# Skyology

## Carbon Dioxide Removal Purchase Application

**Fall 2022**

# General Application - Prepurchase

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

Company or organization name

Skyology Inc

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

Portland, Oregon

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

Swiss Williamson

Brief company or organization description

Skyology is a carbon capture and storage solution. Skyology uses proprietary mobile reactor technology to convert mining waste into a safe form of ocean alkalinity. We then scale using various forms of coastal enhanced weathering. As a result, We cheaply pull gigatons of $CO_2$ directly from the atmosphere and store it in ocean water as bicarbonate.

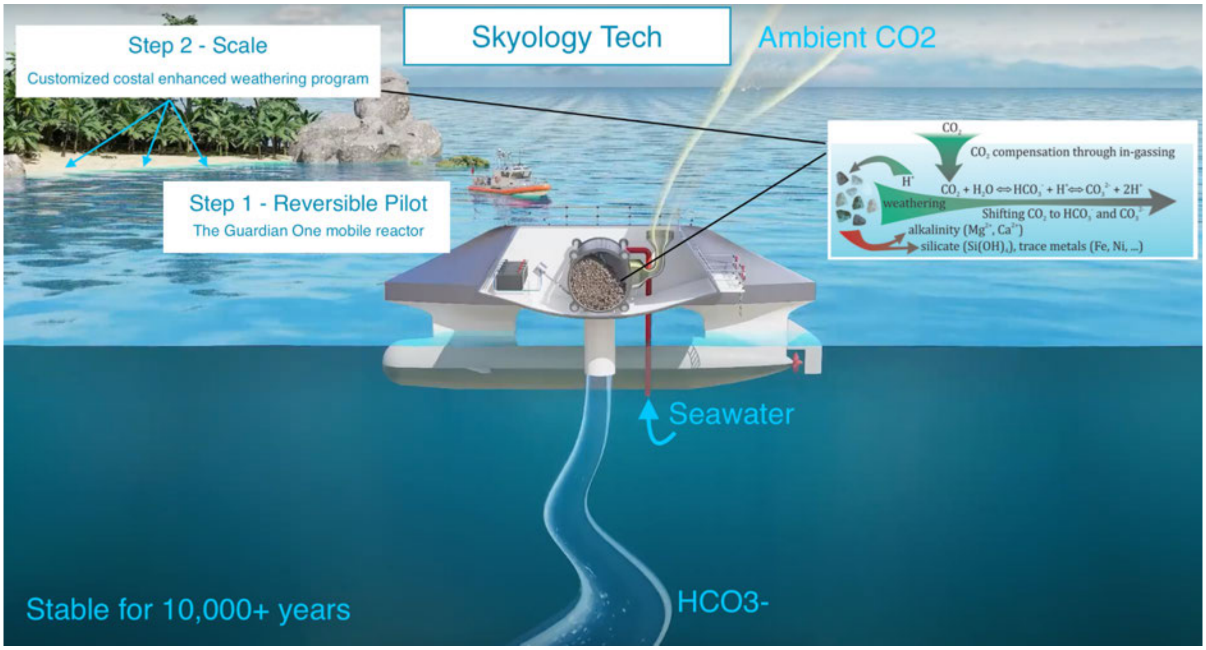
## 1. Project Overview[1]

a. Describe how the proposed technology removes $CO_2$ from the atmosphere, including as many details as possible. Discuss location(s) and scale. Please include figures and system schematics. Tell us why your system is best-in-class, and how you're differentiated from any other organization working on a similar technology.

**Skyology Overview**

[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.

Skyology uses proprietary mobile reactor technology to convert mining waste into a safe form of ocean alkalinity. As a result, We cheaply pull gigatons of $CO_2$ directly from the atmosphere and store it in ocean water as bicarbonate.




### Unfair Advantage

Skyology's unfair advantage over other ocean alkalinity enhancement(OAE) solutions is the containment and mobility of the Guardian One Reactor. The first benefit of Guardian is it has the highest ecosystem safety of any OAE project in the world. Safety of the reactor de-risks political and ecological roadblocks. As a result, Skyology yields a frictionless path to pilot site approval and ultimately, gigaton scale. Guardian One is a mobile floating reactor and obligates a very small amount of land.

Once the pilot site is proofed with specific real-world data, Skyology uses various natural coastal enhanced weathering(CEW) techniques to scale production beyond the reactor. With this two-step process, we can down-select pilot sites in months, not years. Above all, we can collect more accurate real-world data safer than traditional coastal enhanced weathering(CEW). Our customized weathering path for each location opens sites faster while scaling with the lowest energy input per tonne of $CO_{2.}$ With CEW at full scale, our reaction will require no onsight energy input or facility maintenance beyond spreading of material and MRV.

1. Safety

   The Guardian One delivers trustworthiness at scale. For example, if a pilot project reported an unacceptable local impact, the reaction can be halted and relocated immediately. The reactor can relocate seasonally to find the best reaction conditions and lowest impact.

Containing the reaction and mixing alkalized solution only after the solute has fully dissolved is a key to ensuring the most gentle impact on local ecosystems. Leaving no large grain material behind.

2. Rapid Deployability

   Skyology provides unparalleled OAE safety not only because we care deeply for all the crustaceans and sea slugs, but also because we deliver bullet-proof carbon credits at a massive scale. Skyology is building the first-ever zero-risk pilot site. Guardian One de-risks the project for all stakeholders, credit purchasers, local policymakers, municipalities, conservation boards, tourism committees, and indigenous trusts. Local site safety is easier to ensure with a contained reactor. In traditional CEW there is no reversability. Clean-up is costly, and the impact is long-lasting. Our reactor solution makes it easier for multiple interested parties to say "yes!"

3. Scale

   If a site repeatedly shows accelerated reaction and acceptable impact. Scale will be achieved through opening long-term coastal enhanced weathering(CEW) sites. This natural solution offers an extremely low input of energy and low ongoing maintenance. Letting natural waves and sun do the work for us, scaling becomes extremely safe and easy.

   In tandem, a guardian can operate more than 100 miles off the coast, which opens up the lowest bio-dense areas of the ocean to OAE.

**Reactor**

See Confidential Addendum

b. What is the current technology readiness level (TRL)? Please include performance and stability data that you've already generated (including at what scale) to substantiate the status of your tech.

TRL-3

Reactor
The Guardian One components are in testing at a 1/33 scale. The components borrow from existing engineering solutions and implement in novel environments.

Chemistry
This reaction is a part of the Inorganic Carbon Cycle, which has naturally taken place for billions of years, stabilizing Earth's atmospheric $CO_2$. Carbon dioxide removal (CDR) through natural rock weathering consumes ~1 gigaton of $CO_2$ every year (Ciais et al. 2013)

Reaction rates of dunite and quicklime dissolution have been studied in laboratory settings. Reliable reaction rates in natural, coastal conditions are severely lacking. Skyology is conducting numerous experiments to understand the upper limits of accelerated geochemical weathering. Our coastal weathering assumptions from lab tests and third-party observations concur with Moosdorf. These may absorb 1 Gt of CO2 for every 1–2 Gt of olivine-rich rocks when accounting for energy expenses due to mining, mineral grinding, and distribution (Moosdorf et al., 2014)

c. What are the key performance parameters that differentiate your technology (e.g. energy intensity, reaction kinetics, cycle time, volume per X, quality of Y output)? What is your current measured value and what value are you assuming in your nth-of-a-kind (NOAK) TEA?

| **Key performance parameter** | **Current observed value (units)** | **Value assumed in NOAK TEA (units)** | **Why is it feasible to reach the NOAK value?** |
|---|---|---|---|
| **The main differentiator is the business model innovation of months to open a pilot site. | 12 months | three months | Because we contain the reaction and it costs very little to reverse/move the reactor. We can relocate the same reactor to test a new pilot site without requiring coastal land. It lowers the risk for pilot site stakeholders to say "yes" And increases our chances of finding the right conditions for coastal weathering |
| $/t$CO_2$ | $1,600/t$CO_2$ | $60/t$CO_2$* | *EW will only be deployed at a larger or even global scale if it is economically competitive within a climate policy framework. We assessed economic costs to be below 70 $ t rock−1 for grain |

| | | | |
|---|---|---|---|
| | | | sizes around 20 μm, leading to costs of carbon removal around 60 $ t CO2 −1 for dunite and around 200 $ t CO2 −1 for basalt. This is higher than most recent cost estimates for afforestation (24 $ t CO2 −1, [45]) and BECCS (36 $ t CO2 −1, [45]), but still lower than expected costs for direct air capture (430–570 $ t CO2 −1, [45]). If co-benefits from nutrient supply or soil improvement are taken into account, the competitiveness of EW will be further increased. However, parameters to achieve an economic assessment of nutrient supply still need to be compiled.<br>Jessica Strefler et al 2018 Environ. Res. Lett. 13 034010 |
| [add rows as needed) | | | |

d. Who are the key people at your company who will be working on this? What experience do they have with relevant technology and project development? What skills do you not yet have on the team today that you are most urgently looking to recruit?

**Team**
Swiss Williamson - MBA | Aquaculture | Agriculture technology | Aggurculture offsets | IoT integrations

Manish Devana - Ph.D. Student University of Miami, Physical Oceanography | Data Analysis | Climate Research

**Reviewers**
Refer to confidential addendum

**Advisors**

Nick Chiarelli - CEO Ocean Impact Organization | Investor

Tim Silverwood - CEO Take 3 for the sea | OIO Cofounder

Jacek Pruse - CEO Current Foods | YC backed | Plant backed ocean start up

James Tilbury - Partner ERM | Climate Change and Corporate Sustainability

Kate Neary - PM Energy Lab | Consultant

**Currently Hiring**

1. Sr. Marine Engineer
2. Sr. Scientist Geochemistry
3. Project engineer (hull specialist)
4. Softwear engineer
5. Grant Specialist

e. Are there other organizations you're partnering with on this project (or need to partner with in order to be successful)? If so, list who they are, what their role in the project is, and their level of commitment (e.g., confirmed project partner, discussing potential collaboration, yet to be approached, etc.).

| Partner | Role in the Project | Level of Commitment |
|---|---|---|
| Ocean Impact Organization | Investor \| Marine Talent Recruiting \| Advisory | confirmed project partner |
| Airminers | CDR Accelerator program \| industry knowledge \| Advisory | confirmed project partner |
| Energy Lab | Advisory \| Accelerator program | confirmed project partner |
| See Confidential Addendum | | |

f. What is the total timeline of your proposal from the start of development to the end of CDR delivery? If you're building a facility that will be decommissioned, when will that happen?

The timeline is two years (depending on contract size), 2022-2025

Initial pilot site reactors will be repurposed to new sites and decommissioned after 30 years. Our active coastal enhanced weathering site requires no facility but requires the periodic use of a small amount of land (2 hectares raw land) to manage material and station spreading equipment. Contracts can last up to 100 years without any site improvements.

g. When will CDR occur (start and end dates)? If CDR does not occur uniformly over that time period, describe the distribution of CDR over time. Please include the academic publications, field trial data, or other materials you use to substantiate this distribution.

| |
|---|
| 01/06/2023 - 01/12/2025 |

h. Please estimate your gross CDR capacity over the coming years (your total capacity, not just for this proposal).

| Year | Estimated gross CDR capacity (tonnes) |
|---|---|
| 2023 | 50 $tCO_2$ (depends on pilot approval and commissioning timelines) |
| 2024 | 250 $tCO_2$ |
| 2025 | 800 $tCO_2$ |
| 2026 | 2,400 $tCO_2$ |
| 2027 | 30,000 $tCO_2$ (large jump in the capacity as mobile pilot sites convert to long-term coastal weathering contracts) |
| 2028 | 160,000 $tCO_2$ |
| 2029 | 410,000 $tCO_2$ |
| 2030 | 780,000 $tCO_2$ |

i. List and describe at least three key milestones for this project (including prior to when CDR starts), that are needed to achieve the amount of CDR over the proposed timeline.

| | Milestone description | Target completion date (eg Q4 2024) |
|---|---|---|
| 1 | ⅕ scale reactor test completed | Q3 2023 |
| 2 | Full-scale pilot site open | Q4 2024 |
| 3 | Pilot site conversion to coastal enhanced weathering (30,000 tonnes) | Q3 2026 |

j. What is your IP strategy? Please link to relevant patents, pending or granted, that are available publicly (if applicable).

| |
|---|
| The reactor and MRV technology will be protectable IP. CEW is not protectable in itself. |

None of our patent applications are available publicly at this time.

k. How are you going to finance this project?

Venture Capital - 75%

AMC Customers - 20%

Grants, Consumer credits, traditional fundraising - 5%

*Ratios on companywide investment to reach payout, not for individual frontier purchase

l. Do you have other CDR buyers for this project? If so, please describe the anticipated purchase volume and level of commitment (e.g., contract signed, in active discussions, to be approached, etc.).

See Confidential Addendum

m. What other revenue streams are you expecting from this project (if applicable)? Include the source of revenue and anticipated amount. Examples could include tax credits and co-products.

Our number one priority is revenue through credits. Our business model is efficient enough to work without an auxiliary income.

With that in mind, future opportunities could be.

- Reef Recovery Revenue. Working with tourism boards to test the mobile reactor's ability to reduce acidity levels in damaged coral reefs and help ecosystems recover.
- Ocean Recovery Revenue - selling ocean deacidification credits to, say, cruise ships.

n. Identify risks for this project and how you will mitigate them. Include technical, project execution, ecosystem, financial, and any other risks.

| Risk | Mitigation Strategy |
|---|---|
| Eviormental | Mobility & containment of Guardian One Reactor for the pilot site. We also choose to remain material agnostic. We believe different materials will be better for different environments. Testing various materials in our reactor will give Skyology the advantage of adapting to the local environment. |

| | |
|---|---|
| Ocean Policy | As of now, ocean policy is minimal regarding OAE. But as we scale, we must maintain good OAE stewardship. Transparent, and third-party MRV. And using the mobile reactor to derisk the possibility of irreversible damage to pilot sites. |
| Carbon Market Price Volatility | Unknown how stable the CDR prices will remain. Our mitigation is moving to our scale price of coastal enhanced weathering as quickly as possible. |
| Reactor Build Cost | The full-scale reactor will likely present new engineering challenges. We plan to raise over double our estimated reactor build to add a cash buffer for the unknown challenges. |

## 2. Durability

a. Describe how your approach results in permanent CDR (> 1,000 years). Include citations to scientific/technical literature supporting your argument. What are the upper and lower bounds on your durability estimate?

> 10,000 years.
>
> 10,000 - 100,000 years. For example (Renforth, P. and G. Henderson, 2017. “Assessing ocean alkalinity for carbon sequestration,” Rev. Geophys., 55: 636–674. doi:10.1002/2016RG000533)

b. What durability risks does your project face? Are there physical risks (e.g. leakage, decomposition and decay, damage, etc.)? Are there socioeconomic risks (e.g. mismanagement of storage, decision to consume or combust derived products, etc.)? What fundamental uncertainties exist about the underlying technological or biological process?

> The durability risk is extremely low. Once alkalinity has been added it is extremely difficult for the sea-to-air interface to replace any $CO_2$ back into the atmosphere.
>
> (Minx et al. 2018)
>
> *D.C. Jones, T. Ito, Y. Takano, and C.-W. Hsu, Spatial and seasonal variability of the air-sea*
> *equilibration timescale of carbon dioxide. Global Biogeochemical Cycles, 28(11), 1163–1178,*

| |
|---|
| *2014.* |

## 3. Gross Removal & Life Cycle Analysis (LCA)

a. How much GROSS CDR will occur over this project's timeline? All tonnage should be described in **metric tonnes** of $CO_2$ here and throughout the application. Tell us how you calculated this value (i.e., show your work). If you have uncertainties in the amount of gross CDR, tell us where they come from.

| | |
|---|---|
| Gross tonnes of CDR over project lifetime | 312t$CO_2$ |
| Describe how you calculated that value | 1 mobile reactor weathering 40t of material every 14 days for one year. * 60% ratio of material weathering to t$CO_2$ (conservative est) =624 t$CO_2$ * 50% downtime for repairs and upgrades (conservative est) =312 t$CO_2$ |

b. How many tonnes of $CO_2$ have you captured and stored to date? If relevant to your technology (e.g., DAC), please list captured and stored tons separately.

| |
|---|
| <1 tonne |

c. If applicable, list any avoided emissions that result from your project. For carbon mineralization in concrete production, for example, removal would be the $CO_2$ utilized in concrete production and avoided emissions would be the emissions reductions associated with traditional concrete production. Do not include this number in your gross or net CDR calculations; it's just to help us understand potential co-benefits of your approach.

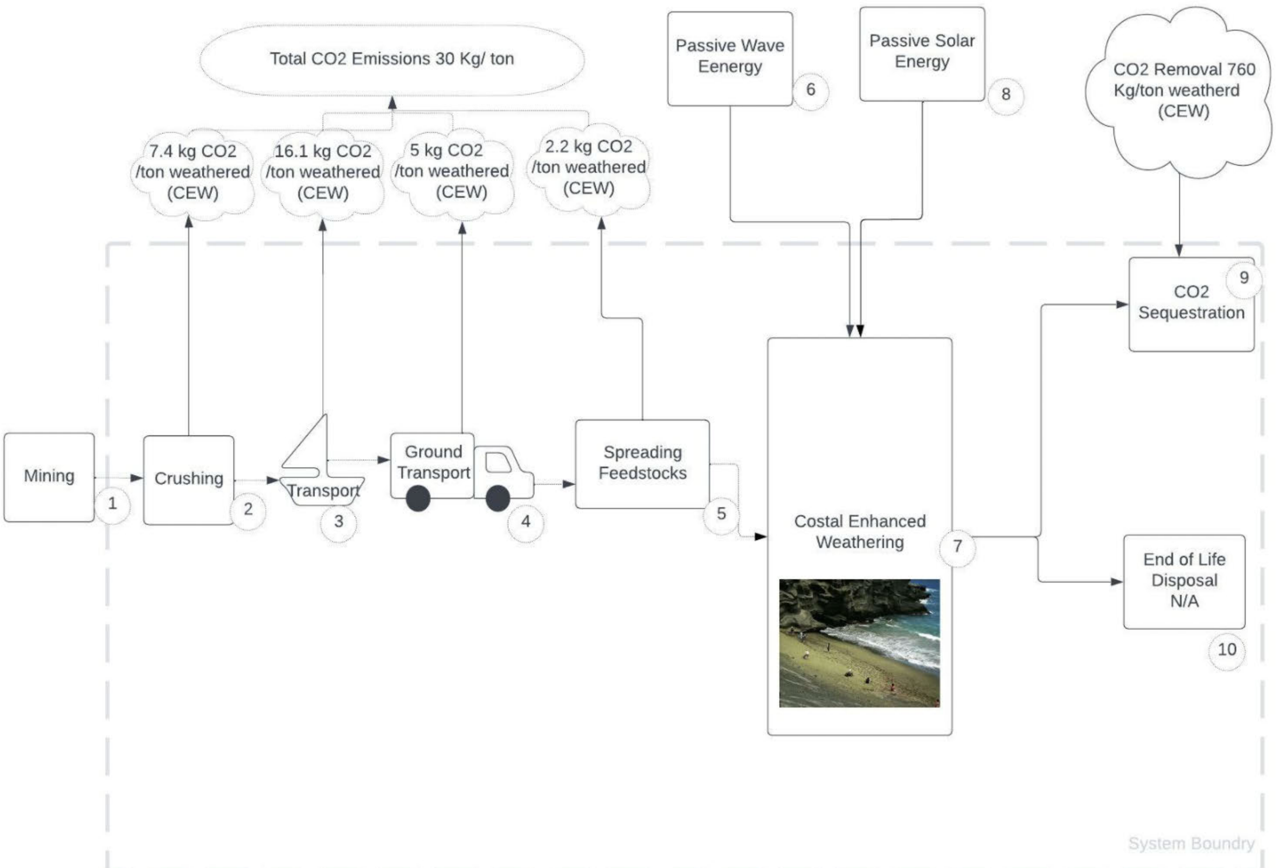
| |
|---|
| N/A |

d. How many GROSS EMISSIONS will occur over the project lifetime? Divide that value by the gross CDR to get the emissions / removal ratio. Subtract it from the gross CDR to get the net CDR for this project.

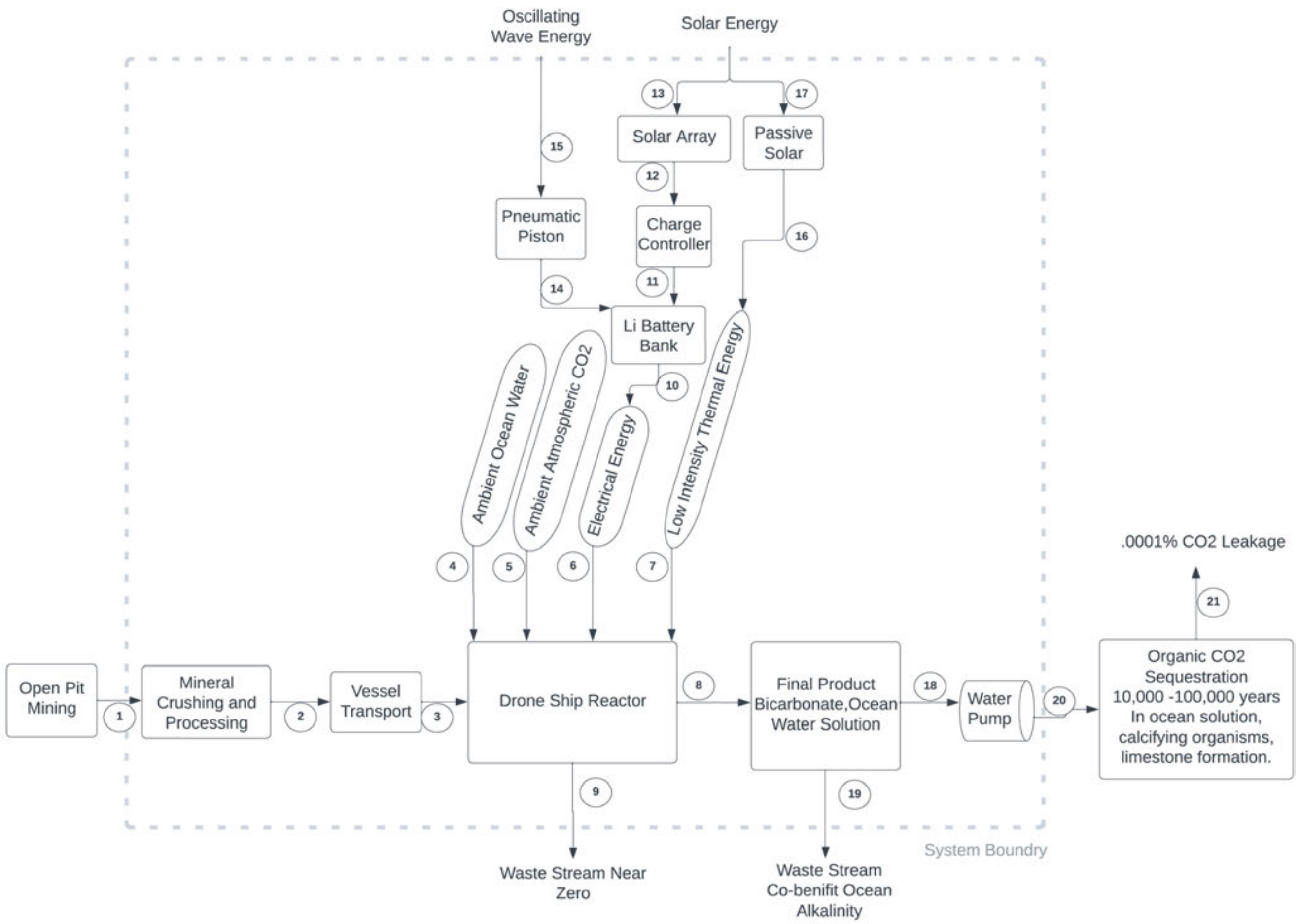
| | |
|---|---|
| Gross project emissions over the project timeline *(should correspond to the boundary conditions described below this table)* | 303 tonnes (gross tonnes of CO2 removal) * 1.5 (material weathering to CO2 draw avg ratio) = 454.5 (weathed tonnes of material) * 30 kg (emissions/tonne of material see diagram & flow chart) = 13.64 tonnes of CO2 emissions. |
| Emissions / removal ratio *(gross project emissions / gross CDR–must be less than one for net-negative CDR systems)* | 1 /.03 |
| Net CDR over the project timeline *(gross CDR - gross project emissions)* | Gross 324 tonnes - 21 tonnes of emissions = 303 tonnes of net delivered. |

e. Provide a process flow diagram (PFD) for your CDR solution, visualizing the project emissions numbers above. This diagram provides the basis for your life cycle analysis (LCA). Some notes:

- The LCA scope should be cradle-to-grave
- For each step in the PFD, include all Scope 1-3 greenhouse gas emissions on a $CO_2$ equivalent basis
- Do not include CDR claimed by another entity (no double counting)
- For assistance, please:
    - Review the diagram below from the CDR Primer, Charm's application from 2020 for a simple example, or CarbonCure's for a more complex example
    - See University of Michigan's Global $CO_2$ Initiative resource guide
- If you've had a third-party LCA performed, please link to it.




**Total Net Removal = 730 kg / ton of costal enhanced weathering(CEW) material**




f. Please articulate and justify the boundary conditions you assumed above: why do your calculations and diagram include or exclude different components of your system?

Excluding mining. Often we will be sourcing from waste materials or already mined materials. Until our production surpasses global mining production roughly 8Gt we are not including mining in our system. We do however take responsibility for crushing and processing.

g. Please justify all numbers used to assign emissions to each process step depicted in your diagram above. Are they solely modeled or have you measured them directly? Have they been independently measured? Your answers can include references to peer-reviewed publications, e.g. [Climeworks' LCA paper](#).

| Process Step | $CO_2$(eq) emissions over the project lifetime (metric tonnes) | Describe how you calculated that number. Include references where appropriate. |
|---|---|---|
| **Material crushing** | 7.4 kg CO2/t of CEW material | Assumptions<br>- Crushing Processing (20kwh/t) Arab J Geosci DOI 10.1007/s12517-013-1260-3<br>- 0.185 kg Co2/kWh (assuming natural gas and electric motor power crusher)<br>- Rock hardness of 7 of 10.<br>20Kwh/t * 0.185 Kg CO2/kWh = 3.7 kg CO2/t of rock crushing<br>- Second cycle rock crushing<br>Total =**7.4 kg CO2/t of crushed material** |
| **Vessel Transport** | **16.140 kg CO2/t of CEW material** | Assumptions<br>- The vessel travel is 30-100km<br>- A cargo ship produces 16.14 grams of CO2 per metric t of goods shipped per kilometer.<br>-<br>100km * 16.14 grams = **Total 16.140 kg CO2/t moved** |
| **Ground Transport** | **5.02 kg /t CEW material** | Assumptions<br>- 10-50km of transport<br>- The average freight truck in the U.S. emits 161.8 grams of CO2 per tonne per mile<br>161.8 g CO2/mile * 31 miles (50km) **= 5.02 kg / t moved.** |
| **Spreading -** with diesel-powered moving equipment | **= 2.2 kg CO2/tof rock moved.** | Assumptions<br>-A Caterpillar D6 dozer is said to burn between |

| | | |
|---|---|---|
| | | 3.5 gal. (13.3 L) and 6.5 gal. (24.7 L) of diesel an hour when operating under moderate conditions.<br><br>-An excavator could be used to dig anywhere from 350 to 1,000 cubic yards per day, depending on a number of factors including bucket capacity, type of ground, operator skill and efficiency level, and more.<br><br>-Because one cubic yard of gravel is equal to 1.13 tonnes, you can multiply your total cubic yards by 1.13 to convert this measurement to tonnes<br><br>- Diesel engines produce 2.7 kg of $CO_2$ per litre of diesel fuel consumed<br><br>- 350 cubic yard*1.13 tonnes = 395 tonnes per day / 10 hr shift = 39.5 tonnes/hour.<br><br>- 39.5 tonnes per hour /60 minutes = .65 tonnes/minute (Roughly 1 tonne every two minutes)<br>- 24.7 L diesel per hour /60 minutes = .41L/h = .82 L every two minutes (roughly L per tonne<br>- 2.7 kg of $CO_2$/ Liter * .82 L/tonne<br>-<br>**= 2.2 kg $CO_2$/t of rock moved.** |
| *(include additional rows as needed)* | | |

## 4. Measurement, Reporting, and Verification (MRV)

Section 3 above captures a project's lifecycle emissions, which is one of a number of MRV considerations. In this section, we are looking for additional details on your MRV approach, with a particular focus on the ongoing quantification of carbon removal outcomes and associated uncertainties.

a. Describe your ongoing approach to quantifying the CDR of your project, including methodology, what data is measured vs modeled, monitoring frequency, and key assumptions. If you plan to use an existing protocol, please link to it. Please see [Charm's bio-oil sequestration protocol] for reference, though note we do not expect proposals to have a protocol at this depth at the prepurchase stage.

| |
|---|
| MRV Metrics<br>- Contained weathering rate (delta in grain size)<br>- Direct measurement Bicarbonate ratio in solution |

| |
|---|
| - Alkalenity and bicarbonate transport frequent sampling |

b. How will you quantify the durability of the carbon sequestered by your project discussed in 2(b)? If direct measurement is difficult or impossible, how will you rely on models or assumptions, and how will you validate those assumptions? *(E.g. monitoring of injection sites, tracking biomass state and location, estimating decay rates, etc.)*

| |
|---|
| Weathering mass/CO2 draw down mass ratios will be modeled and cross confirmed by contained pilots and bicarbonate sensors and third party lab studies. |

c. This tool diagrams components that we anticipate should be measured or modeled to quantify CDR and durability outcomes, along with high-level characterizations of the uncertainty type and magnitude for each element. We are asking the net CDR volume to be discounted in order to account for uncertainty and reflect the actual net CDR as accurately as possible. Please complete the table below. Some notes:

- In the first column, list the quantification components from the Quantification Tool relevant to your project (e.g., risk of secondary mineral formation for enhanced weathering, uncertainty in the mass of kelp grown, variability in air-sea gas exchange efficiency for ocean alkalinity enhancement, etc.).
- In the second column, please discuss the magnitude of this uncertainty related to your project and what percentage of the net CDR should be discounted to appropriately reflect these uncertainties. Your estimates should be based on field measurements, modeling, or scientific literature. The magnitude for some of these factors relies on your operational choices (i.e., methodology, deployment site), while others stem from broader field questions, and in some cases, may not be well constrained. We are not looking for precise figures at this stage, but rather to understand how your project is thinking about these questions.
- See this post for details on Frontier's MRV approach and a sample uncertainty discount calculation and this Supplier Measurement & Verification Q&A document for additional guidance.

| **Quantification component**<br>Include each component from the Quantification Tool relevant to your project | **Discuss the uncertainty impact related to your project**<br>Estimate the impact of this component as a percentage of net CDR. Include assumptions and scientific references if possible. |
|---|---|
| *Extremely low durability risk cited above* | *N/A* |
| *(include additional rows as needed)* | |

d. Based on your responses to 4(c), what percentage of the net CDR do you think should be discounted for each of these factors above and in aggregate to appropriately reflect these uncertainties?

| |
|---|
| 0.0001% |

e. Will this project help advance quantification approaches or reduce uncertainty for this CDR pathway? If yes, describe what new tools, models or approaches you are developing, what new data will be generated, etc.?

> The Guardian One will be a first of its kind. This reactor is the bridge between mesocosm experiments (very small sample, low variables) and CEW (large sample, lots of variables). This data will teach Skyology and the rest of the world what materials will match what climate, and how we can adjust them.

f. Describe your intended plan and partners for verifying delivery and registering credits, if known. If a protocol doesn't yet exist for your technology, who will develop it? Will there be a third party auditor to verify delivery against that protocol or the protocol discussed in 4(a)?

> Confidential Addendum

## 5. Cost

We are open to purchasing high-cost CDR today with the expectation the cost per tonne will rapidly decline over time. The questions below are meant to capture some of the key numbers and assumptions that you are entering into the separate techno-economic analysis (TEA) spreadsheet (see step 4 in Applicant Instructions). There are no right or wrong answers, but we would prefer high and conservative estimates to low and optimistic. If we select you for purchase, we'll work with you to understand your milestones and their verification in more depth.

a. What is the levelized price per net metric tonne of $CO_2$ removed for the project you're proposing Frontier purchase from? 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), but we will be using the data in that spreadsheet to consider your offer. Please specify whether the price per tonne below includes the uncertainty discount in the net removal volume proposed in response to question 4(d).

> $1,650/t ***The TEA spreadsheet references seemed to break with alot of the assumptions we added from coastal enhanced weathering. This is mostly because the costs to place material and MRV. or the two major expenses. Please contact us if you would like to discuss or see a cost model that works for OAE, and CEW. *** swiss@skyology.io

b. Please break out the components of this levelized price per metric tonne.

| Component | Levelized price of net CDR for this project ($/tonne) |
|---|---|
| Capex | $1095 |
| Opex (excluding measurement) | $380 |

| | |
|---|---|
| Quantification of net removal (field measurements, modeling, etc.)[2] | $135 |
| Third-party verification and registry fees (if applicable) | $40 |
| **Total** | $1,650 |

c. Describe the parameters that have the greatest sensitivity to cost (e.g., manufacturing efficiencies, material cost, material lifetime, etc.). For each parameter you identify, tell us what the current value is, and what value you are assuming for your NOAK commercial-scale TEA. If this includes parameters you already identified in 1(c), please repeat them here (if applicable). Broadly, what would need to be true for your approach to achieve a cost of $100/tonne?

| Parameter with high impact on cost | Current value (units) | Value assumed in NOAK TEA (units) | Why is it feasible to reach the NOAK value? |
|---|---|---|---|
| Capex is all from Reactor build | | | This is a primary sunk investment to open costal enhanced pilot sites safer. Once proven that sitewill not require a reactor to continue running we will use costal weathering which is a slower reaction, but can be done at very low cost. |

d. What aspects of your cost analysis are you least confident in?

Reactor builds, we may find that our ⅕ scale reactor is completely sufficient to plant pilot site confidence. But we may also need to spend years refining its operations.

e. How do the CDR costs calculated in the TEA spreadsheet compare with your own models? If there are large differences, please describe why that might be (e.g., you're assuming different learning rates, different multipliers to get from Bare Erected Cost to Total Overnight Cost, favorable contract terms, etc.).

***The TEA spreadsheet references seemed to break with alot of the assumptions we added from costal enhanced weathering. This is mostly because the costs to place material and MRV. or the two major expenses. Please contact us if you would like to discuss or see a cost model that works for OAE, CEW. *** swiss@skyology.io

[2] This and the following line item is not included in the TEA spreadsheet because we want to consider MRV and registry costs separately from traditional capex and opex.

f. What is one thing that doesn't exist today that would make it easier for you to commercialize your technology? (e.g., improved sensing technologies, increased access to X, etc.)

> A cheap risk-free way to test and proof pilot sites. This is why we want to build the mobile reactor.

## 6. Public Engagement

In alignment with Frontier's Safety & Legality criteria, Frontier requires projects to consider and address potential social, political, and ecosystem risks associated with their deployments. Projects with effective public engagement tend to:

- Identify key stakeholders in the area they'll be deploying
- Have mechanisms in place to engage and gather opinions from those stakeholders, take those opinions seriously, and develop active partnerships, iterating the project as necessary

The following questions help us gain an understanding of your public engagement strategy and how your project is working to follow best practices for responsible CDR project development. We recognize that, for early projects, this work may be quite nascent, but we are looking to understand your early approach.

a. Who have you identified as relevant external stakeholders, where are they located, and what process did you use to identify them? Please include discussion of the communities potentially engaging in or impacted by your project's deployment.

> 1. Indigenous councils
> 2. Local municipalities
> 3. Conservation board
> 4. Tourism boards
> 5. Recreation councils
> 6. Fishing councils

b. If applicable, how have you engaged with these stakeholders and communities? Has this work been performed in-house, with external consultants, or with independent advisors? If you do have any reports on public engagement that your team has prepared, please provide. *See Project Vesta's community engagement and governance approach as an example and Arnestein's Ladder of Citizen Participation for a framework on community input.*

> Early in our work, we spoke with other coastal weathering organizations who told us about the difficulties of getting the first pilot sites. Then we spoke with local policymakers. We asked them, "what would it take to let CEW happen in their backyard?" The response was overwhelming. They wanted safe local tests and to be capable of calling off the process if it had any negative impact. Reversability and Transparency are essential to winning the trust of local stakeholders and our customers.

c. If applicable, what have you learned from these engagements? What modifications have you already made to your project based on this feedback, if any?

> These engagements inspired us to build a contained and mobile OAE reactor. To accelerate local stakeholders to a “yes” by giving them the safety and reversibility they wanted up front. Other CEW operations seem to ask for a “marriage relationship” right away by depositing material on the coast before testing it in that local environment.”

d. Going forward, do you have changes to your processes for (a) and (b) planned that you have not yet implemented? How do you envision your public engagement strategy at the megaton or gigaton scale?

> We have worked closely with Seabin ASU and plan to invest more in a grassroots campaign. They found it was easier to engage policymakers by educating citizens to speak up for them. .

## 7. Environmental Justice[3]

As a part of Frontier’s Safety & Legality criteria, Frontier seeks projects that proactively integrate environmental and social justice considerations into their deployment strategy and decision-making on an ongoing basis.

a. What are the potential environmental justice considerations, if any, that you have identified associated with your project? Who are the key stakeholders? Consider supply chain impacts, worker compensation and safety, plant siting, distribution of impacts, restorative justice/activities, job creation in marginalized communities, etc.

> Local job creation and MRV monitoring, material management, and local jobs in transport. We believe the Skyology reactor can be a hub of marine education. We plan to introduce free marine biology and geochemistry classes onsight to the public, including guided tours of life around the reactor.

b. How do you intend to address any identified environmental justice concerns and / or take advantage of opportunities for positive impact?

> We identify coastal communities that are concerned about reef health. Using it as a food source, and tourism, recreation. We believe in empowering the local community to take responsible care of the reefs. Our technology could be a great launching point to understanding how temperature, alkalinity, and atmosphere influence the reef's health. We have an opportunity to bring more local youth into physics, chemistry, and engineering earlier on and a chance to see it happening in their own backyard.

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[3] For helpful content regarding environmental justice and CDR, please see these resources: C180 and XPRIZE’s Environmental Justice Reading Materials, AirMiners Environmental and Social Justice Resource Repository, and the Foundation for Climate Restoration’s Resource Database

## 8. Legal and Regulatory Compliance

a. What legal opinions, if any, have you received regarding deployment of your solution?

Norwegian center for the law of the sea. The reactor can legally operate on the high seas, and in costal regions, it is determined by the country and state law.

CEW is being slowly introduced in the Dominican Republic and New York. So far no legal issues have occurred.

b. What permits or other forms of formal permission do you require, if any, to engage in the research or deployment of your project? What else might be required in the future as you scale? Please clearly differentiate between what you have already obtained, what you are currently in the process of obtaining, and what you know you'll need to obtain in the future but have not yet begun the process to do so.

There are established processes for securing permits for pumping or discharging seawater in
the ocean, and the jurisdictions where we operate will govern the legal and regulatory requirements. There is some uncertainty on the local permit requirements pending specific
installation locations.

In international law, the definition of “waste” does not technically include this type of use. Espissialy if used to help mitigate erosion. So there seems to be a legal route for now. Our main practice as we scale is safety. If Skyology can continue to steward OAE in the safest way possible, be believe international law will be inclined to treat OAE its own set of protections aside from other forms of mineral dissolution.

c. Is your solution potentially subject to regulation under any international legal regimes? If yes, please specify. Have you engaged with these regimes to date?

N/A London protocol appears to allow for coastal enhancement, but not waste dumping. The lack of mentioning OAE directly could leave it in some grey area of debate.

d. In what areas are you uncertain about the legal or regulatory frameworks you'll need to comply with? This could include anything from local governance to international treaties. For some types of projects, we recognize that clear regulatory guidance may not yet exist.

Mostly the latter. Clear regulatory guidelines for OAE do not exist in most governance.

e. Do you intend to receive any tax credits during the proposed delivery window for Frontier's purchase? If so, please explain how you will avoid double counting.

| |
|---|
| N/A |

## 9. Offer to Frontier

This table constitutes your **offer to Frontier**, and will form the basis of contract discussions if you are selected for purchase.

| | |
|---|---|
| **Proposed CDR** over the project lifetime (tonnes) *(should be net volume after taking into account the uncertainty discount proposed in 4(c))* | 303 t |
| **Delivery window** *(at what point should Frontier consider your contract complete? Should match 1(f))* | 2025 Q3 |
| **Levelized Price** ($/metric tonne $CO_2$) *(This is the price per tonne of your offer to us for the tonnage described above)* | $1,650/t |

# Application Supplement: Ocean

**(Only fill out this supplement if it applies to you)**

## Physical Footprint

1. Describe the geography of your deployment, its relationship to coastlines, shipping channels, other human or animal activity, etc.

Step 1 mobile reactor
Mobile reactors can be deployed off the coast in remote locations. Even locations without road access could be suitable. After they are tested for various sea conditions, they can work 100+ miles from the coast. Ideally where there is a good amount of mixing going on and a protectable place to more the vessel should a storm arise.

Step 2 Scale and coastal weathering
In relationship to the coastlines, these sites are chosen on two bases.

1. How high is a weathering/drawdown in this location? (tested by mobile)
2. Can we operate with the highest degree of safety? (tested by mobile)

These sites are not dependent on being close to fresh water, electrical grid power, agriculture, or shipping. In fact, Skyology can choose locations that are inconspicuous and have fewer amenities.

The most common party we may interact with is aquaculture and fishing vessels. We foresee little disturbance to these activities, but our increased data and monitoring in the area could also be a co-benefit to the industry if positioned correctly.

2. Please describe your physical footprint in detail. Consider surface area, depth, expected interaction with ocean currents and upwelling/downwelling processes, etc.
    a. If you've also filled out the Biomass supplement and fully articulated these details there, simply write N/A.

At full-scale production, our coastal sites must periodically use a stable dirt lot of dry land to park spreading materials and maintenance vehicles. Up to 2 hectares in size, but typically much less. The spreading will occur on up to 2km of coastline. This is not included in our footprint because this coastal area is still usable by local biology and humans.

3. Imagine, hypothetically, that you've scaled up and are sequestering 100Mt of $CO_2$/yr. Please project your footprint at that scale, considering the same attributes you did above (we recognize this has significant uncertainty, feel free to provide ranges and a brief description).

    a. If you've also filled out the Biomass supplement and fully articulated these details there, simply write N/A.

At this scale, we estimate being in over 9,000 coastal areas less than 2 kilometers long. In reality, some may be much larger or smaller, 2km is an average size. At each location, Skyology would need a 4-week period of deployment using the 2 hectares mentioned above. In total, we would have used 18,000 hectares of undeveloped land for a period of 4 weeks during the staging of the location. This land may often be included in our contracts, in some cases, we assume we may need to rent the field from a local farmer or land owner.

After four weeks of staging, our solution requires no permanent facilities.

## Potential to Scale

4. Building large systems on or in the ocean is hard. What are your core engineering challenges and constraints (not covered already within 1(n)? Is there any historical precedent for the work you propose?

Core challenges are stabilizing our mobile reactor for the many challenges of the ocean environment. We are addressing this by see confidential addendum.

## Externalities and Ecosystem Impacts

5. What are potential negative impacts of your approach on ocean ecosystems?

Trace metals - Nickel, Chromium, Iron, Magnesium, Calcium.

Containment - mentioned above. In pilot sites containing the reaction in the mobile reactor to monitor and control the interface between alkalinity and ocean solution.

Reversability - mentioned above. The reactor's mobility gives each project a fail-safe. We can turn off our site with lower financial risk than other OAE solutions.

Material diversity - Other costal enhanced weathering projects seem to try to select the“universally best” material. Skyology knows the uniqueness of environments, biology, and transport should dictate our choice of the material blend. The reactor can test various materials within months to see what could be the best fit for the specific area.

MRV - Skyology is spending a large portion of its current budget contracting and developing the sensors need to monitor the local ecology. Deployment at scale will include full-time sail drones. Monitoring reactions at every layer of the water column.

6. How will you mitigate the potential for negative ecosystem impacts (e.g., eutrophication and alkalinity/pH)? How will you quantify and monitor the impact of your solution on ocean ecosystems and organisms?

Although we believe the risk of biological harm is low. We take safety very seriously. We will be collaborating with many third parties to help complete ecotoxicology studies and understand the unique organisms in every site. Microalgae can have positive feedback on changes in alkalinity when perturbed. One of the ways we can mitigate this is our system of material blending can prohibit favoring the environment for calcifying organisms and cyanobacteria over diatoms or vice versa,  to maintain the local level of microbiology.