Flux Carbon Pte Ltd (Flux)

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

Flux (Flux Carbon Pte Ltd)

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

HQ and operations in Kenya. Flux Carbon Pte Ltd is registered in Singapore.

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

Sam Davies

Brief company or organization description <20 words

Flux is unlocking the potential of agriculturally deployed ERW in Africa to permanently remove CO2 and improve farmers yields.

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. 1000-1500 words

Overview
Flux is unlocking the potential of Enhanced Rock Weathering in Africa. There are around 530 million hectares (ha) of farmland in Sub-Saharan Africa (SSA), 185 million of which are in areas with ideal

[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.

climatic conditions for ERW. Combined with a prevalence of highly suitable ERW feedstocks, and some of the most favourable weathering conditions on the planet, this could capture roughly 1 billion tonnes of atmospheric carbon dioxide (tCO_2) via ERW.

Flux's mission is to unlock this potential by driving down the cost of high quality MRV and implementing scalable tech.

Our technology facilitates the removal of atmospheric CO_2 through a process known as Enhanced Rock Weathering (ERW). This approach involves the strategic deployment of finely crushed silicate minerals, such as basalt, onto agricultural land. Basalt, rich in weatherable minerals like calcium (Ca^{2+}) and magnesium (Mg^{2+}), undergoes accelerated weathering upon application, promoting CO_2 sequestration through a series of well-defined geochemical reactions.

As the fine silicate powders weather, alkaline earth metal cations and bicarbonate anions are released to regional groundwaters and rivers and eventually reach subsurface aquifers or accumulate in the ocean. In each of these terminal reservoirs (aquifer, ocean, mineral precipitation), CO_2 is permanently removed from the atmosphere on timescales of 10,000 to 100,000 years, ensuring effective long-term carbon storage (Middelburg et al., 2020; Renforth and Henderson, 2017).

Alternatively, these ions build up in agricultural soils (as soil inorganic carbon) and can precipitate as carbonate minerals as in the equation below:

$2Mg^{2+}$ (or $2Ca^{2+}$) + $4HCO_3^-$ → $2MgCO_3$ (or $CaCO_3$) + CO_2 + H_2O

Additionally, ERW has been demonstrated to improve soil health in agricultural land and lead to greater crop yield. In Africa, this effect is exacerbated due to low baseline soil health levels, high soil acidity, and lack of access to agricultural inputs.

Flux uses a combination of established ERW MRV methods, such as soil-based mass balance and pore water alkalinity, combined with innovative research, to further scientific knowledge of ERW in Africa and around the world. Flux is committed to answering pressing research questions, and unlocking the potential of ERW across the continent.

Why Flux is best-in-class

We believe there are several reasons that form a compelling argument that Flux is best placed to unlock the potential of ERW.

1) Optimal climatic/geological conditions. Warm temperatures (average high = 29°C), high annual rainfall (>1300 mm), low soil pH, and proximity of basalt formations create the ideal conditions for speeding up weathering rates and reducing LCA costs from transporting rocks over large distances.

2) Outsized yield and soil benefits. Degraded soils and limited access to fertilisers in SSA creates a unique opportunity for ERW. Applying crushed silicate minerals can significantly improve soil health and lead to substantial yield increases, surpassing those observed in regions with better soil conditions or more established farming practices found throughout the global North. This co-benefit, alongside the environmental benefits of ERW, fosters farmer-driven demand due to the improved soil fertility proposition. Ultimately, ERW becomes a more attractive and scalable solution for cost-effective deployment across millions of hectares in SSA.

3) Research Center and low costs. At this early stage, ERW research is about generating data. In Kenya, Flux is establishing the '**F**lux **E**nhanced Weathering **R**esearch **C**enter **(FERC)'** in Kisumu County, which is where the deployments for this project will take place. Flux is taking over management of this 385 hectare sugarcane farm, with free reign to implement R&D through greenhouse, mesocosm, plot, and large scale field experiments. With low costs of labour, transport, construction, and feedstock, Flux has a huge advantage in accelerating the innovative research required to drive down the cost of ERW MRV. Practically, we can take more samples, employ more technicians, spread more rock, and analyse more data than many other ERW companies for the equivalent cost.

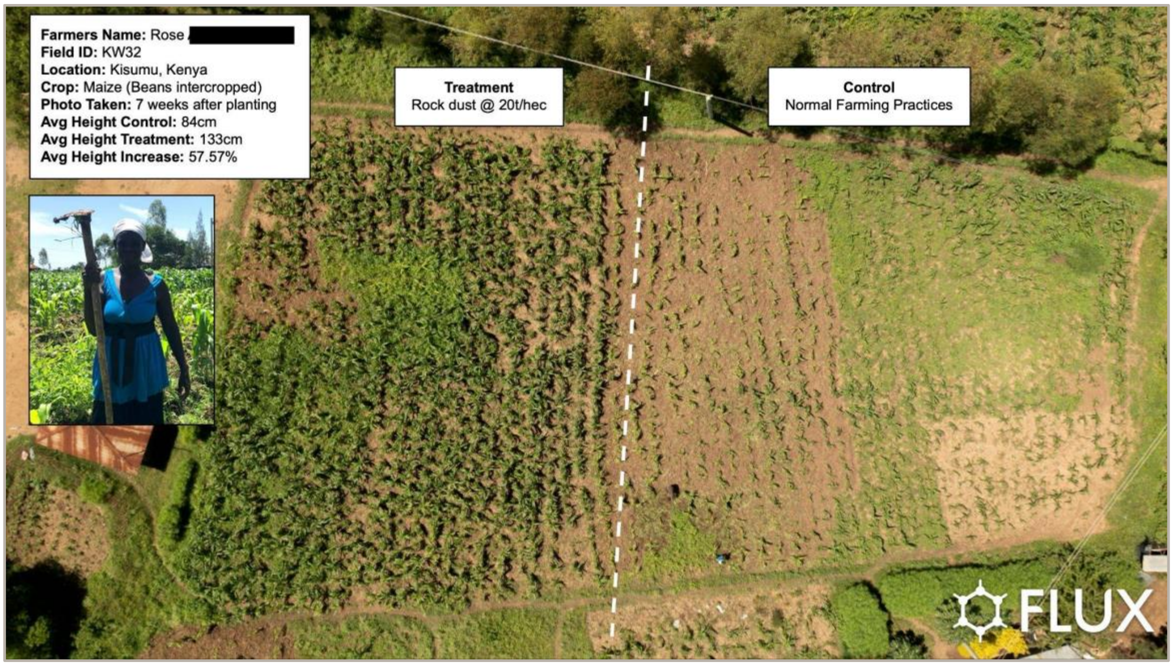
4) Partnership and Franchise model for scaling across the continent. Whilst initially focusing on our own deployments, such as the project proposed in this RFP, we realise that for ERW to truly scale, we will need to empower those who are already plugged into local ecosystems and able to deliver the operational capabilities required. To do this, **Flux is developing an operational tech platform** that will give these providers all the tools that they need to track operations and conduct robust MRV. Flux will link together all the members of the broader ERW ecosystem (e.g. quarries, logisticians, contractors, and farmers) and make it simpler for them to focus on spreading rock and scaling operations.

Flux addresses the following Frontier RFP Priority areas:

1) **Deploying in under-represented geographies.** Whilst there is consensus around the potential for both CO2 removal and socioeconomic impact from deployments, Flux is Africa's first ERW company. We are well positioned to champion the sector on the continent and have a catalytic effect on scaling ERW beyond our own organisation.

2) **Deployment conditions that further scientific understanding of optimal weathering environments.** High rainfall, high temperatures, low soil pH. Kenya is the perfect place for weathering silicate rocks, and FERC will quantify this data.

3) **Projects that provide local environmental and economic co-benefits that build community and policy support.** After the success of our initial pilot, we have 2000+ smallholder farmers on our waiting list for future deployments. The co-benefits of ERW in Kenya and SSA are significant, and will make meaningful differences to people's lives, not just improve agricultural bottom lines. See image below of a recent trial in Kenya, showing impacts of amended plots vs control plots on plant growth.



4) **Accelerating ERW using enzymes.** At FERC, our 385 ha research centre, we are exploring the use of carbonic anhydrase enzymes to accelerate ERW in collaboration with Novonesis, a leading enzyme supplier, and FabricNano, a biotech startup. This is FOAK research in Africa and all data generated will be publicly available.

5) **Accelerating ERW using mycorrhizae.** We are also researching the use of mycorrhizae in ERW deployments to understand the potential accelerating effects, in collaboration with Groundwork BioAg. This study will also take place at our research centre and data made public.

6) **Best-in-class logistics and roadmapping to scale ERW.** Our recent MOU with a partner in Cameroon to implement ERW on 205,000 ha of maize over the next 5 years provides proof of concept for how to rapidly scale with large deployments in Africa. This partnership alone could capture 1 million tCO_2. Partnering with local organisations that understand their regional operating environment removes the need for Flux to do this heavy lifting and be slowed down by learning in new jurisdictions.

7) **Pioneering MRV methods to close the gap on outstanding uncertainties for the broader ERW community.** The feedstock for this project will be deployed at FERC, the first ERW research centre in Africa. This centre gives us an opportunity to conduct detailed and innovative analysis on a broad range of ERW research questions. In addition, the Mbogo River runs parallel to Flux's deployment fields on the northern edge of FERC. Notably, the Mbogo River is a tributary for the Nile River headwaters, which gives Flux a unique opportunity to measure and constrain downstream losses in the riverine system and chemical fluxes from land to the local waterways.

Flux is serious about advancing ERW science for the greater benefit of the CDR community. Operating in Africa is difficult, but the CDR potential is huge and is driven by outsize co-benefits for farmers. Unlocking this potential is our core mission, and we are proud pioneers of ERW on the continent - hopefully leading the way for many more.

Flux has partnered with InPlanet, another global south ERW provider, to convene a session at the 2024 AGU Fall Meeting aimed at advancing tropical ERW by bringing together researchers from academia, government, and industry.

Flux is taking a broad view to MRV, trialling various accepted and innovative methods to both expand knowledge of current approaches, and trial novel ones. FERC gives us a unique opportunity to conduct best-in-class experiments under a wide range of conditions, putting Flux in a position to unlock ERW in Africa and drive down uncertainties that will benefit the whole sector.

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

What Flux is building?

Flux is headquartered in Nairobi, Kenya, and has an operational logistics base and FERC in the Kisumu region of Western Kenya. Flux has a strong foothold already in the region, with community engagement officers, geologists, project managers and farmer reps working out of this hub.

Our vision for scaling ERW across Africa is to provide our tech platform and MRV solutions to operational partners on the ground in different jurisdictions across the continent. These operational partners may be quarries, large-scale ag developers, or local entrepreneurs, all of whom have in-depth local knowledge to bring different ecosystem players together and scale distribution of silicate rock powders, but who will require expertise to capture their data and do robust MRV.

Flux believes that the largest barrier to ERW scaling to gigaton scale in Africa is the cost of MRV, and our core mission is to reduce this cost. To do this, Flux will first conduct its own deployments in Kenya, building powerful data sets and MRV tools, before working with operational partners.

Alongside this, we are committed to advancing ERW research in general and are regularly looking for innovative ways to accelerate weathering and decrease MRV costs whilst maintaining integrity.

For the purpose of the project in this application, Flux will deploy 5000t of powdered basalt rock on 250ha of sugarcane fields at FERC, which is located in Kisumu County, Kenya. FERC is a 385 ha sugarcane farm that is under Flux's management.

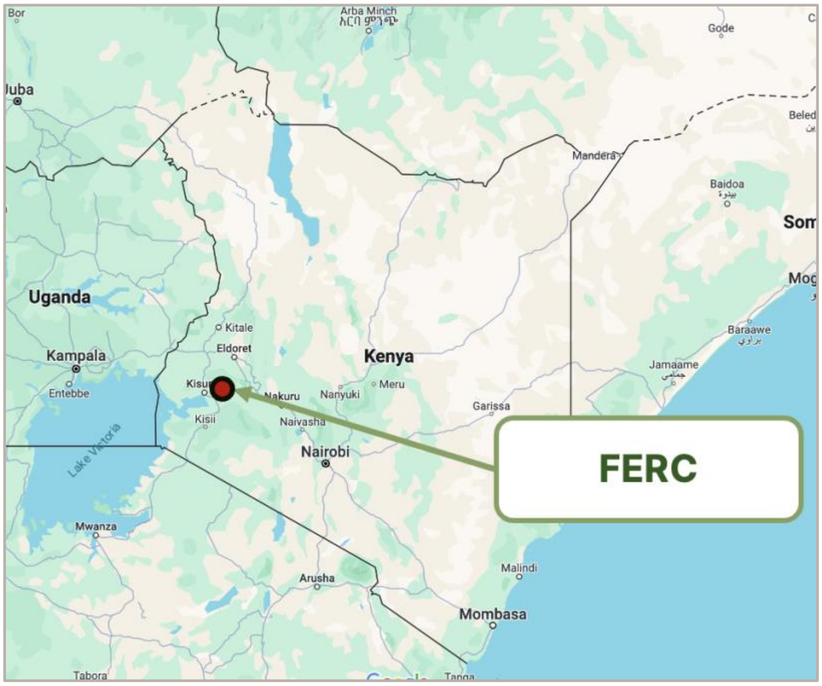
This gives us the best possible opportunity to conduct the thorough R&D that is required for ERW in Africa; Flux will have free reign over the fields and will establish a series of greenhouse, mesocosm, plot, and field trials adjacent to the deployments to assess other under-served research areas and validate our in-field MRV. This will also involve collaboration with external research organisations, academic institutes, commercial partners, and NGOs, all with the aim of providing them with the opportunity to further ERW research within the African context.

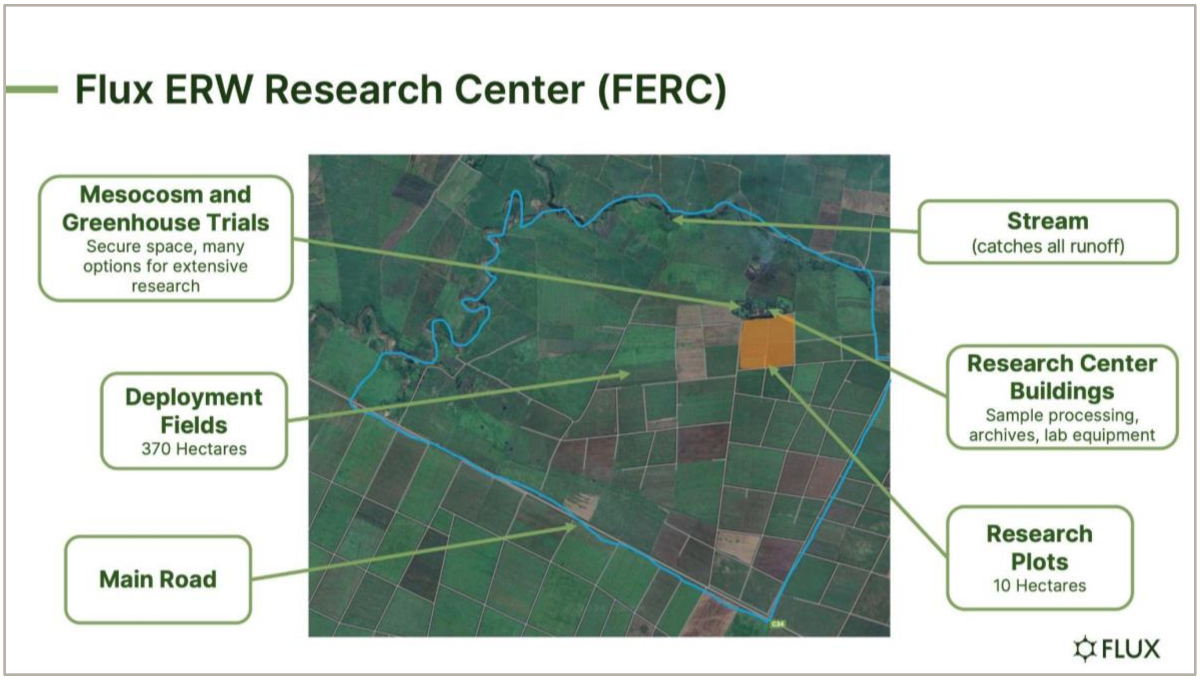
FERC sits in the 'Kisumu Basin', a 60,000ha sugarcane farming region. All these farms share the same crop types, farming practices and climatic conditions, and will be served by the same rock feedstocks.

[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.

This makes for an ideal region to repeat and scale our FERC operations whilst eliminating some variables.

In western Kenya alone, there is a total of 205,000ha of sugarcane, with around 1.5 million hectares across SSA. Sugarcane grows in wet and warm climates and is therefore an ideal crop to start ERW expansion in Africa. The research conducted at FERC will also expand to other crop types, including maize, cassava, rice, and legumes, which are the most prominent crops in SSA.





Current Cost Breakdown

Flux's current cost breakdown per tCO_2 is as follows:

Item	Cost $ / tCO_2
CapEx	97
Fixed OpEx	28
Variable Opex	90
MRV	180
Total	**395**

Flux's approach to quantifying CDR

Flux quantifies carbon removal through direct measurements at the field-scale, including both solid- and aqueous-phase measurements. The approach correlates with the fundamental principles of determination 1 of Isometric's Enhanced Weathering in Agriculture v1.0 protocol, in that measurements of feedstock weathering in the topsoil are combined with the direct detection of weathering products in the pore water. Biogeochemical models will be used to account for processes not covered by direct measurements, such as outgassing from rivers and the ocean.

The core of our MRV approach is the quantification of feedstock dissolution in the topsoil via soil-based mass-balance (SBMB) measurements. Although this method, which has been proposed and validated at the lab-scale by Reershemius et al. (2021), is relatively new and has clear practical limitations (Suhrhoff et al., 2024), several factors make it particularly suitable to Flux's operating context:

This method is best suited for highly weathered, tropical soils with fast weathering rates and a chemical signature that is distinct from the feedstock (Suhrhoff et al., 2024);

Alkaline volcanic rocks from the East African Rift are often highly enriched in suitable immobile trace elements such as titanium and niobium;

This method is operationally simple without the need for high sampling frequency and soil sampling is "low-tech" with less risk of human error than for pore water samples; and

The relevant parameters are insensitive to storage conditions (e.g., no cold chain required, unlimited storage possible).

The key issue inhibiting the method's widespread adoption is the relatively low signal-to-noise ratio. It has been suggested that reducing the analytical error by employing high-precision, high-accuracy methods such as Isotope-Dilution-ICP-MS (ID-ICP-MS), could be the most effective way to mitigate this issue (Reershemius et al., 2023). This, however, requires relatively complex and expensive sample preparation that is not currently available as a standard service at commercial laboratories. The reliance on academic institutions, and the practical difficulties involved in maintaining mass spectrometers, lead to a major bottleneck for scaling SBMB.

Flux believes there are a number of ways to solve this issue and unlock SBMB measurements as the most suitable MRV approach for the Global South:

Maximising the signal-to-noise ratio to compensate for higher analytical uncertainties and thereby enabling standard ICP-MS as the primary analytical method. This includes the selection and matching of feedstocks and soils with strongly contrasting chemical signatures and the use of high (but agronomically sensible and environmentally safe) application rates.

Optimization of the sampling design. Flux uses high sampling densities (enabled by the lower cost of standard ICP-MS analysis) and new strategies on sample pooling (such as those developed by the Yale Center for Natural Carbon Capture as part of the USDA Climate Smart Commodity project) to reduce overall analytical uncertainties. Flux has developed a tech stack to track and mark soil core collection and to allow sample collectors to ensure they have met statistical thresholds.

Collaborating with large commercial laboratories (e.g., SGS) and other ERW project developers to evaluate the possibility of introducing ID-ICP-MS as a routine measurement. This will involve the formulation and preparation of several spike solutions, tailored to a number of common immobile trace elements and element ratios. Flux expects that the combined sample volume from multiple ERW companies will warrant the expenditure on method and protocol development on the side of the service providers and drive down the cost of analysis.

The SBMB measurements will be complemented by the sampling and analysis of pore water using suction lysimeters. These will deliver direct detection of the dissolved weathering products and the increased bicarbonate fluxes, as well as information on the extent of possible non-carbonic acid weathering.

Measurements of exchangeable fractions and TIC at different soil depths will account for time lags caused by these (transient) cation pools, whereas biomass sampling on control and treatment plots will enable the quantification of plant cation uptake.

What needs to happen for our CDR solution to approach Frontier's cost and scale criteria?

MRV forms the bulk of our cost. Most of this is due to the high price of lab analysis of soil and pore water samples and the high sampling density currently required due to a lack of data. There are three main levers to pull to reduce this cost.

1) Increase the tCO_2/ha. Samples are taken on a per hectare per year basis; increasing the tCO_2 captured per hectare per year directly decreases the volume of measurements required. This could be achieved by leveraging new feedstocks with higher CDR potential, crushing rocks to smaller particle sizes, applying more rock per hectare, or using accelerants such as enzymes or fungi to speed up weathering rates. Deploying in the optimal weathering conditions of tropical Africa already gives Flux a unique advantage to accelerate feedstock dissolution.

2) Reduce required volume of expensive analyses. SBMB approaches require the chemical analysis of soil samples with either a high analytical accuracy and precision (ID-ICP-MS) or at a very high density, and are therefore relatively costly. As we generate more data in a specific deployment context, the better quantitative understanding of the distribution and behaviour of relevant parameters will allow us to progressively reduce sampling densities and rely more strongly on statistical modelling (e.g., regression analysis). Alternative analytical methods (e.g., LIBS) could also enable cost reductions.

3) Reduce sampling requirements through complex modelling. Whilst empirical measurements will always be required for robust MRV, with large volumes of accurate in-field data, Flux will train and test complex biogeochemical models. These models are in their early stages, and should not be relied upon as a ‘magic wand’ for lowering costs of ERW MRV - but should be viewed as a progressively more useful tool that can be used to lower sampling density as appropriate.

Flux has a unique advantage to generate a large amount of data at low cost that is suited to tropical/African soils, crops, and feedstocks that we will use to parameterize and improve our models.

The **CapEx** costs listed above will reduce significantly as Flux partners with operational suppliers of feedstock and steps back from this side of the business. Future deployments will leverage these partner’s existing infrastructure for extracting, crushing, processing, and spreading rocks.

This strategy will also drive down **Variable Opex** with large offtake agreements for feedstocks, more of the process being taken in-house by quarries (e.g., transport), and driving initiative from suppliers who will be incentivised to improve their bottom line.

This partnership model is the best pathway to reaching gigaton scale via ERW in Africa - allowing the existing infrastructure in place for crushing, transporting and spreading rocks to access carbon financing by licenced MRV and operational data capture.

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

Please see our *Supplementary Materials - Annex A* for a detailed risk assessment.

The biggest risks from Flux’s assessment, and our mitigations, have been highlighted below:

Sampling accuracy, reliability, and representativeness. This is a key risk for us; if baseline, or follow-on, samples are not accurately collected, then all subsequent analysis and quantification will be

compromised and MRV will be impossible. To mitigate this, we have developed a rigorous sampling protocol with our scientific partners that provides clear guidelines. We then conduct extensive training with all soil sampling staff and ensure that they meet a quality threshold before becoming qualified to collect samples in the field. The **Flux App** then comes into play, allowing samplers to GPS tag every single soil core that is collected and track how many have been taken over a specific area, which will archive this data trail. It will also flag the team if more cores need to be taken to reach certain statistical thresholds and reject inadequate sampling densities. **Feedstock suppliers: Malpractice, cancelling contracts, or poor quality.** Having a single point of failure at any point in the supply chain represents an unacceptable risk for Flux, especially in feedstock production. To diversify our suppliers and mitigate our risk, we have identified multiple high-quality feedstocks in the same area that are able to supply similar feedstocks and have developed relationships with all of them up to the point of contracting. This allows us to quickly switch feedstock suppliers if required, having already completed the full suite of requisite vetting to confirm CDR capacity and safety. This has the added bonus of providing expansion pathways for future use. **Extreme weather events.** Flooding poses the most impactful risk on our assessment, with potentially catastrophic consequences if not mitigated. Although the likelihood is low, these events are more prominent in a changing climate. The main risk for us would be rock feedstock being washed away from fields before weathering, resulting in a lack of bicarbonate precipitation data and potentially erroneous mass balance data. To mitigate this, we will incorporate the rock powders in the topsoil following normal farming practices and have chosen to deploy on sugarcane fields that are accustomed to handling excess water with drainage systems in place to limit topsoil runoff. Further, sugarcane crop is only removed from the ground every 5-6 years, leaving the topsoil intact and held together by robust root systems. These factors move the risk from unacceptable to tolerable. **Financial risks.** Whilst this project will be almost entirely funded by Frontier's pre-purchase, financing uncertainties for future projects at scale is a significant area of risk for us and one where we are currently dedicating vast resources to identify innovative solutions. Financing projects with equity capital is non-viable as the risk of not selling the ex-post credits leaves the company too vulnerable. To mitigate this, we are seeking long-term offtake contracts. These must still be financed and come with risk in estimating weathering timelines and future price points, and Flux is exploring several innovative financing mechanisms to lower the cost of capital and diversify risk for financiers.

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)*	1142 tCO_2
Delivery window *(at what point should Frontier consider your contract complete? Should match 2f)*	CDR start: Mar 2025 Contract complete: Mar 2034
Levelized cost (\$/ton CO_2) *(This is the cost per ton for the project tonnage described above, and should match 6d)*	\$395
Levelized price (\$/ton CO_2)[3] *(This is the price per ton of your offer to us for the tonnage described above)*	\$438

[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).