Flour Yield Project

FLOUR YIELD RESEARCH NOTE

Enhanced Rock Weathering Economics

Why CDR Yield, Climate and Logistics Determine Project Viability

> *A viable Enhanced Rock Weathering project is not created by basalt availability alone. It depends on the alignment of suitable material, suitable land, climate and hydrology, efficient logistics, credible measurement and verification — and economically viable realised net carbon removal.*

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Executive Summary

Enhanced Rock Weathering (ERW) is a carbon dioxide removal (CDR) pathway, not an automatic carbon-crediting mechanism. ERW applies suitable crushed silicate rock, including basalt, to land to accelerate natural weathering reactions that convert atmospheric CO_2 into dissolved and mineral forms. Applying rock does not, by itself, create a carbon credit.

The economics are set by the denominator. Most costs — sourcing, grinding, transport, spreading, monitoring — are incurred whether or not weathering proceeds as expected. Revenue potential depends on credible, independently verified net tonnes of CO_2 removed. Cost per verified net tCO_2, not tonnes of basalt applied, is the metric that decides viability.

Published cost ranges are wide because site conditions dominate. A 2023 techno-economic and lifecycle study of ERW supply chains in the Midwestern United States, modelling mining-waste feedstock, estimated approximately US$45–472 per net tCO_2 removed depending on CDR yield and transport configuration. A 2026 follow-up covering waste and virgin rock sourcing across the United States estimated approximately US$123–926 per net tCO_2, with cradle-to-farm-gate emissions of 44–371 kg CO_2e per tonne removed.

MRV is a commercial function, not a compliance afterthought. Measurement, reporting and verification is both a material cost and the evidence layer that converts physical activity into potentially monetisable verified removal under frameworks such as the Puro Standard's ERW methodology and Frontier's pay-on-delivery offtake structures.

Project development is where value is created — and capital is protected. Site selection, material characterisation, feasibility modelling, controlled pilots and MRV readiness determine whether a location merits scale. Flour Yield's intended approach is evidence-first: characterise, screen, model, pilot, measure, verify — then make a scale or no-scale decision conditional on both technical evidence and a credible route to market.

> The core conclusion: **ERW economics are driven not by tonnes of basalt applied, but by the cost of producing a credible, verified net tonne of CO_2 removal.**

1 ERW Economics Begin With Realised CDR Yield

Basalt and other calcium- and magnesium-rich silicate rocks have a theoretical geochemical capacity to consume atmospheric CO_2 as they weather. Theoretical capacity, however, is not the same as the removal that will actually occur — and be verified — within a commercially meaningful period. Field conditions determine how quickly minerals dissolve and how weathering products move through soil and water. Recent scientific reviews emphasise substantial uncertainty in effective CDR efficiency along the land–ocean continuum and call for site-specific assessment and long-term monitoring.

For commercial screening, the basic relationship is simple:

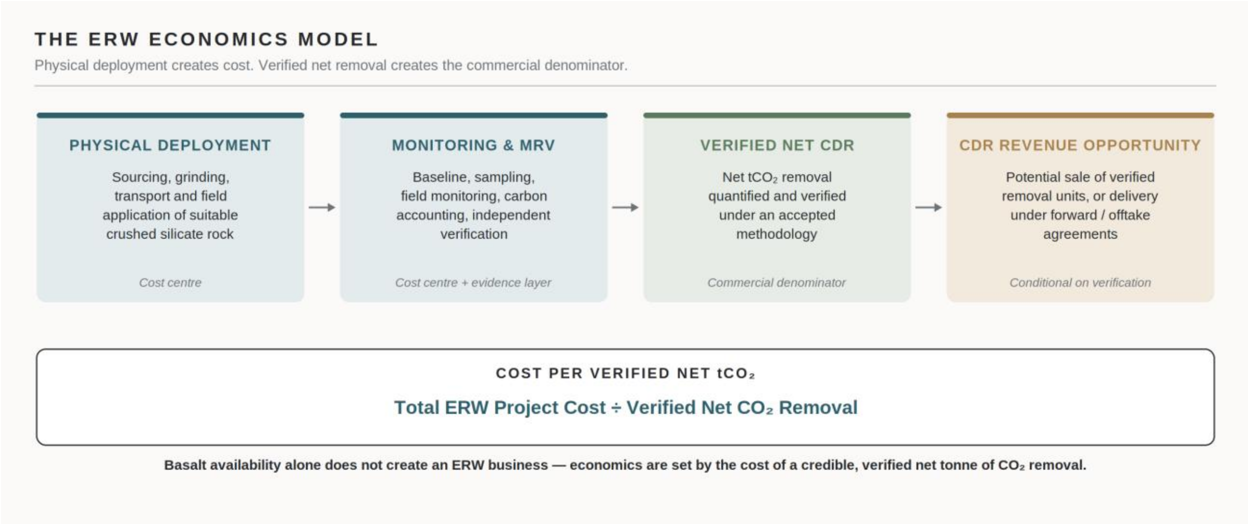

Figure 1 — The ERW economics model: deployment and MRV create cost; verified net removal creates the commercial denominator.

Verified net CDR means net atmospheric carbon dioxide removal that has been quantified under an accepted methodology, after relevant project emissions and uncertainty adjustments, and independently verified.

The denominator matters enormously. Mining or sourcing material, crushing and grinding it, transporting it, applying it and running an MRV programme all create cost. If realised CDR yield is low, those costs are spread across fewer verified tonnes — and project economics can deteriorate rapidly when performance falls below assumptions. This is why realised CDR yield is a fundamental commercial variable, not merely a scientific parameter.

2 From Physical Deployment to Commercial Value

An ERW project earns carbon-removal revenue only when it can demonstrate, quantify and independently verify net atmospheric CO_2 removal under an accepted methodology. The simplified commercial pathway runs from material characterisation through deployment, measurement, carbon accounting and independent verification to verified CDR units that can be sold or delivered.

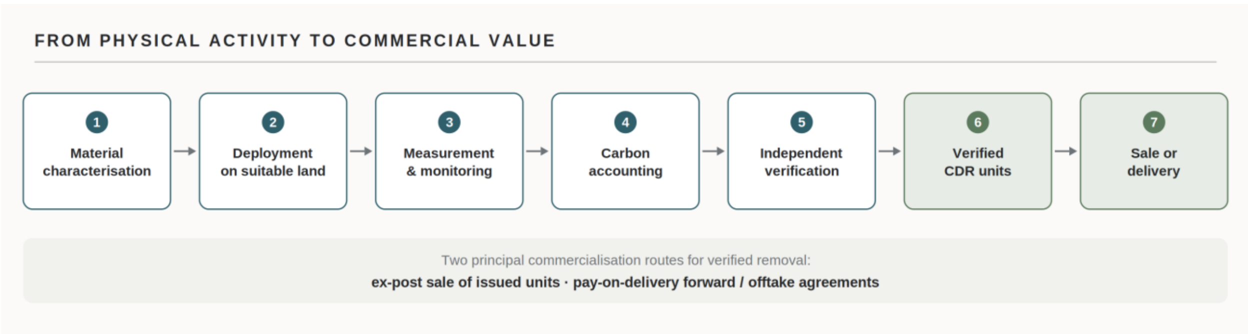

Figure 2 — From physical activity to commercial value. Verified units arise only after independent verification.

Market infrastructure: how verified removal is certified and bought

Puro.earth operates a dedicated Enhanced Rock Weathering methodology under the Puro Standard. Puro.earth's updated ERW Edition 2025, launched in November 2025, became the current methodology for new audit preparation following the transition from Edition 2022 in early 2026. It requires suppliers to combine two independent measurement approaches, accounts explicitly for loss terms (such as secondary mineral formation, cation adsorption and river and ocean losses) and applies an uncertainty discount to the removal calculation. Crediting is ex-post: independent auditors verify project evidence before CO_2 Removal Certificates (CORCs) are issued through the Puro Registry, after which suppliers can sell or transfer certificates to buyers.

Frontier — an advance market commitment to purchase US$1.8 billion of permanent carbon removal between 2022 and 2040 — illustrates the demand side. Its offtakes are pay-on-delivery, multi-year purchase agreements: third-party verification of delivered tonnes and registration on a recognised registry are required before payment. Smaller prepurchase agreements, paid up front to support earlier-stage suppliers, transfer more delivery risk to the buyer and should be distinguished from conventional offtakes. In June 2026, Frontier approved Puro.earth's ERW Edition 2025 methodology for use by its suppliers — a signal of convergence between certification standards and institutional procurement requirements.

Two principal routes to carbon-removal revenue

Ex-post credit sales. The project performs the removal activity first; verified units are issued and then sold. The developer carries execution and performance risk until issuance.

Forward / offtake agreements. Buyer and supplier agree in advance on future delivery of verified removal, specifying volumes, prices, delivery periods and verification conditions. Offtakes can improve revenue visibility and financeability — but payment still depends on verified delivery.

Carbon-removal units are not EU emission allowances

A verified carbon-removal unit or certificate should not be confused with an EU Allowance (EUA) under the EU Emissions Trading System. An EUA is a regulated entitlement to emit a defined quantity of greenhouse gases within the EU ETS cap. A voluntary carbon-removal unit represents something different: independently verified removal of atmospheric CO_2 under an applicable methodology. ERW project economics currently belong primarily to the emerging voluntary carbon-removal and CDR-procurement market, not to compliance allowance trading.

3 Market Access Is an Economic Variable

Delivering a credible verified net tonne of CO_2 removal is necessary, but it is not by itself sufficient to create project revenue. A commercially viable ERW project also requires access to a creditworthy buyer, a contractual offtake arrangement or another credible route to market.

Today, high-quality durable carbon dioxide removal is purchased primarily through voluntary, bilateral procurement arrangements. These markets remain comparatively small, heterogeneous and concentrated among a limited number of well-capitalised corporate buyers and buyer coalitions. A voluntary ERW removal unit is not interchangeable with an EU Allowance and does not discharge an operator's EUA surrender obligation under the current EU Emissions Trading System.

Market access should therefore be assessed alongside material, site, logistics and MRV conditions. Key questions include whether the selected methodology is accepted by prospective buyers, when verification and delivery can occur, how delivery risk is allocated, and whether a credible offtake pathway exists before deployment is scaled.

European carbon-removal infrastructure is developing, including voluntary certification initiatives and demand-aggregation efforts. These developments may improve future market access, but they should not be treated as a guaranteed route to ERW revenue. For project developers, evidence-first discipline should be paired with offtake-first discipline: **scale only where technical evidence and credible buyer demand align.**

4 The Major Economic Drivers

A commercial ERW assessment combines geochemical, agronomic, logistical and financial variables. Climate is itself an economic input: research across roughly 1,000 modelled agricultural sites worldwide shows material climate sensitivity in ERW carbon-removal performance, with temperature and hydrology producing very different outcomes from identical applications. Early field evidence points the same way — a 2025 study of a basalt-amended soybean plot in southeast Virginia, using continuous in-soil CO_2 monitoring, measured removal equivalent to approximately 1.04 tCO_2 per hectare per year, concentrated in the growing season and following significant rainfall pulses. As a single instrumented site using a novel method — and the subject of ongoing scientific discussion — it illustrates both the promise of direct measurement and why one field's result cannot be generalised. More rainfall does not always mean more removal: too little water constrains dissolution and transport, while saturation, drainage and downstream geochemistry introduce their own limits. The supportable concept is site-specific hydrological suitability.

The rock itself matters equally. Not all basalt is identical: mineralogy and chemistry determine theoretical capacity, weathering behaviour and environmental suitability, and feedstock must be screened for undesirable trace elements — a constraint that recent reviews identify as fundamental, since rocks with high removal potential often carry elevated nickel or chromium. And because ERW moves large tonnages of mineral material, transport distance and mode drive both cost and the project's own lifecycle emissions: in the 2026 US-wide assessment, rock type, sourcing and transport mix alone spanned a cost range from roughly US$123 to US$926 per net tonne removed.

Category	Driver	Economic effect
Geochemical & material	**Realised CDR yield**	The decisive denominator: determines how much verified removal results from deployed material
	Mineralogy & chemistry	Set theoretical capacity, weathering kinetics and environmental suitability
	Particle size & grinding	Finer material can weather faster but raises energy, cost and lifecycle emissions
	Trace elements	Must be screened for agricultural and environmental safety
Site & climate	**Temperature**	Influences reaction rates
	Rainfall & soil moisture	Govern water–rock interaction and transport of weathering products
	Soil conditions	Influence dissolution pathways and cation behaviour
	Suitable land	Affects application, sampling and monitoring practicality
Logistics & operations	**Distance to source**	Major cost and lifecycle-emissions variable
	Transport mode	Truck, rail and barge differ sharply in cost and emissions per tonne-km
	Field application	Determines cost per hectare and records quality
Commercial & verification	**MRV cost**	Required to credibly quantify removal
	Time to verification	Affects crediting timing, cash flow and financing
	CDR price	Determines potential carbon-removal revenue
	Project-development cost	Screening, feasibility and pilots shape economics before deployment begins

The strategic screening combination: **suitable rock + suitable land + short logistics + credible route to market**. A large mineral reserve alone does not create an attractive ERW project; proximity to suitable deployment land can matter just as much.

5 The Economic Weight of the Denominator — an Illustration

Consider a simplified project that incurs €1.0 million in total deployment and MRV costs. If it ultimately generates 10,000 verified net tCO_2, its production cost is €100 per verified tonne; at an illustrative selling price of €180 per tCO_2, the carbon-removal activity is economically positive. If the same physical project instead yields 3,000 verified net tCO_2 — because realised weathering falls short of expectations — the cost rises to roughly €333 per verified tonne, and at the same illustrative price the activity is economically negative. Same rock, same logistics, same monitoring spend; a completely different business outcome.

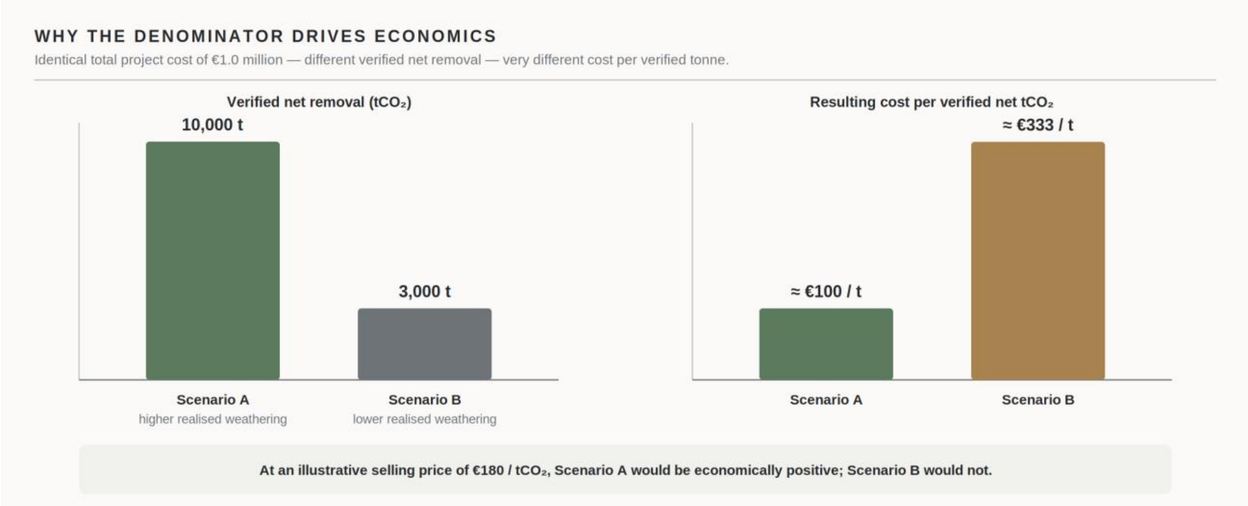

Figure 3 — Identical total cost, different verified removal, very different unit economics. All figures are illustrative and are not forecasts, targets or Flour Yield project assumptions.

There is no universal threshold at which realised CDR efficiency makes a project profitable or uneconomic. A project's actual break-even depends on its individual cost structure — feedstock, grinding, transport, application, MRV, financing, project development, time to verified removal — and on the achievable price for verified CDR. What the illustration shows is sensitivity: because most costs are fixed at deployment, unit economics move sharply with realised performance. This is precisely why disciplined site screening precedes capital commitment.

6 MRV Is Part of the Business Model

Measurement, reporting and verification is central to ERW economics for two connected reasons. First, MRV is a cost: sampling, laboratory analysis, environmental monitoring, data management and independent verification are substantial project expenses, and current research continues to highlight genuine difficulty in quantifying effective removal and tracking weathering products across the land–water system. Second — and decisively — MRV enables monetisation. It is the evidence layer that transforms an assumed environmental benefit into a credible, potentially monetisable verified outcome. Under the Puro Standard's ERW methodology, for example, certificates are only issued after independent audit of the full evidence base.

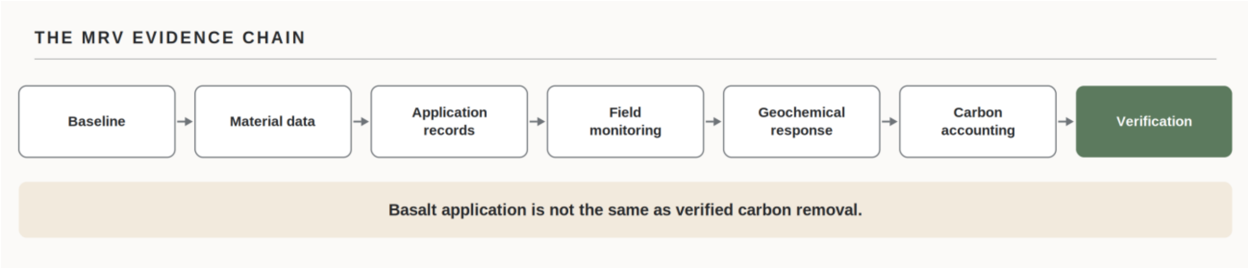

Figure 4 — The MRV evidence chain. Every link must hold before verified units exist.

The commercial consequence is blunt: cheap deployment without credible measurement does not necessarily create a viable carbon-removal project. A developer that treats MRV readiness — baselines, batch data, application records, monitoring design — as a day-one design requirement, rather than a retrofit, protects both the credibility and the economics of everything that follows.

7 The Flour Yield and Balkan Basalt Approach

The economics set out above support treating ERW as a structured project-development discipline rather than the distribution of crushed basalt. The role of a project developer is to identify where material, climate, soil, land, logistics, MRV and economics align — and, just as importantly, to establish early and at low cost where they do not. Not every technically possible ERW site will be commercially viable; professional screening and controlled pilots prevent capital from being committed to locations where expected CDR performance cannot justify deployment cost. The workflow therefore closes with two gates rather than one: verified technical evidence, and validated buyer demand — a credible offtake pathway or other route to market — before any scale decision.

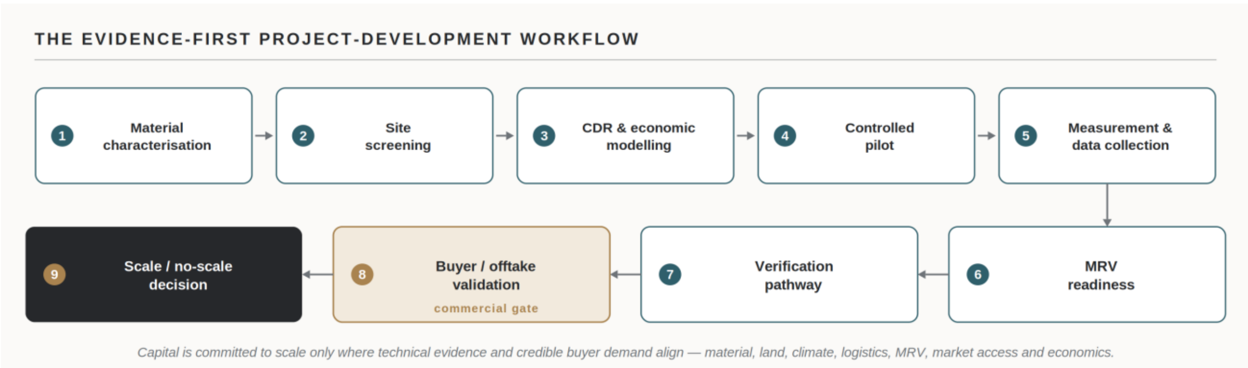

Figure 5 — Flour Yield's intended evidence-first workflow. Buyer / offtake validation is an explicit commercial gate: the scale / no-scale decision depends on both technical evidence and credible buyer demand.

Within this framework, **Balkan Basalt** contributes the material-side and regional partner context: basalt resources whose suitability is to be established through characterisation — mineralogy, chemistry, particle-size behaviour and trace-element screening — rather than assumed. **Flour Yield**, as a GreenFi ecosystem developed by Insela UAB, is oriented towards the project-development value layers this Research Note describes: site screening and feasibility work, deployment coordination, environmental data management and MRV readiness. These services are economically distinct from carbon-credit revenue and do not depend on it exclusively; verified CDR can form an additional commercial layer where a project ultimately satisfies the relevant scientific, methodological and economic requirements.

FYT is the digital utility layer of the wider Flour Yield ecosystem. The ERW economics discussed here concern the underlying real-world activity. They do not constitute a forecast of FYT value, token demand or financial returns, and nothing in this Research Note should be read as implying that deploying basalt automatically creates carbon credits or token value.

8 Conclusion

Enhanced Rock Weathering has significant potential and meaningful scientific and commercial uncertainty. Four findings from current research carry the most economic weight:

- realised CDR performance is site-specific;
- logistics materially affect both cost and net climate performance;
- realised CDR yield is the decisive denominator; and
- verification is what connects physical activity to economic value.

Applying basalt creates a potential removal pathway — credible measurement and verification are required before that potential can become verified CDR capable of supporting revenue, and a credible route to market is required before verified CDR can become revenue in fact. Scale decisions should rest on both technical evidence and validated buyer demand.

> **ERW is a project-development and evidence challenge before it becomes a financing challenge.** Basalt availability alone does not create an ERW business. A viable project requires the right material, the right land, suitable environmental conditions, efficient logistics, credible MRV and a credible route to market — assessed through evidence before capital is committed to scale.

For GreenFi, that distinction matters. It is the difference between marketing a resource and building the disciplined, verifiable operating capability that partners, buyers and ecosystem participants can trust.

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European Commission, DG Climate Action. EU CRCF Buyers' Club for carbon removals and carbon farming. As of August 2026, ERW is not among the first permanent carbon-removal methodologies adopted under the EU CRCF. The CRCF Buyers' Club is therefore relevant as emerging European market infrastructure, not as a currently established certification or revenue route for ERW. *Commission documentation.* climate.ec.europa.eu — EU CRCF Buyers' Club
Voluntary demand-aggregation platform for CRCF-certified units, announced under the November 2025 EU Bioeconomy Strategy, with initial design details presented at the CRCF Days in May 2026. A developing initiative — not a guaranteed route to ERW revenue.

About this Research Note. This Research Note summarises selected peer-reviewed literature, public carbon-removal market infrastructure and Flour Yield's analytical interpretation. ERW outcomes are site- and material-specific; quantified removal claims require appropriate characterisation, baselines, monitoring, carbon accounting and independent verification. Illustrative prices and scenarios explain economic sensitivity only and are not forecasts. It is not a feasibility study, a carbon-credit offering document or an investment recommendation, and does not establish a valuation of, or any financial return on, FYT.