



Veolia ES UK Ltd

Carbon dioxide removal prepurchase application

Summer 2024

General Application

(The General Application applies to everyone; all applicants should complete this)

Public section

The content in this section (answers to questions 1(a) - (d)) will be made public on the [Frontier GitHub repository](#) after the conclusion of the 2024 summer purchase cycle. Include as much detail as possible but omit sensitive and proprietary information.

Company or organization name

Veolia ES UK Limited

Company or organization location (we welcome applicants from anywhere in the world)

Veolia United Kingdom is pioneering Enhanced Weathering within the Veolia Group which operates in 58 countries around the world.

Name(s) of primary point(s) of contact for this application

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Brief company or organization description <20 words

Veolia is the world's leading environmental service company, operating across waste, water and energy sectors in five continents with nearly 218,000 employees. Veolia UK's enhanced weathering operations form a key part of its wider strategy to GreenUp across the globe.

1. Public summary of proposed project¹ to Frontier

a. Description of the CDR approach:

Describe how the proposed technology removes CO₂ from the atmosphere, including how the carbon is stored for > 1,000 years. Tell us why your system is best-in-class, and how you're differentiated from any other organization working on a similar approach. If your project addresses any of the priority innovation

¹ We use "project" throughout this template, but the term is not intended to denote a single facility. The "project" being proposed to Frontier could include multiple facilities/locations or potentially all the CDR activities of your company.

areas identified in the RFP, tell us how. Please include figures and system schematics and be specific, but concise. 1000-1500 words

Veolia is the world's largest multi-national environmental services corporation with a proven capability and track record of scaling solutions across the 58 countries it operates in. Within the wider Veolia Group, Veolia UK is pioneering enhanced weathering and additional carbon removal pathways with a strategic objective to establish key systems, procedures and partnerships in the UK to expand globally in the near future.

Over the past 24 months, Veolia UK has been developing its enhanced weathering operations and has deployed 5,500 tonnes of basalt rock fines to land. Through this process, Veolia has successfully developed key partnerships, business systems, procedures and commercial opportunities which will open up the expansion of enhanced weathering within Veolia to scale to the most suitable business units in the 58 countries we operate in around the world. This will be supported by Veolia's GreenUP strategic €2 billion investment fund.

Our enhanced weathering operations involve spreading basalt to land to remove carbon dioxide from the atmosphere through the silicate weathering reaction between carbon dioxide, rainwater and the basalt which leads to the formation of bicarbonate ions. Bicarbonate is a dissolved inorganic carbon which remains stable within the soil and washes through the soil pore water into river and ocean systems, where it remains for over 10,000 years. After which, a secondary reaction can occur where the bicarbonate undergoes carbonate precipitation within the water systems forming a metal carbonate, locking the carbon away for millennia. This process is a well-established and high-quality carbon removal pathway that permanently removes carbon dioxide from the atmosphere with multiple co-benefits to the environment and local communities (1).

Carbon removal via enhanced weathering is empirically quantified by the measurement of dissolution over time. This is calculated by tracking the loss of Magnesium, Calcium, Sodium and Potassium cations relative to an alkaline feedstock tracer element, typically Titanium within soil solid phase measurements. This is calculated by analysing the alkaline feedstock, soil samples taken before application, and soil samples taken 6-12 months subsequently, for a period of up to 5 years.

Fields are sub-divided into 1-hectare plots and 15 sub-samples are taken at 20cm depths and homogenised to represent a composite sample to provide statistically significant data that is interpolated to generate field scale estimates. Alkaline feedstocks and soils are analysed using ICP-MS with borate fusion, a method that provides full recovery of the cations and tracer elements with suitable limits of detection of 0.01%, allowing for accurate calculation of CDR from weathering. Counterfactual control plots are conducted on each farm deployment or for every 40 hectares (a typical UK field size is 10 hectares), whichever is smaller. Soil type, hydrology, agronomic data and historical and current farming practices are taken into account to ensure a representative control plot is selected.

Veolia differentiates itself from other organisations working on enhanced weathering by deploying two distinct innovations to both increase the scale of our operations and drive costs down. The first of these innovations is with the deployment of basalt fines into land restoration settings which supports significantly higher application rates (>10x) compared to standard agricultural deployments. These high application rates are due to the non-food chain use of the land and deeper integration of basalt fines within the soil profile. Additionally, due to the non-food chain use of the land, there are higher permissible limits of potentially toxic elements when deploying rock fines which supports the use of other alkaline feedstocks in these restoration settings, including materials such as steel slag, which have a much higher carbon removal potential. Around the world, there are [34,000](#) mines on 10 million hectares of land needing restoration. The US holds over [532](#) active and 466 recently closed landfills, while the UK has in the region of [300,000](#) hectares of land with contaminated soil to restore.

The second innovation which differentiates Veolia from the other organisations in this sector is with the co-application of Carbonic Anhydrase with alkaline feedstocks to significantly accelerate the weathering rates in both agricultural and restoration settings. Extensive field trials are required to examine the optimal enzyme formulations, application rates and varying enzyme sources that determine fastest acceleration of weathering rates in the variety of different environmental conditions. The rate of weathering and carbon removal is the greatest uncertainty within the enhanced weathering industry and to combat this uncertainty, there is a requirement for rigorous direct

measurements. This however comes at a significant cost which therefore demands the application of fast weathering feedstocks in the most optimal conditions to ensure the extensive measurements result in revenue generating carbon credits. Commercially viable operations which meet the necessary scientific quality standards in arable agricultural settings with suitable pH and agronomic conditions, require feedstocks to have high carbon removal potential and have super fine particle sizes with high specific surface area. Based on data from our key MRV partner, this contributes to a high likelihood of achieving the full carbon removal potential within a 3-5-year period as opposed to coarse 0-4mm basalt fines that fully weather considerably slower over 30-40 year timeframes. The available volume of super fine basalt is, however, not in the volumes necessary to meet the climatic gigatonne requirements of this industry. Therefore Veolia is committed to identifying a viable solution to utilise alternative rock fines such as the coarser 0-4mm, 0-2mm & 63µm-1mm quarrying outputs of basalt that are available in megatonne quantities nationally in the UK and gigatonne quantities globally. As these larger rock fines weather and remove carbon dioxide at significantly slower rates, the revenue generated from the carbon removal from these deployments is not sufficient to support these applications of enhanced weathering. Innovations that accelerate these weathering rates are needed to address this issue to successfully remove carbon within relevant timescales to combat climate change and effectively scale up the enhanced weathering sector. To address this challenge, Veolia UK is undertaking significant and extensive scientific research and development to apply the enzyme carbonic anhydrase, responsible for accelerating the formation of carbonic acid, in combination with alkaline feedstocks in both agricultural and restoration settings.

To summarise, our innovation with restoration deployments increases the density of fines applied per hectare with our enzyme innovations increasing the rate of carbon removal. Together these innovations have the potential to significantly improve both the scale and rate of carbon removal from enhanced weathering. These innovations, when combined with improvements in machine learning predictive models that reduce sampling requirements over time, have the potential to enable Enhanced Weathering to reach climate-relevant scales at c.\$100/ton price points.

Veolia UK ensures the highest level of quality and permanent carbon removal through its partnership with Isometric and adherence to its enhanced weathering protocol. This partnership ensures Veolia approaches enhanced weathering with the highest level of scientific robustness and verification of carbon removal credits.

In conclusion, Veolia UK stands at the forefront of carbon removal via enhanced weathering, leveraging our extensive experience, innovative approaches, and strategic partnerships to deliver best-in-class solutions. Our enhanced weathering operations, underpinned by the application of basalt fines in restoration and agricultural settings alongside the use of Carbonic Anhydrase, offer a scientifically robust and commercially viable pathway to large-scale low cost carbon dioxide removal with significant co-benefits to local communities and the environment.

Our differentiation lies in our ability to scale operations globally across the 58 countries we operate in, supported by Veolia's GreenUP strategic €2 billion investment fund, and our commitment to continuous innovation. We are addressing the key challenges within enhanced weathering that impact the whole sector at scale and are pushing the boundaries of what is possible in this sector. Our focus on restoration deployments and enzyme innovations, coupled with machine learning predictive models, positions us to significantly improve both the scale and rate of enhanced weathering on its path to reaching climate-relevant scales at competitive price points.

References:

- (1) Hartmann, J., et al., 2013. Enhanced chemical weathering as a geoengineering strategy to reduce atmospheric carbon dioxide, supply nutrients, and mitigate ocean acidification. *Review of Geophysics*. 51(2). <https://doi.org/10.1002/rog.20004>

- b. **Project objectives:** What are you trying to build? Discuss location(s) and scale. What is the current cost breakdown, and what needs to happen for your CDR solution to approach Frontier's cost and scale

criteria?² What is your approach to quantifying the carbon removed? Please include figures and system schematics and be specific, but concise. 1000-1500 words

Veolia is building an approach to enhanced weathering that is globally scalable to gigatonne volumes of carbon removal at low costs per tonne and with significant co-benefits to the environment and local communities.

The extensive field trials being undertaken by Veolia and its partners will be assessing the viability of enhanced weathering with the co-application of enzymes in both agricultural and restoration application settings. The proposed project offer to Frontier is the following:

- Preliminary small scale arable and pasture field trials testing the effectiveness of co-application of enzymes with scaling up to larger trials in 2025 on the same sites.
- Scientifically robust two year field trial in partnership with a leading University testing the effectiveness of enzymes in arable cropping.
- Restoration field trial deployment at supply chain partners landfill to test the effectiveness of enzymes in accelerating the weathering of blast furnace slag, steel slag and basalt.
- Restoration field trial deployment at supply chain partners former opencast coal mine to test the effectiveness of enzymes in accelerating the weathering of basalt fines with comparison of super fines and standard 0-4mm.

This is through the development core business unit functions in combination with highly innovative approaches to enhanced weathering. These innovations accelerate the carbon removal rates of enhanced weathering through the co-application of enzymes and increase economies of scale by performing deployments in both standard agricultural and high application land restoration settings. Veolia is building the key systems and procedures for generating enhanced weathering carbon removal credits in the UK initially with a strategy to expand operations to Veolia's existing business units around the world. Veolia acknowledges that the UK is not the most favourable environment for enhanced weathering and more tropical regions within Latin America, Asia and Africa that Veolia operations in are more favourable due to naturally accelerated weathering rates. This expansion is also necessary to achieve the gigatonne scales needed to combat global warming and Veolia's 220,000 employees are a significant workforce to enable this. Veolia is well established at replicating and adapting projects from individual business units to the 58 countries it operates through processes supported by 600 dedicated staff at Veolia's Paris headquarters.

To achieve Frontier's cost and scale criteria of \$100 per tonne and 0.5 Gt of removal per year there are significant developments required within the enhanced weathering sector. These innovations that Veolia is aligned with and developing include:

Transition from direct measurement based MRV to model based MRV: The most significant costs impacting the price per tonne of enhanced weathering credits is determined by the rigorous requirements for dense and frequent direct measurement to validate carbon removal. Undertaking the necessary sampling to determine this contributes significantly to the costs to produce verified enhanced weathering credits. This requirement for intensive sampling can only be supported through the deployment of super fast weathering rocks which remove carbon within the first three to five years, otherwise without this, the amount of credits and therefore revenue generated from slower weathering rocks is not sufficient to cover the costs of the operation. Sampling costs will decrease over time as sophisticated machine learning modelling software develops an integrated understanding of the complex interactions between sources of rock, soil conditions, crops, and climates that lead to varying rates of weathering. This data generation is based on super fine sources of rock which are in a relatively low availability in terms of the climatic gigatonne scales needed to combat global warming.

Innovations that accelerate the weathering rates of enhanced weathering feedstocks: Deployments with super fine basalt sources are limited in scale and alone do not scale to address the challenges

² We're looking for approaches that can reach climate-relevant scale (about 0.5 Gt CDR/year at \$100/ton). We will consider approaches that don't quite meet this bar if they perform well against our other criteria, can enable the removal of hundreds of millions of tons, are otherwise compelling enough to be part of the global portfolio of climate solutions.

faced by the carbon removal sector. Enhanced weathering solutions must utilise sources of rock with scalability to address the challenges of the sector. Once the stockpiles and annual production of super fine basalt sources are utilised to the maximum then there is an impending requirement to explore solutions to accelerate the weathering rates of sources of rock found in gigatonne scales globally which are significantly larger in particle size distribution. Conventional crushing and screening methods to reduce the particle sizes and increase the carbon removal reactivity of quarry outputs such as 0-4mm basalt fines presents challenges with high energy costs, low production outputs, high capital costs, dependency on calm and dry weather conditions, and ultimately high costs. These challenges lead to the conventional methods of crushing and screening to contribute to accelerated weathering rates being ineffective and not a viable route to scale. For these reasons Veolia is developing a solution that deploys carbonic anhydrase enzymes to increase the formation of carbonic acid directly onto or in very close proximity to alkaline feedstocks to accelerate the weathering rates.

Expansion of deployment settings: From arable agriculture to high application land restoration and grassland. Veolia is deploying alkaline feedstock for enhanced weathering in land restoration applications such as closed landfills, former open-cast mines and contaminated land where it is possible to apply at least ten times the standard application rates for agriculture. This is due to the permissible nutrient application limits being calculated over ten years due to the non-agricultural use and deeper integration into the soil profile from the integration with JCB 360 excavators. At sites requiring restoration, the top 40cm of existing degraded or low-quality surface soil is excavated with a 360-degree digger. Biosolids are then deposited into this area and the excavated soil is placed back and the biosolids and soil are all then mixed with the machinery. Basalt will be distributed to the soil before the initial 40cm of soil is excavated so that this material is mixed into the soil when it is first excavated and again when the biosolids are deposited to create as homogenous a mix as is practically feasible. The novelty of this approach is highly relevant to the wider development of the enhanced weathering sector towards mega and gigatonne scales as there is a significantly large worldwide availability of land restoration sites that could support high application rates.

Global Enhanced Weathering Operations: Veolia has the required expertise to deliver enhanced weathering at scale based on our extensive logistical and agricultural capabilities from transporting and processing over 48 million tonnes of waste annually. In addition, Veolia operates in many of the world's regions most suitable for enhanced weathering, including Latin America, Northern Ireland, North America, Australia, China, India, Eastern/Northern and Southern Europe, alongside 30 countries within Africa. Veolia is pioneering enhanced weathering within the wider Veolia Group in the UK and setting the foundations for the global expansion of this carbon removal pathway. Key to this expansion is the development of replicable systems and procedures alongside the partnerships with key supply chain organisations such as technology providers, feedstock sources and academic institutions.

Demand for Carbon Credits: Critical confidence in the voluntary carbon market and multi-year offtake agreements will determine the level of investment and the rate of our global expansion. Frontier has the potential to catalyse Veolia's UK and global expansion by providing advanced market commitments to secure our business cases for additional investment which are the predominant limiting factor.

The current costs for Veolia's operations in both agriculture and restoration with the co-application enzymes varies significantly depending on the source of feedstock, proximity to application site, specific site conditions, the application rates, the sampling requirements and expected carbon removal rates. The current blended cost per tonne of carbon removal for our deployments with enzyme innovations in both restoration and agricultural settings is in the region of \$450-\$500. We forecast there to be significant reductions in the price per tonne over the next 4-5 years to \$150-\$250 per tonne. Veolia foresee these reductions resulting from the development of our project in the key areas of: the transition to a more model based approach reducing sampling costs, accelerated weathering rates from enzymes opening up additional feedstock opportunities, new deployment settings into land restoration enabling economies of scales with higher application rates and global expansion to more tropical areas of operation with naturally accelerated weathering rates. Veolia is expertly positioned to effectively scale enhanced weathering globally by leveraging its existing and well established business unit functions in combination with these key innovations.

- c. **Risks:** What are the biggest risks and how will you mitigate those? Include technical, project execution, measurement, reporting and verification (MRV), ecosystem, financial, and any other risks. 500-1000 words

At Veolia we are committed to delivering high-quality carbon removal credits through our innovative enhanced weathering process. We understand that potential risks may arise from our approach, and we have developed robust strategies to mitigate these risks.

Technical Risks: Our process utilises enzymes to accelerate the removal of carbon dioxide from the atmosphere. However, we recognise that the effectiveness of these enzymes can vary under different environmental and agronomic conditions. To mitigate this risk, we are investing in extensive field trials with research and development to establish a comprehensive understanding of these variations and optimise our enzyme formulations and application rates accordingly. In addition to this, in high application restoration deployments there is a technical risk that the weathering rates will be slowed as experienced in previous high application agricultural field trials, to combat this, we are undertaking extensive field trials to determine the optimum application rates for a restoration deployment.

Production Scaling Risks: Scaling the production of enzymes to match the growth of the sector is another challenge. We are addressing this by partnering with FabricNano, a UK based startup, for the specific formulation optimisation of the enzymes and Novonesis, an established Danish corporation with extensive capabilities to produce large volumes of enzymes. These partnerships enable us to scale up production efficiently and sustainably. Veolia is also exploring low cost and highly sustainable production methods for enzymes and expands further in the sections below.

Perception Risks: We are aware of the potential negative perception of enzymes among farmers. To counter this, we are conducting extensive outreach and education efforts to inform farmers about the benefits of our enzymes, backed by solid scientific evidence gathered from our extensive agricultural field trials with Newcastle University. We are also working closely with agronomists and agricultural contractors to promote the acceptance of our technology among the farming community.

Methodology, Reporting and Verification Risks: Deployments with the restoration setting and with the co-application of enzymes are both relatively understudied and therefore it is critical to increase both the sampling frequency and density to mitigate the uncertainties from the carbon removal in these settings. For these field trials, Veolia is carrying out extensive field trials studying the full suite of agronomic analysis' including all relevant potentially toxic elements, soil organic carbon, available nutrients, yield alongside comprehensive feedstock analysis in line with Isometric's protocol and ICP-MS analysis of soils over time to account for carbon removal via the TiCAT method. This coupled with high density and high frequency sampling significantly reduces the uncertainties in the MRV.

Soil Sampling Challenges: Consistency in sampling depths from plot to plot and over time is a known challenge. We are mitigating this risk by providing clear guidelines on sampling procedures and by using advanced soil sampling equipment that ensures consistent depth. We also conduct regular audits to ensure compliance with these procedures.

Enzyme Degradation Risks: The degradation of enzymes over time and the requirement for reapplication is another risk. Our project partners are continuously working on improving the stability of our enzymes to extend their lifespan and studying the external factors that influence this as well. Once established we will provide clear guidance to farmers on when and how we reapply the enzymes to maintain their effectiveness to maintain the farmers engagement in the project.

Ecosystem Risks: Lastly, we are mindful of the potential negative impact of our enzymes on crop and soil health. Our enzymes are thoroughly tested for their safety and efficacy before they are released into the market. We also monitor their impact on the field continuously and are ready to make adjustments as necessary to ensure the health of the ecosystem. For our initial field trials, the crops produced on the trial plots will not be sold for food chain use and will instead be transformed into energy. Prior to this, Veolia will send samples of the production to laboratories for safety analysis. This information will provide key safety data on the crops to enable future trials and deployments to be sold into the existing food chain markets for the farmers.

In conclusion, while we acknowledge the potential risks associated with our approach, we are confident in our ability to manage these risks effectively. We are committed to continuous

improvement and innovation to deliver high-quality carbon removal credits via enhanced weathering and contribute to the global fight against climate change.

- d. **Proposed offer to Frontier:** Please list proposed CDR volume, delivery timeline and price below. If you are selected for a Frontier prepurchase, this table will form the basis of contract discussions.

Proposed CDR over the project lifetime (tons) <i>(should be net volume after taking into account the uncertainty discount proposed in 5c)</i>	1076
Delivery window <i>(at what point should Frontier consider your contract complete? Should match 2f)</i>	Septmber 2024 - September 2027
Levelized cost (\$/ton CO ₂) <i>(This is the cost per ton for the project tonnage described above, and should match 6d)</i>	\$581
Levelized price (\$/ton CO ₂) ³ <i>(This is the price per ton of your offer to us for the tonnage described above)</i>	\$581

³ This does not need to exactly match the cost calculated for “This Project” in the TEA spreadsheet (e.g., it’s expected to include a margin and reflect reductions from co-product revenue if applicable).