Frontier

Veolia ES UK

Carbon dioxide removal prepurchase application

Summer 2023

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 2023 summer purchase cycle. Include as much detail as possible but omit sensitive proprietary information.

Company or organization name

Veolia ES (UK) Limited

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

United Kingdom

Global presence in 45 countries

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

Charlie Hendry-Smith
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Brief company or organization description <20 words

Veolia is the global leader in optimised resource management, providing water, waste, and energy management solutions for sustainable development.

1. Public summary of proposed project[1] to Frontier

a. **Description of the CDR approach:**

Describe how the proposed technology removes CO_2 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 areas identified in the RFP, tell us how.

Please include figures and system schematics and be specific, but concise. Aim for 1000-1500 words.

With a broad geographic footprint that covers five continents, Veolia is a truly global entity. Its multifaceted expertise is evidenced through its innovative strategies in water, waste, and energy management, contributing significantly to the sustainable development of diverse communities and industries worldwide. From ensuring water quality and availability to creating sustainable waste management systems, and optimizing energy usage, Veolia's comprehensive suite of services shapes the core of sustainable practices in over 45 countries. This global perspective and expertise uniquely position Veolia as a pioneer and leader in driving the transition to a net zero circular economy in the first half of the 21st century.

A core pillar of Veolia's strategic plan in the United Kingdom is centred around the advancement of sustainable agricultural projects, cognizant of the fact that this sector, being resource-intensive and a significant contributor to greenhouse gas emissions, plays a substantial role in climate change and environmental degradation.

Our focus is particularly on enhanced weathering, a technique that presents a compelling dual benefit. Not only does it aid in the sequestration of carbon dioxide, a key factor in mitigating climate change, but it also bolsters crop yield without necessitating additional land use.

Enhanced weathering involves spreading finely ground silicate rock on land to speed up natural weathering. The rock reacts with CO2 in the air or soil, locking it into stable carbonates that are washed into the ocean. Critical factors include rock type, particle size, and environmental conditions. The process requires diligent monitoring for quantifying carbon removal and assessing ecosystem impacts. It also requires careful planning for efficient sourcing, processing, and application of rock material, considering logistical challenges and local conditions. We are confident that with a robust MRV, enhanced weathering holds significant potential for large-scale, cost-effective carbon sequestration.

Veolia has selected its United Kingdom operations to lead the introduction and implementation of enhanced weathering across the group. Our UK headquarters, centrally located in London, serves as the hub of our operations, supported by an extensive network of offices and depots spread throughout England, Scotland, Wales, Northern Ireland and Ireland.

Veolia UK has an extensive track record of managing agricultural landspreading operations throughout the UK and processes over 500,000 tonnes of composts and bio-solids annually, demonstrating the breadth and depth of our operational capabilities. This operational acumen,

[1] We use "project" throughout this template, but note that 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.

combined with our extensive logistical network, positions us uniquely to execute the enhanced weathering project across any region within the UK.

As we pivot to this innovative project, it's crucial to appreciate the rigorous and data-driven methodologies it demands, particularly given the intricate science behind enhanced weathering. In this new venture, we must underscore the importance of maintaining meticulous records, and consistently verifying the efficiency of our carbon dioxide removal technologies. The process of enhanced weathering, being a naturally occurring but scientifically complex one, calls for a systematic approach to data management and integrity. By doing so, we can ensure not only the successful execution of the project but also contribute substantively to the broader development of sustainable agricultural practices and carbon dioxide removal technologies.

The science behind enhanced weathering can be elegantly understood by breaking down the steps involved in this complex yet naturally occurring process. The initial stage involves the formation of carbonic acid from CO2 and water. This equilibrium-controlled reaction represented as $CO_2 + H_2O \rightleftharpoons H_2CO_3$, results in the creation of carbonic acid. However, it's crucial to note that under typical environmental conditions, only a small proportion of CO2 in water undergoes this transformation.

The next stage involves the dissolution of minerals. The weak carbonic acid generated percolates through the soil and reacts with specific minerals present, such as olivine and pyroxene, which are abundant in magnesium and iron silicates. This reaction effectively breaks down these minerals, liberating metal cations and silica into the solution.

The final and most crucial phase is the creation of bicarbonate. Here, the metal cations, predominantly calcium (Ca^{2+}), magnesium (Mg^{2+}), and iron (Fe^{2+}), react with bicarbonate anions (HCO_3^-), leading to the formation of metal bicarbonates. These bicarbonates act as sinks for the captured CO2, thereby sequestering it. This reaction is pH-dependent, occurring more readily under alkaline conditions. Moreover, the formation of bicarbonates involves an additional reaction where carbonic acid donates a proton (H^+), transforming into bicarbonate (HCO_3^-).

While this series of reactions occur naturally, the speed at which it transpires is far too slow to effectively combat the rate at which we are adding CO2 to the atmosphere. This is where our enhanced weathering process comes in. By utilising fines sourced from quarries, we can significantly increase the surface area exposed to the reactions, thereby accelerating the process. These fines are then land spread over large areas of suitable land, allowing for direct interaction with carbonic acid from rainfall and thus facilitating the carbon sequestration process.

The result of this chain of reactions is bicarbonate ions, which represent a geologically stable form of carbon. Bicarbonate ions are easily transported via waterways, eventually making its way into the ocean. There, it can reside in the water column for tens of thousands of years. Moreover, in marine environments, the bicarbonate ion and the accompanying cations can precipitate as carbonate minerals like calcium carbonate ($CaCO_3$), forming limestone and dolomite.

Our operational excellence and global footprint enable us to implement and scale up this method efficiently. With existing operations and expertise in managing complex operations and supply chains across various countries means we can rapidly scale up to the targeted removal rate of over 0.5 Gt per year at a <$100 per tonne cost.

The unique innovations Veolia brings to enhanced weathering set us apart from other players in the field and solidify our position as a leader in this technology. These include:

- Veolia's longstanding reputation and credibility are unmatched, importantly within the quarrying sector and among prominent buyer-side corporations. Our relationships within these industries alongside established systems and procedures provide a robust foundation for successful project execution.

- Our expansive network of over 50 landfills across the UK, suited for enhanced weathering and present a novel approach to commercial-scale enhanced weathering.

- With the management of over 500,000 tonnes of compost and bio-solids annually, we're poised to co-apply these materials with silicate minerals. Compost and bio-solids complement the nutrient profiles of these minerals making an attractive proposition for landowners and initial research also suggests co-application has the potential to accelerate the CDR. This approach of co-application is novel in the field of enhanced weathering.

- Our existing network of over 2,000 farmers, to whom we supply fertilisers and animal bedding, represents a significant land bank for our enhanced weathering operations. This existing client base ensures an immediate potential demand further supporting the execution of our project.

- Veolia's operational efficiency, honed through years of managing landspreading activities, enables us to achieve costs highly competitive cost structure for applying bio-solids, a testament to our cost-effectiveness and ability to executive commercial scale CDR via enhanced weathering.

- Our proprietary software efficiently manages operations, including landowner networks, application rate calculations, tracking of soil and rock analysis, environmental permit generation, GPS tracking, and process carbon footprint calculations. Streamlining processes and ensuring comprehensive monitoring and efficiency to further support the thorough execution of our project.

- As Veolia is committed to reducing and offsetting emissions from our Energy Recovery Facilities as well as selling credits to the voluntary market, there is an internal incentive to reduce the cost of carbon credits resulting from enhanced weathering. This commitment aligns with our business and environmental objectives, creating a win-win scenario.

- As an established waste management company, Veolia has access to a range of materials that are also suitable for CDR via enhanced weathering and these include: steel slag, cement kiln dust, returned or demolished concrete, and calcium sulphate.

Veolia's multinational footprint, covering 45 countries with diverse climatic and geological conditions, is uniquely poised to exploit the optimum rates of weathering in the most suitable environmental contexts. This breadth of operations facilitates the identification and usage of the most suitable sites for enhanced weathering across the globe. Our established supply chains and local industry relationships further streamline the logistics of sourcing, transporting, and applying the required rock materials at scale.

Veolia's in-depth, cross-sector expertise in environmental management solutions allows us to navigate complex regulatory landscapes and engage effectively with local communities and stakeholders, which is crucial for the broad acceptance and success of our enhanced weathering initiatives.

Our capacity for extensive research and development is also an integral part of our strategy. Leveraging our wealth of operational data, we can optimise application rates, weathering process monitoring, and ultimately the cost-effectiveness of carbon sequestration.

In short, our global presence, existing infrastructure, logistical capability, and our ability to engage effectively at local levels make Veolia an unparalleled leader in the field of enhanced weathering

technology, well-positioned to make significant contributions to global carbon dioxide removal efforts.

In summary, these unique facets of our project and operational capabilities distinguish Veolia in the arena of enhanced weathering and position us at the vanguard of this crucial technology. Veolia strategically well positioned to establish itself as best-in-class with a novel and credible approach with the capabilities to execute effectively and provide Frontier with a solution that bolsters the diversity and depth of their CDR portfolio.

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 $100/t and 0.5Gt targets? What is your approach to quantifying the carbon removed? Please include figures and system schematics and be specific, but concise. Aim for 1000-1500 words.

Veolia is building a network key stakeholders to enable a large scale commercial operation spreading rocks suitable for enhanced weathering supported by rigorous and independently verified measurements, and reporting for carbon dioxide removal. Veolia has ambitions to scale applications of silicate minerals in agricultural settings at lower application rates, however, this approach presents significant logistical challenges at gigatonne scale operations. Our project aims to revolutionise CDR by combining enhanced weathering with degraded large scale sites. The opportunity at land restoration sites is an approach that presents significant opportunities for low cost commercial scale CDR.

Veolia operates in 45 countries globally and we plan to deploy this innovative approach at a scalable level across multiple countries, focusing initially on pioneering these practices in the Scotland, close to Glasgow, with a view to expanding to the countries where we have existing operations with the most favourable conditions.

The potential scale of this approach is significant, with opportunities to apply material to tens of thousands of hectares of land at high applications rates. Our current pilot project in Scotland, is phased over three scaled applications over three years, aims to refine our understanding, methodology and optimise our systems and procedures. Following the success of the pilot, we anticipate scaling the operation to multiple different sites, aiming for tens of thousands of hectares within a decade. Veolia manages over 50 landfills throughout the UK that would be suitable candidates for subsequent applications along with this Veolia has established relationships with a number of significant companies with large holdings of land suitable for restoration.

Initially, the costs of this approach will be high as we rigorously test the impact of site conditions and application rates on CDR. But over time, the costs of this approach will decrease as we generate data on the geochemical process, reducing the need for in-situ measurements with a greater dependence on modelling software informed on real world data. Along with this as we undertake trials, we will gain certainty over the optimum application rates and techniques that balance tonnes applied with fast weathering rates. Initially, but subject to the conclusion of the first trials, we forecast the costs of generating credits from this approach to be in the region of $500-$600 per tonne of CO2 removed as there are comprehensive MRV requirements and extensive field trials required. With the operational improvements and a better understanding of optimal conditions for weathering, we forecast costs falling below $100 per tonne in our Nth of a Kind operation.

Presently, our costs break down into four primary components:

Raw Material Acquisition: This includes obtaining silicate minerals and one day bio-solids and

preparing these for application.

Application: This covers the physical process of applying our mixture to the restoration sites, including the logistics of transport and the operation of application machinery.

Monitoring and Verification: This comprises the cost of measuring the effectiveness of our process, including geochemical monitoring, modelling and third-party verification of carbon sequestration.

Administrative and Overhead Costs: These are the costs associated with project management, research, regulatory compliance, and other administrative elements.

To approach Frontier's target cost of $100/t CO2 and a sequestration target of 0.5 Gt CO2 per annum, significant efficiencies are need to be realized, Veolia is well positioned to drive this innovation as the world leader for environmental services driving the transition to a net zero circular economy with exisitng and extensive global experience of highly optimised agricultural landspreading operations that synergise with enhanced weathering.

Reductions in raw material costs could be achieved through economies of scale as we expand operations, and strategic partnerships with quarries and biosolid/compost suppliers. Lowering application costs could be facilitated by investing in efficient application machinery and optimizing logistical operations. Meanwhile, improvements in monitoring technology, combined with data analysis automation, could reduce the costs associated with monitoring and verification.

Quantifying the carbon removed is a critical part of our project. We employ a detailed monitoring, reporting, and verification approach, using state-of-the-art geochemical measurement techniques to track key markers of weathering and carbon sequestration All data is subject to third-party verification to ensure accuracy and credibility.

Regarding system schematics, we are leveraging a comprehensive system comprising material sourcing, preparation, application, and monitoring units. These units work in sync to ensure the smooth operation of our project. Upon application, a dedicated team of researchers and data analysts monitor the site, ensuring the effectiveness of our CDR solution.

A critical aspect of our global ambition is to enhance public understanding and acceptance of enhanced weathering. We aim to communicate the benefits and safety of this approach effectively to the public, regulatory authorities, and other stakeholders. Success on this front would help overcome resistance to new technologies and catalyse a faster, broader acceptance of enhanced weathering as a tool for climate change mitigation.

Our global ambitions extend to fostering collaborative relationships across various sectors. By partnering with other corporations, governments, and non-governmental organizations, we aim to share knowledge, pool resources, and create a united front against the global climate crisis.

In summary, our goal is not only to build an efficient, cost-effective, and scalable CDR solution but also to shift the paradigm of climate action worldwide. Through the large-scale application of enhanced weathering, the introduction of technological advancements, setting industry standards, and building collaborative partnerships, Veolia aims to lead the way in global climate action and lead the transition to a habitable and sustainable future for our global society.

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. Aim for 500-1000 words.

Our project's innovative nature, where we co-apply silicate minerals with bio-solids at a large scale sites for carbon dioxide removal via enhanced weathering, presents a new opportunity for low-cost commercial scale carbon credits. However, like any groundbreaking approach, it carries its own suite of challenges and risks. The risks we face range from technical and project execution to measurement, reporting, verification, ecosystem, financial, and others. Let's delve into these challenges and consider our strategies to address them effectively.

Technical risks are prominent due to the novelty of our approach, applying these minerals to restoration sites. The setting of this application is pioneering and untested, presenting uncertainties that could disrupt our forecasted outcomes. Nevertheless, we view these uncertainties not as roadblocks but as opportunities for refining our processes. By committing to a continuous cycle of extensive research, development, and testing, we aim to build our knowledge base and technical expertise, thereby reducing uncertainty and mitigating technical risk. Additionally, by applying a phased rollout and scaling-up approach, we can progressively build on small-scale success and learn from any challenges.

High application rates of silicate minerals and bio-solids, another technical risk, present an unexplored scenario impacting geochemical processes. The dynamics of these interactions in various soil conditions could potentially affect the weathering rates and thus the CDR. To address this, our approach emphasizes a combination of high density and high frequency sampling for our initial extensive field trials. This approach allows us to build a detailed understanding of the geochemical interactions and identify the optimum application rates, therefore minimising potential pitfalls.

The biosolids and weathering dynamics present another unique challenge. If nitric acid from biosolids weathers silicate minerals instead of carbonic acid, it could potentially reduce the CDR. This risk necessitates a thorough understanding of these dynamics and a strategy to ensure an increase in dissolved bicarbonate. Exact impacts of nitric acid weathering from biosolids will only be known once empirical measurements are taken.

Project execution risks, particularly related to the sites, are also a concern. The heavy degradation and low microbiological activity of these degraded sites could impact weathering rates and the effectiveness of the CDR process. Our strategy incorporates a rigorous site assessment process prior to application, followed by regular monitoring of the site conditions, allowing us to track progress and adjust our methods based on the site's response to treatment.

Public perception represents another pivotal risk. Given the novelty of our concept, there may be public resistance, regulatory scrutiny, or stakeholder concern. To address this, our strategy centers on an open, transparent, and proactive communication approach. We will develop comprehensive information campaigns to educate and inform the public, regulatory authorities, and stakeholders about our approach's safety, benefits, and role in climate action. By engaging in regular dialogue with stakeholders, we can build trust and understanding.

Financial risks stem from our engagement with the relatively new voluntary carbon markets, which differ from our traditional business areas. Our board understandably holds reservations about investing in unfamiliar markets. The opportunity to enter into this pre-purchase agreement with Frontier presents our project with the opportunity to mitigate this risk. These agreements can secure revenue streams, providing our board with the confidence to continue supporting the funding of our business unit.

Ecosystem risks, particularly potential impacts on local biodiversity, soil health, and water quality, need careful consideration. Our risk mitigation strategy involves comprehensive environmental impact assessments before project initiation, monitoring during project execution, and rigorous post-project evaluation. We will be working with independent agronomist to ensure our applications have as minimal impact on the environment as possible.

The risks outlined are substantial, yet they are characteristic of any pioneering work such as ours. It is through addressing these challenges that we can refine our strategies, improve our processes, and continue on our path towards scalable and cost-effective carbon removal. We are committed to continuously learning from our experiences and employing robust risk mitigation strategies that safeguard our project's objectives and our stakeholders' interests.

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) *(should be net volume after taking into account the uncertainty discount proposed in 5c)*	847
Delivery window *(at what point should Frontier consider your contract complete? Should match 2f)*	September 2023 to September 2026
Levelized Price ($/ton CO_2)* *(This is the price per ton of your offer to us for the tonnage described above)*	$550

** 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).*

[redacted]