Buyer Principles for Responsible Procurement of Carbon Removal from Enhanced Weathering in Working Lands

Enhanced weathering (EW) of alkaline materials is a promising carbon dioxide removal (CDR) pathway. EW accelerates the silicate weathering process, the key regulator of Earth's long-term carbon cycle, and can lead to highly durable carbon removal. In addition to CDR, land-based EW could provide meaningful co-benefits, including increasing agricultural yields, reducing N_2O emissions, and regulating pH in fields.

Furthermore, unlike most other highly durable CDR pathways, spreading alkaline rock dust in fields is relatively inexpensive and uses existing infrastructure. Logistically and operationally, there is a path to deliver large-scale CDR from EW at a relatively low cost.

The catch? It is not possible to directly measure all CDR occurring throughout the system. Instead, EW developers must rely on a combination of measurements and models to estimate weathering rates and any ensuing losses of the resulting bicarbonate as it moves from fields to rivers to oceans, the intended durable carbon sink.

Weathering rates are a key determinant of the rate of CDR resulting from rock application. These rates vary widely depending on the characteristics of the rock applied, local environment, and agricultural practices. Post-application losses can also be significant, but are typically better constrained.

Most EW developers operating today recognize this meaningful uncertainty in weathering rates and other drivers of EW CDR volumes over time. We commend early EW projects that heavily prioritize collecting and sharing large amounts of data. This data is essential for future model performance improvements and for effective measurement, reporting, and verification (MRV). As EW is a relatively new CDR pathway, full transparency is essential to build widespread understanding and to support compensatory claims.

The current voluntary carbon market structure creates significant EW quality risk as this CDR pathway scales. There are low barriers to entry. So, new, profit-focused developers can easily market CDR credits after spreading rocks in ways that may deliver minimal or no actual CDR. Worse, these poorly designed and measured projects could harm, not improve, soil health.

While the scientific underpinnings of enhanced weathering are strong, robust standards are essential to avoid low-quality or harmful projects that squander real potential to scale a meaningful climate solution.

As early buyers and other parties committed to supporting this newly developing market, we propose a set of four principles to help safeguard quality in this emerging CDR pathway.

1. Deploy responsibly by mitigating potential harms and maximizing benefits to communities and ecosystems:

- **Minimize risks of harm to farms and ecosystems**. There are a wide diversity of alkaline rocks that can be spread for enhanced weathering. Some of these feedstocks may contain undesirable trace materials such as heavy metals or asbestos. Enhanced weathering suppliers should provide robust and representative feedstock composition sampling and pre- and post-application soil sampling both for MRV purposes and to track potential heavy metal contamination. Projects that use dedicated mining for alkaline materials must actively minimize impacts on local ecosystems and communities.

- **Ongoing measurements of ecosystem health should underpin future purchases.** If heavy metal accumulation is higher than expected or crop yields are negatively impacted, buyers should discontinue purchases in EW even if there is remaining value in the contract. We recognize that new data may disprove our thesis that EW could deliver large scale, high-quality CDR while supporting healthy ecosystems in some or all circumstances, even if we think such outcomes are unlikely today.

- **Develop and execute a clear plan to deliver community benefits.** This includes embedding **considerations of procedural, distributive, and reparative justice in project design and implementation.** Project developers should facilitate meaningful engagement with affected stakeholders throughout the project lifecycle, especially early in a project's development, and be responsive to community input. Projects should have concrete plans for maximizing benefits and minimizing harms, and evaluate the distribution of those benefits and harms. Guidelines for best-in-class community benefits plans can be found here.

2. Use empirical measurements to validate rock weathering and determine credit generation in early deployments until models are more fit for purpose:[1]

- **Count carbon removal only after measured weathering occurs**. Tons should only be delivered to and retired by buyers ex-post of measured weathering. Buyers should not count tons ex-ante based on the spreading of rock given the current large uncertainties in weathering rates. While some particle sizes, feedstocks, and soil conditions may result in complete weathering over the course of years, others may take multiple decades or centuries to fully weather.
- **Purchases today should include direct, redundant measurements to reduce uncertainty**. While we hope to rely heavily on models complemented by more limited empirical sampling in the future, today's weathering models are not fit to support compensatory CDR claims. Current deployments should empirically measure in-field weathering rates (e.g. through analysis of soil cores or soil waters)[2]. Measurement design should include a sampling density that can provide

[1] While modeling has advanced on many aspects of tracking CDR through enhanced weathering (e.g., tracking downstream carbon leakage), there is a consensus of experts in the field that models tracking initial carbon dioxide removal in soils are not currently fit for making compensatory claims.
[2] Reershemius et al., 2023, Beerling et al.2023, Kantola et al., 2023

high confidence in observed weathering, as well as sufficient control strips that can detect any spurious weathering signals. Suppliers must also measure feedstock composition and particle size distribution. Finally, today's early purchases should use multiple independent approaches (such as solid-phase, dissolved-phase, gaseous-phase, and soil and buffer pH) in representative research fields to help validate the scalable measurements used in larger deployments.

3. Ensure conservative accounting of measurement uncertainties, post-field carbon leakage, lifecycle emissions, and other potential CDR losses:

- **Suppliers must account for uncertainties both within and beyond fields when calculating net CDR**. Weathering rates are an important source of uncertainty in EW CDR estimates, though not the only source of uncertainty. Suppliers must accurately account for potential losses in effective CDR from strong acid (e.g. non-carbonic acid) weathering, secondary mineral formation (e.g. clays),[3] terrestrial carbonate precipitation, plant cation uptake, evasion from streams and rivers,[4] losses in the ocean due to carbonic acid system equilibration,[5] counterfactual carbonate weathering sink,[6] and any potential system lags in effective CDR. More details on uncertainty elements that should be considered for enhanced weathering can be found in the CDR Verification Framework.
- **Suppliers must incorporate measurement uncertainty and discounting into project tons**. CDR resulting from EW should include an appropriate uncertainty discount that accounts for the effects of strong acid on CDR rates and post-field riverine and ocean losses. When weathering is measured, suppliers should provide conservative confidence intervals (e.g. ~90% confidence). Delivery timelines should clearly account for any system lags in effective atmospheric removal. Suppliers should use the best available science and update protocols regularly as new data and academic research results emerge.

4. Commit to best practices for scientific data sharing:

- **Prioritize open data transparency**. Enhanced weathering is a relatively young field. Additional data collection and analysis is essential to reduce quantification uncertainties and allow for a future of more economical, model-based EW estimates. Early buyers can subsidize the research and data collection needed to mature the pathway and drive EW down the cost curve. Early purchases can best catalyze cost reductions and EW advancement by subsidizing open, accessible data resulting from commercial deployment. Buyers should incentivize transparent sharing of data and methodologies (with anonymization or some aggregation when necessary to protect farmer privacy) to ensure that results benefit the broader scientific community.[7]

If you are a carbon removal buyer or ecosystem partner interested in signing these principles, click here.

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[3] Michalopoulos and Aller 1995
[4] Zhang et al 2022
[5] Kanzaki et al 2023
[6] Gibbons et al 2014
[7] See the FAIR principles for guidance on effective data sharing.

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