calls for the establishment of a digital soil health data portal, a hub providing access to soil data in aggregated form. The portal primarily includes the data collected by the Member States and the Commission.
India	<u>Soil Health Card Scheme</u>	The Government of India launched the Soil Health Card (SHC) scheme in 2015 to encourage site-specific and soil test-based integrated nutrient management to boost nutrient use efficiency. The SHC is a printed card issued to farmers every two years containing information on 12 parameters obtained after testing soil samples in laboratories. This program has led to a significant increase in new laboratories and improvements to existing laboratories.	A portal on soil health has been prepared by the <u>National Informatics Centre (NIC)</u> for creating soil health cards.
China (Black Soil Regions)	<u>Black Soil Protection Law</u>	The law mandates a black soil surveying and monitoring system.	Governments conduct surveys on the distribution, quantity, quality, protection, and other aspects of the black soil and maintain a black soil archive containing the collected data.