Brilliant Planet

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

Brilliant Planet Limited

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

Russell Building, West Common, Harpenden, AL5 2JQ, United Kingdom

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

Adam Taylor

Brief company or organization description <20 words

Brilliant Planet permanently removes atmospheric CO_2 by growing and burying marine microalgae biomass using land-based ponds in coastal deserts.

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

[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.

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.

Overview

Brilliant Planet is building a Biological Carbon Removal and Storage (BiCRS) solution that optimizes CDR efficiency, nutrient export, and costs. Our technology does not compete with food production for arable land and enables positive ecosystem and community impact. The process utilizes a low-energy-penalty CO_2 capture technology and lends itself to a straightforward and rigorous MRV approach.

We cultivate locally sourced, wildtype, unmodified phytoplankton using deep seawater that is pumped through a series of open, land-based ponds, before rapidly solar drying the biomass and burying it underground. Figure 1 outlines all the steps within our process:

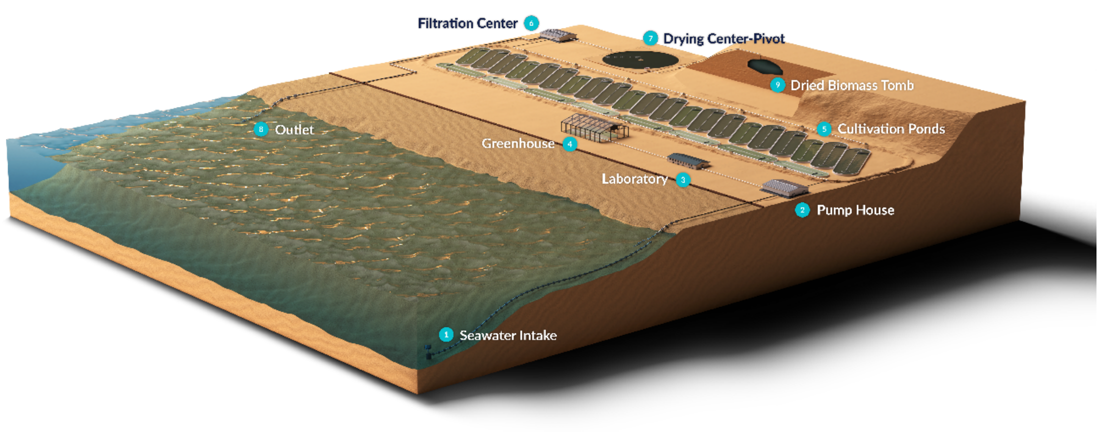

Figure 1: Schematic of Brilliant Planet Demonstration site

We achieve high productivity by controlling the light field, temperature, mixing energy and CO_2 availability in our ponds, to ideally match the physiological needs of our production organisms.

Process

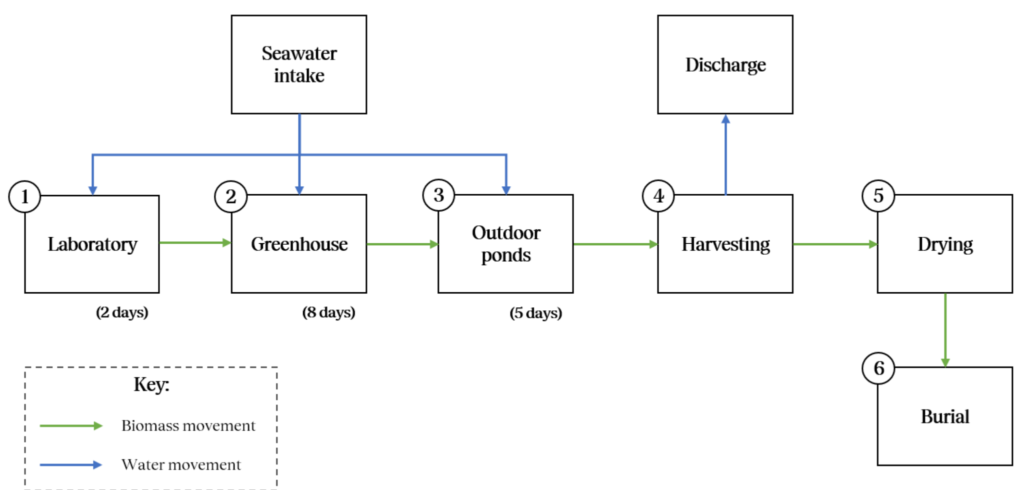

Figure 2: Process flow diagram

Step 1 - Lab:

Every day a fresh, clean inoculum of algae is prepared in the lab. Preparing the monoculture in the lab gives us the ability to control environmental conditions and kick-start the ‘Bloom’ phase – a state in which the algae experience rapid or exponential growth and division. Beneficial coastal algae blooms are responsible for 20% of the global carbon cycle and are 10-50x more efficient at CO_2 fixation than terrestrial plants per unit area.

Step 2 - Greenhouse:

After two days in the lab, the blooming algae are transferred into a greenhouse. This allows the organisms to acclimate to ambient desert conditions, so the cells can achieve maximum growth rate and density.

Step 3 - Outdoor ponds:

After eight days, we move the organisms into outdoor ponds, where they spend the remaining five days of the production cycle. Due to the exponential growth, >97% of the algae biomass is produced in the last 5 days. The growth cycle from start to harvest is 15-17 days, much shorter than legacy systems.

Each pond is approximately twice as large as the previous one in the process. We transfer the algae from one pond to the next every day and fill the extra volume with additional new seawater, to accommodate its growth, in a serial batch system. The seawater used is naturally rich in nutrients and is sourced from below the ocean’s mixed layer and biologically active surface waters. Each final pond takes up an area of 12,000m^2 – approximately two football fields.

Step 4 – Harvesting:

The last algal cultivation pond is drained by gravity over rotary mesh screen filters that permit the pond water to penetrate the fabric and retain the algae. The algal biomass that is retained by the screens is removed and forms a slurry that is transferred to the spray drying process. The filtered seawater is discharged back into the shallow ocean surface from the harvest building.

Step 5 – Drying:

To create suitable conditions for permanent biomass storage, we have developed an energy-efficient spray drying method. We pump the biomass slurry produced at harvest to a drying tower, which sprays the fluid into the warm, windy desert air. The mist particles dry as they float back to earth in the hot desert sun and attain the desired properties within minutes, by the time they land on the collection pad beneath the tower.

Step 6 – Storage:

The dry biomass is subsequently collected, weighed, and pushed into geomembrane-lined biomass burial sites located outside of watersheds and above projected future sea levels. We select the sites to mitigate the risk of water intrusion (e.g. streams from rare desert rains). The biomass burial site is lined and covered with a durable geomembrane that diverts condensate from the biomass and protects it from moisture intrusion.

We adhere to existing regulations stipulated by the EPA and other accredited bodies to responsibly manage burial sites.

Durability

We employ a ‘triple lock’ mechanism to ensure the buried biomass remains stable for >1,000 years:

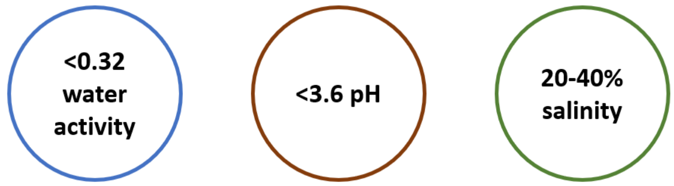

Figure 3: Dried Biomass Characteristics

- **Low water activity:** levels of water activity are below the threshold at which enzymatic or other microbial processes can occur and break down the biomass.
- **High salinity:** during the drying process, the water content of the slurry evaporates. The dry salt in the biomass creates an end product with a very high salinity content, which prevents biological activity and microbial growth.
- **High acidity:** the properties of the biomass ensure that during drying, it self-acidifies. The acidity prevents enzymatic function.

These processes are described in more detail in Section 3 of the application.

Technological Advantages

Brilliant Planet’s technology features advantages in the following priority innovation areas:

- **No use of arable land:** our sites are located in coastal deserts with very low net primary productivity (NPP). As a result, our ponds create **new net primary productivity** in the otherwise barren areas where we operate our sites.
- **Low biomass transportation costs:** our storage sites are co-located with production, so there is minimal complexity, energy usage, and infrastructure required for bulk transport and handling. Furthermore, our ability to self-produce biomass enables us to side-step many of the supply constraints associated with other BiCRS approaches.
- **Low nutrient export:** our algae strain was selected because it requires very low quantities of nitrogen in order to grow. Additionally, as our approach utilizes seawater nutrients rather than soil-derived nutrients, we do not run a risk of depleting nutrient reserves.
- **Rigorous MRV approach:** we operate a closed-loop process – we maintain control over our system boundaries and produce and store all biomass on site. This enables us to control and continuously measure the carbon flow across the system. During our production process, an automated system tracks a set of identified removal parameters. We employ a robust methodology to track the status of our biomass in storage and ensure no decay is present. More detail on our MRV approach is provided in Section 5.

Additional Benefits

- **Social benefits:** Brilliant Planet is the largest employer in the local community where we currently operate, providing professional opportunities, including jobs and upskilling trainings, among other benefits.
- **Ecosystem benefits:** As part of our approach, we discharge large quantities of de-acidified water back to the environment, which improves biodiversity by restoring the local coastal ecosystem and increasing coccolithophorid and mollusc growth, as detailed in the Biomass Supplement.

Integrated Learnings from the Biofuel era

In the 2000s, significant investments were made in highly capital-intensive artificial bioreactors and other algae production systems to grow algae for biofuels. Many of these technologies faced commercialization challenges. Our approach incorporates learnings from the Biofuel era to "scale down the ocean" rather than scaling up a test tube:

- **Relative process simplicity:** We operate in stable, low-density outdoor ponds.
- **System resilience:** Because the algae are local to the environment where they are cultivated, they are **resilient to fluctuations in the natural environmental and the composition of the intake seawater**. Therefore, we can produce biomass with untreated seawater year-round, and the algae grow significantly faster than in other "bioreactor" production systems. For reference, our **biomass more than doubles in mass every day**, whereas traditional algal production systems require 8-21 days to double.
- **Wildtype strains:** Utilizing **wildtype strains allows us to cultivate the algae in open environments without posing a risk to the local environment**. Engineered and genetically altered organisms need to be kept in isolated and brittle systems, which require significantly more upfront investment and energy to operate.
- **Low nutrient requirements:** Nutrient supplementation accounts for only ~1% of Nitrogen used relative to the nutrients per unit of biomass used in biofuel systems. The remaining nutrients come from the deep upwelled seawater, that would not have otherwise reached the surface.
- **Larger algae organisms:** We grow larger organisms than the species grown by the algae industry, making them far easier to harvest. The algae strain we have selected is up to 10 times larger than Chlorella, a species commonly harvested for biofuels.
- **Lower energy intensity:** We use gravity-based harvest systems similar to the ones used in mining in place of the energy-intensive solutions typically associated with algae production.

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.

We are building a 30-hectare demonstration site, located in proximity to our existing pilot site in Akhfennir, Morocco.

Brilliant Planet has operated a pilot project in Southern Morocco (see Figure 4 below) since 2018, in addition to its previous pilot sites in South Africa (2013) and Oman (2014).

Figure 4: Brilliant Planet's current pilot site in Akhfennir, Morocco, operating since 2018

Scalability of Our Approach

There are 18.2 million km^2 of hot deserts, many of which reach the coast. Our global GIS search indicates that there are 500,000km^2 of suitable land for our CDR method globally, which is sufficient for >3.1 Gt CDR per year. This analysis is based on identifying low-lying, coastal desert unencumbered by any form of prior use in politically stable countries. The search criteria are:

- Binary:
    - Outside of urban areas
    - 5 degrees north/south of the equator (for high incident light)
    - Political stability/ease of doing business (exclude the bottom 60 countries of the World Bank ease of doing business rankings).
    - Minimum site size is 1,500 hectares in any one continuous area
    - Site gradient <5%
    - Maximum NDVI 0.5
- Weighted:
    - Elevation (cutoff 50 meters)
    - Distance inland (cutoff 50km)

Based on the above, we have identified ~0.5 million km^2 of prime areas suitable to be used for our technology, in the following locations:

Rank	Country	Area [km²]	Rank	Country	Area [km²]
1	Australia	117,581	17	South Africa	4,141
2	Saudi Arabia	62,556	18	Senegal	3,855
3	Iran, Islamic Rep.	39,533	19	Russian Federation	3,567
4	Mexico	39,025	20	India	3,369
5	Morocco	32,803	21	Azerbaijan	2,456
6	Egypt, Arab Rep.	27,406	22	Djibouti	1,725
7	Oman	23,940	23	Brazil	1,158
8	United Arab Emirates	22,017	24	Colombia	961
9	Argentina	20,220	25	Chile	938
10	Tunisia	17,706	26	Spain	413
11	Pakistan	15,916	27	Bahrain	268
12	Kazakhstan	15,594	28	Jordan	211
13	Peru	14,912	29	Israel	127
14	Qatar	9,682	30	China	107
15	Namibia	8,773	31	United States	85
16	Kuwait	7,082	32	Rest of World	441
				Total	**498,568 km²**

Figure 5: List of identified suitable locations

Cost Curve

Brilliant Planet's technology can reach **$100/t once it has deployed nine 1,000-hectare full-scale commercial sites.** The technology can be scaled further to reach 0.5Gt (and beyond) per the GIS analysis above. Cost improvements are driven by three primary factors:

1. Economies of scale

As our sites expand from the demonstration stage into commercially viable, full-scale facilities, we have identified several areas that will benefit from economies of scale, within both capital expenditure and operating costs. These include: scale benefits associated with water intake design, lab and greenhouse infrastructure sharing between modules, optimized site layouts, and more efficient maintenance and labor requirements. Based **purely on these economies of scale**, we expect our costs will be **$256/t at the 1,000-hectare scale to start**.

2. Business-as-usual process improvements

We have identified several initiatives we will implement as soon as our first full-scale facility is operational. Implementing these identified improvements will bring the unit costs of our first full-scale site from **$256/t to $200/t**. These initiatives include:

- **Growth rate optimization**: increasing algal growth rate (μ) – we have recorded μ significantly above the assumed values in the lab.
- **Lower nutrient requirements**: fully eliminating the small amounts of nitrogen supplementation by incorporating nitrogen-fixing bacteria and new strains into production system.
- **Increase operational stability**: decreasing equipment downtime through preventative maintenance scheduling.
- **Optimize energy consumption**: designing the system to only pump water to the height required for each pond, instead of relying on gravity-based filling of the entire system.
- **Improve system efficiency**: optimize Capex and Operational costs by revising process flow and asset load scheduling.

3. Learning rates

By the time our first commercial-scale sites are online, we will have started to incorporate learnings based on running the demonstration and smaller commercial sites. We expect to reach **<$100 once we have deployed nine full-scale facilities**.

Additional factors that could contribute to cost improvements include:

- We are developing several optimizations at lab scale relating to seawater chemistry, biology, genetics, and system optimization. We do not see significant barriers to implementing each of these, and each one individually will have a significant impact on efficiencies.
- We believe we will be able to reduce our current LCA offset of 13% (Scope 1, 2, and 3 emissions) by the time our full-scale commercial sites go online. The figures above do not include the positive impact of this potential reduction.
- A modular capacity roll-out may enable us to capture and incorporate learnings faster than expected.

Reaching these targets is predicated on market and internal factors. The company needs to secure the necessary funding to be able to build the full-scale commercial sites, successfully mitigate the highlighted risks, and realize its projected learning rates.

Quantification

Net CO_2 removal is calculated as follows:

Net Removed CO_2 = Σ CO_2 taken from the atmosphere and sequestered as buried biomass
- Σ CO_2 emissions from biomass production and harvesting
- Σ CO_2e emissions in the drying process
- Σ CO_2 emissions from biomass transport
- Σ CO_2 emissions from burial
- Σ CO_2e from fugitive emissions

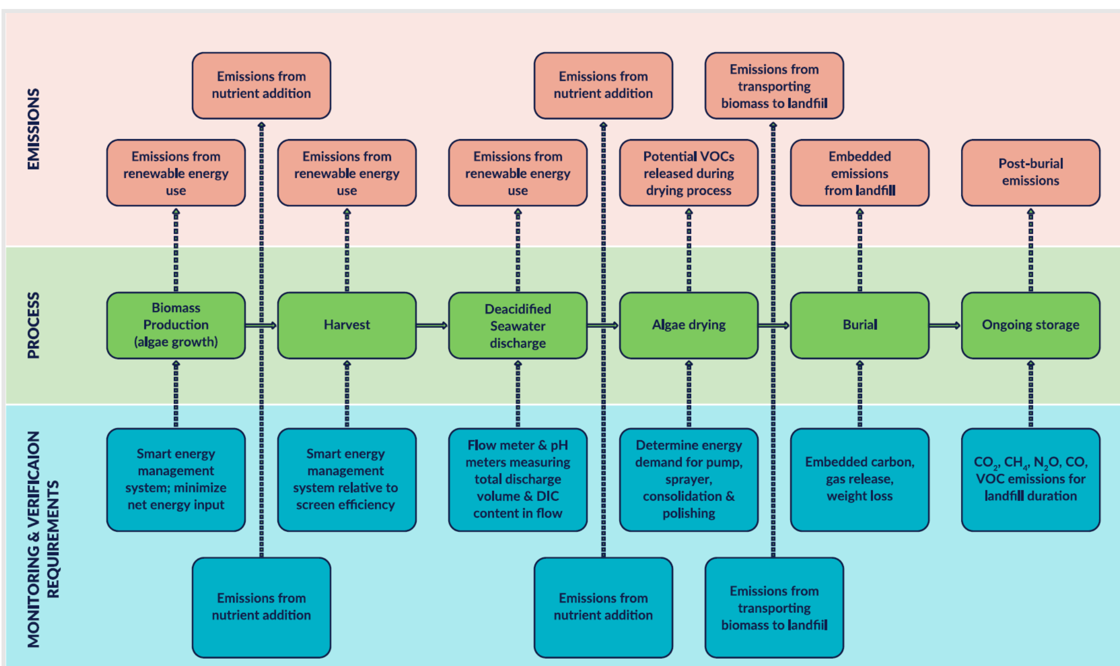

Figure 6: Diagram illustrating process MRV requirements

Our approach to quantifying the carbon removed is based on carbon content analysis of the buried biomass, combined with measuring the weight of the biomass and directly comparing this to the carbon across the pond-air interface and the de-acidification of the discharged seawater. These measures allow us to precisely quantify the amount of atmospheric CO_2 that has been removed.

Furthermore, we continuously measure the properties of the stored biomass and the environmental conditions in the burial chamber to ensure no decay is underway. Our methodology enables **straightforward, direct content analysis of the buried biomass**. We measure both **environmental conditions** within the burial site and the **properties of the biomass itself**.

The environmental conditions in the burial chamber serve as a **leading indicator for undesirable biological activity and biomass decay.** We measure moisture and humidity, temperature, and oxygen levels, as well as a set of trace gases (CO_2, CO, methane, hydrogen sulfide, nitrous oxide and volatile organic measures in the 0.01% and ppm range) to determine whether any of the subterranean conditions have changed.

We also bury **electrical conductivity sensors in the biomass itself**. These sensors track **moisture content, which is the leading indicator of decay**. A rapid increase of electric conductivity indicates that the biomass has become moist, as water enables the diffusion of salt ions.

All measurements described above are available to third parties. To date we have not measured any traces of decay, even at the ppm level.

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.

Project execution

We have invested in developing an experienced Engineering Design & Implementation Division to mitigate project execution (facility construction) risks.

The division is headed by Mert Yesugey, our Engineering Director. Mert has led multi-billion-dollar construction projects as Special Projects Director at Mott MacDonald, a 20,000+person global engineering firm. These projects have included complex infrastructure development in both development and emerging markets.

Supporting Mert is a team of 10 experienced specialist design engineers (civil, hydrology, electrical, mechanical, automation etc.) and a Project Management Office staffed by professionals with extensive experience in multi-hundred-million-dollar infrastructure projects. We receive consultancy support from the world's most experienced engineering firms, including Mott MacDonald and WSP.

Our CEO, COO, and other professional staff have also been responsible for the delivery of infrastructure and industrial projects throughout Africa. This engineering and project management capacity ensures we are well-placed to mitigate execution risk.

Technical

Much of the technical risk has been mitigated and retired by trialing the process in real-world conditions for over a decade. The company has operated pilot scale projects in South Africa (2013), Oman (2014-18), and Morocco (2018 onwards), each of which provided valuable data we have used to develop our commercial system.

We have continued to learn and improve aspects of the site in Morocco to demonstrate the commercial readiness of the technology. Recent developments include:

- Piloting SCADA-based automated process control, integrated into our remote sensing and atmospheric & oceanographic forecasting models as part of our AGRI-SATT project. Agri-Satt was a £5m grant-funded project supported by Innovate UK.
- Continuous, high-resolution monitoring of biomass buried at the future burial site demonstrating CO_2 storage permanence.
- Ongoing prospecting and biodiversity mapping of different algae strains to further develop our understanding of photo physiology and key traits which make specific organisms more energy efficient at CO_2 removal.

Ecosystem safety

We have evidence that our project does not cause ecosystem harm, and instead provides a net benefit to the local ecosystems where we operate.

However, given our process operates within a natural ecosystem, we maintain a high degree of vigilance with respect to monitoring our environmental footprint and are developing ecological and NPP baselines to track our impact.

To operate in Morocco, we have filed an Environmental Impact Assessment (EIA), which was reviewed and signed by 27 separate government ministries and agencies, including marine, terrestrial, housing, development, and social agencies.

Financial

As with any infrastructure project, our ability to develop the demonstration facility is dependent on obtaining the necessary funding.

We are confident we will be able to mitigate this risk. Our senior leadership team has experience in working with and securing funding from institutional investors, including venture capital funds, development finance institutions, concessionary and non-concessionary lenders, government funding programs, pension funds, endowments, and corporate JVs.

Community Engagement

We are committed to maintaining a positive relationship with our local communities, and have taken measures to promote dialogue with local, regional, and national stakeholder groups and ensure our continued alignment with the community's needs and priorities. These measures include:

1. **Daily interactions with staff from the local community.** Our local town has a population of ~4,000 and Brilliant Planet is the largest employer.
2. **Community meetings.** We hold monthly community meetings to receive feedback from the residents and provide updates.
3. **Ad-hoc meetings with government officials, NGOs, and visitors.**
4. **Inbound correspondence**
5. **Other notifications:** Company updates and available job openings are advertised on notice boards placed at the municipality, the Caid's Office (local leader) and on our site notice board.

We operate a stakeholder engagement and social management system based on the IFC Best Practice Performance Standards. Our executive team has extensive experience in stakeholder management from their prior careers developing industrial projects in Africa and has worked

successfully with several institutions (e.g. IFC, FMO, Finnfund, IFU, DGGF) that set a very high bar for stakeholder management. For our four years of operations we have enjoyed a positive relationship with our local community, regional government, and national government. All are enthusiastic to see job creation and economic development in this under-served area. **Political** Brilliant Planet maintains strong relations with local, regional, and national authorities. Our activities in Morocco align closely with government priorities, particularly the blue economy (coastal development), green economy (including climate change mitigation) and rural job creation. Our primary contacts within the national government are the Ministry of Agriculture through both the National Marine Fisheries Service (INRH) and the National Aquaculture Development Agency (ANDA) and the Ministry of Commerce. We are a showcase company in Morocco's contribution to the UN Blue Belt Initiative and have participated as part of the Moroccan delegation in both the COP 22 and COP 26 meetings. We have sound professional relations at the ministerial level and administrative levels of both organizations and have become a trusted development partner during our years in Morocco. Our investment in Morocco is governed by a framework agreement, a "Convention Cadre" and a specific agreement "Convention Specifique" with a 30-year duration with the option to extend for subsequent 30-year periods. Both conventions have been approved by the relevant government ministries.

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)*	2025: 200 tons 2026: 200 tons 2027: 250 tons
Delivery window *(at what point should Frontier consider your contract complete? Should match 2f)*	December 2027
Levelized Price ($/ton CO_2)* *(This is the price per ton of your offer to us for the tonnage described above)*	$800/t

** 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).*