Applicant Instructions: Prepurchase track

Thank you so much for your work on carbon dioxide removal (CDR), and thank you in advance for taking the time to apply for Frontier's purchase. Please read the following information carefully and in full before beginning your application, as well as take a look at Frontier's Fall 2022 Request for Proposals which includes information regarding our target purchase criteria, how we review applications, and what our team is looking for. For your reference, all previously submitted applications are available here (2020-2021) and here (2022 onwards).

We invite you to attend one of two application coaching sessions we will be hosting at 9 am PDT on Sept 20 and 10 am PDT on Oct 4 for general application guidance. If you have any further questions as you work through, please email us at suppliers@frontierclimate.com.

Timeline

- **October 7, 2022 9:00 pm PDT:** This application is due. You are welcome to submit early.
- **Mid October:** Frontier will review your application for completeness and basic scientific validity with respect to our criteria. Qualified applications will be sent to our expert reviewers for review against the criteria we outlined in the RFP. Each application will receive 2 scientific reviews and 1 governance review.
- **Early November:** Frontier will share anonymous reviewer comments and questions with you, and give you two days to submit a response to these comments, if you choose to.
- **Mid November:** Frontier will invite a subset of applicants to advance to a video interview to discuss your application.
- **Late November:** Frontier finalizes decisions and notifies applicants of prepurchase and small offtake (FYI, a separate template) awards. Together, Frontier and teams define renewal criteria, project milestones, and tonnage pricing within Frontier's standard purchase agreement templates. Larger offtake applicants will be notified if they are Finalists and invited for additional diligence that we will perform in early 2023.
- **Mid December:** Frontier will announce prepurchase and small offtake purchases and upload applications to Frontier's public GitHub.
- **First half of 2023:** Frontier's review team will conduct additional diligence with larger offtake Finalists, including a site visit to your facility.
- **Mid 2023:** Frontier signs larger offtake agreements.

How to apply

Step 1: Determine which category supplements apply to your project

- This document includes the General Application as well as all category supplements. All applicants should fill out the General Application, as well as whichever (typically 1 - 2) supplements apply to your approach.
- You should fill out applicable supplements IN ADDITION to the General Application.
- Using examples from Frontier's existing portfolio:

  - AspiraDAC would fill out the DAC supplement AND the Geologic Injection supplement.
  - Lithos Carbon would fill out the Surface Mineralization/Enhanced Weathering supplement
  - Running Tide would fill out the Biomass supplement AND the Ocean supplement.
  - CarbonBuilt would fill out the CO_2 Utilization to storage supplement.
- If it's not clear which supplements apply to your project, please ask at suppliers@frontierclimate.com.

Step 2: Delete the supplements that don't apply to you.

- This results in a document with the General Application and your applicable supplements only. Please delete these first four pages of instructions too!

Step 3: Fill out the application in this document.

- If you have any questions, attend one of two application coaching sessions we will be hosting at 9 am PDT on Sept 20 and 10 am PDT on Oct 4 for general application guidance or email us at suppliers@frontierclimate.com. Please reach out with questions as early in the application process as possible.

Step 4: Complete the techno-economic analysis (TEA) spreadsheet.

- We included a Google Sheet containing a TEA in the same Google Drive folder (specific to your application) as this template. Instructions on how to fill it out are included in the START HERE tab.

- We recorded a webinar with instructions for filling out the spreadsheet. The passcode is provided in your application invitation. We encourage you to review the spreadsheet early on and ask any questions you might have–either by email or attending an application coaching session.

Step 5: Prepare any materials you would like to submit confidentially [optional].

- We remain committed to a public RFP process because commercial-scale permanent CDR is a nascent field, and we are trying to advance transparency and knowledge-sharing across the ecosystem. However, companies applying for a prepurchase will be able to share select information confidentially.
- A confidential addendum, which can be up to six pages, may be submitted. It should be limited only to select data (e.g., specific site locations or supplier names, material formulations, revealing performance data, business plans, etc.) you wish to exclude from the main application. This confidential addendum and the TEA spreadsheet will not be made public.
- To submit a confidential addendum, create a Google Doc or upload a Word or PDF to the same Google Drive folder as this application and the TEA. All of your application materials must be in this folder.
- Frontier's expert reviewers have non-disclosure agreements (NDAs) in place with Frontier. If you have any concerns around confidentiality, please contact our team to discuss.

Step 5: Submit your application by October 7, 2022 9:00 pm PDT

- This application, the TEA spreadsheet, and confidential addendum (if applicable) must be in the Google Drive folder by this time.
- **Your submission constitutes your consent for Frontier to make your full application and all of its content - excluding the TEA spreadsheet and confidential addendum– available publicly under a CC-0**

"Public Domain" License, regardless of whether or not Frontier selects you for purchase. For more details, see "Why we make applications public" below.

What we're looking for

Please refer to Frontier's [Fall 2022 Request for Proposals] for a characterization of projects Frontier is excited to support and details on our selection process. There, we discuss the three lenses we use when making purchase decisions: approach, execution, and portfolio. Our approach criteria are:

Criteria	Description
Durability	Stores carbon permanently (>1,000 years)
Physical footprint	Takes advantage of carbon sinks less constrained by arable land
Cost	Has a path to being affordable at scale (<$100 per ton)
Capacity	Has a path to being a meaningful part of the carbon removal solution portfolio (>0.5 gigatons per year)
Net negativity	Results in a net reduction in atmospheric carbon dioxide
Additionality	Results in net new carbon removed, rather than taking credit for removal that was already going to occur
Verifiability	Has a path to using scientifically rigorous and transparent methods for monitoring and verification
Safety and legality	Is working towards the highest standards of safety, compliance, and local environmental outcomes; actively mitigates risks and negative environmental and other externalities on an ongoing basis

Why we make all applications public

All applications to our earlier purchase cycles were made public, and can be accessed here and here. We're grateful to all our applicants for providing this level of transparency; hopefully this will enable impact beyond the dollar amount of any particular purchase we may make, including visibility and the opportunity for potential collaborators and investors to connect with you. Making applications public enables subsequent academic works and independent analysis from nonprofits like CarbonPlan (examples here, here), and we've heard from a wide range of investors, engineers, and scientists that the shared applications are a valuable source of data on the current state of the field and opportunities for advancement. For these reasons, we're again making applications from this purchase cycle primarily public.

That said, in previous cycles, some companies have told us that this level of transparency can be challenging, particularly if the company is in stealth or in the process of patent filing. We understand the need to balance transparency with protecting business-sensitive information, and thus will accept a confidential addendum that will not be published. We still expect as much information as possible to be included in the public-facing portion of the application so that it is a comprehensive, standalone representation of the merits of what you're building.

Fine print

We intend to make the selection process as informal as possible. However, we do expect that (a) the content of your application is, to the best of your knowledge, complete and correct; (b) you do not include any content in your application that breaches any third party's rights, or discloses any third party's confidential information; (c) you understand that we will publicly publish your application, excluding the TEA spreadsheet and materials in the confidential addendum, at the conclusion of the selection process. You also understand that Frontier is not obliged to explain why or how it decided to purchase the CDR that it did, and that Frontier may decide to not purchase CDR from your application or make an offer to purchase less than what you proposed. Finally, if you are selected as a recipient for funding, Frontier will not be under any obligation to provide you with funding until such time as you and Frontier sign a formal written agreement containing the funding commitment.

Acknowledgements

Frontier gratefully acknowledges assistance and discussions from the following, who helped improve this application template and our purchasing process:

- AirMiners environmental justice working group for their many suggestions on the Public Engagement and Environmental Justice section
- CarbonPlan for their partnership on shaping measurement, verification and reporting requirements
- M. Van der Spek (Heriot-Watt University) for developing the TEA spreadsheet
- Microsoft and XPRIZE Foundation for perspective on life cycle analysis (LCA) and TEA tools

Carbon Blue Ltd.

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

Carbon Blue Ltd

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

Israel

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

Iddo Tsur, Dan Deviri

Brief company or organization description

Carbon Blue develops a highly-scalable, economical, and land area efficient 'ocean-capture' method for removing CO2 from the atmosphere.

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.

Carbon Blue develops CDR plants that extract CO_2 from the ocean, enabling the ocean to reabsorb a similar amount of atmospheric CO_2. The extracted CO_2 is injected into a geologic formation, where it is stored for thousands of years.

[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.

The ocean is one of the earth's most critical CO_2 pumps, naturally sequestering roughly 30% of CO_2 emissions. The reason is simple: CO_2 is acidic and seawater is alkaline, so an acid-base reaction transforms the CO_2 into carbonate (CO_3^{-2}) and bicarbonate (HCO_3^-) ions, allowing more atmospheric CO_2 to dissolve in the seawater. In chemical equilibrium, the total molar concentration of dissolved inorganic carbon (DIC) in seawater, consisting of CO_2, H_2CO_3, HCO_3^-, and CO_3^{-2}, is about 2.3 millimolar. This concentration is about 140-fold larger than the atmospheric concentration of CO_2.

Carbon Blue's proposed technology removes CO_2 from seawater while conserving its alkalinity, which is known as Direct Ocean Capture (DOC). DOC renders the seawater sub-saturated in CO_2 and allows it to reabsorb atmospheric CO_2 in equal amounts to the CO_2 removed, thus lowering the atmospheric concentration of CO_2. Carbon Blue proposes a technology to remove carbon. We will sell carbon removal credits generated by a future partnership between a geo-sequestration (injection operator) company (TBD) and Carbon Blue, the DOC company.

DOC has two clear qualitative advantages over direct air capture (DAC) as an engineered approach for carbon dioxide removal (CDR): First, the ocean's vast surface area naturally exchanges gases with the atmosphere and alleviates the need for expensive air contactors. Second, the seawater DIC concentration is higher than the atmospheric CO_2 concentration, which implies more significant mass transport from seawater to the pure CO_2 phase. Therefore the physical size of DOC plants, the capital expenses needed to construct them, and their operating costs may all be reduced compared to DAC plants of similar capacity. Below, we present the DOC technology Carbon Blue develops, which we term ocean-based calcium looping (see Fig. 1).

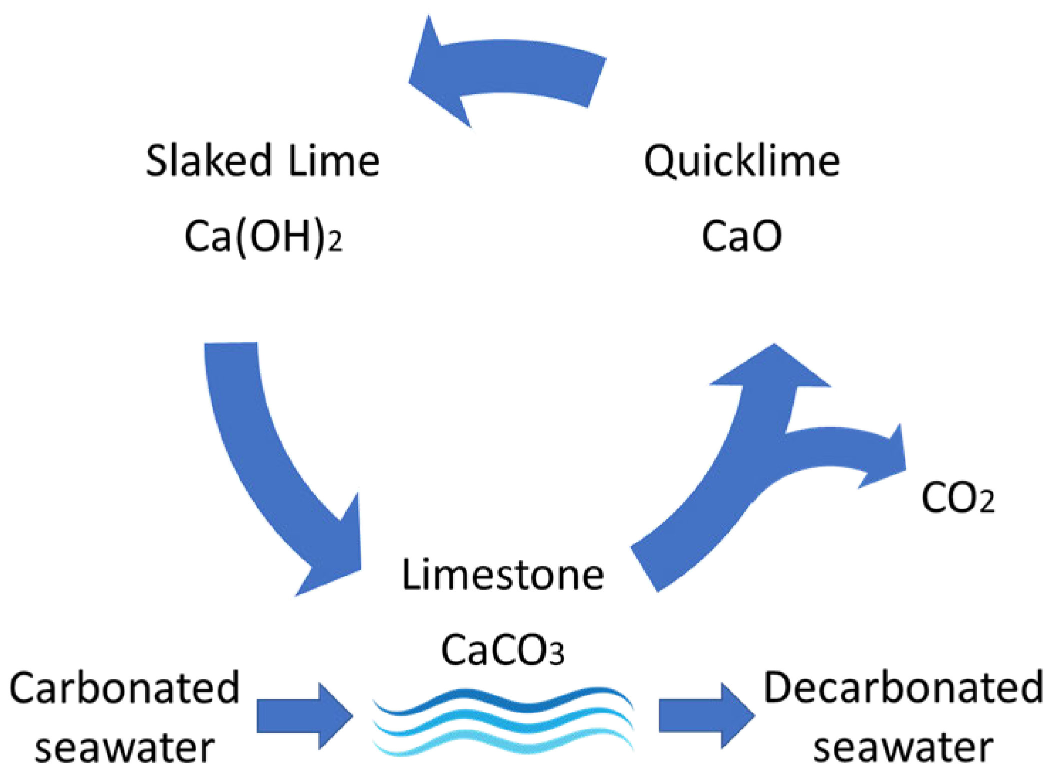


Figure 1: Schematic description of our process as an ocean-based calcium-looping

Seawater is naturally supersaturated with CO_3^{-2} and calcium ions, but the presence of inhibitors hinders the precipitation of the mineral calcium carbonate ($CaCO_3$). These inhibitors prevent the nucleation of $CaCO_3$ seeds that subsequently grow. In our proprietary reactor, we remove this barrier, allowing accelerated precipitation of $CaCO_3$, which removes a portion of the seawater's DIC. In addition, we compensate for the alkalinity lost due to $CaCO_3$ precipitation by adding an alkaline mineral. The alkaline material also increases the seawater pH and converts HCO_3^- ions to CO_3^{-2} ions, which consequently increases the precipitation potential of $CaCO_3$ and DIC removal (see Fig. 2). In Carbon Blue's technology, the $CaCO_3$ precipitate is processed into calcium hydroxide ($Ca(OH)_2$), the alkaline mineral added to the seawater.

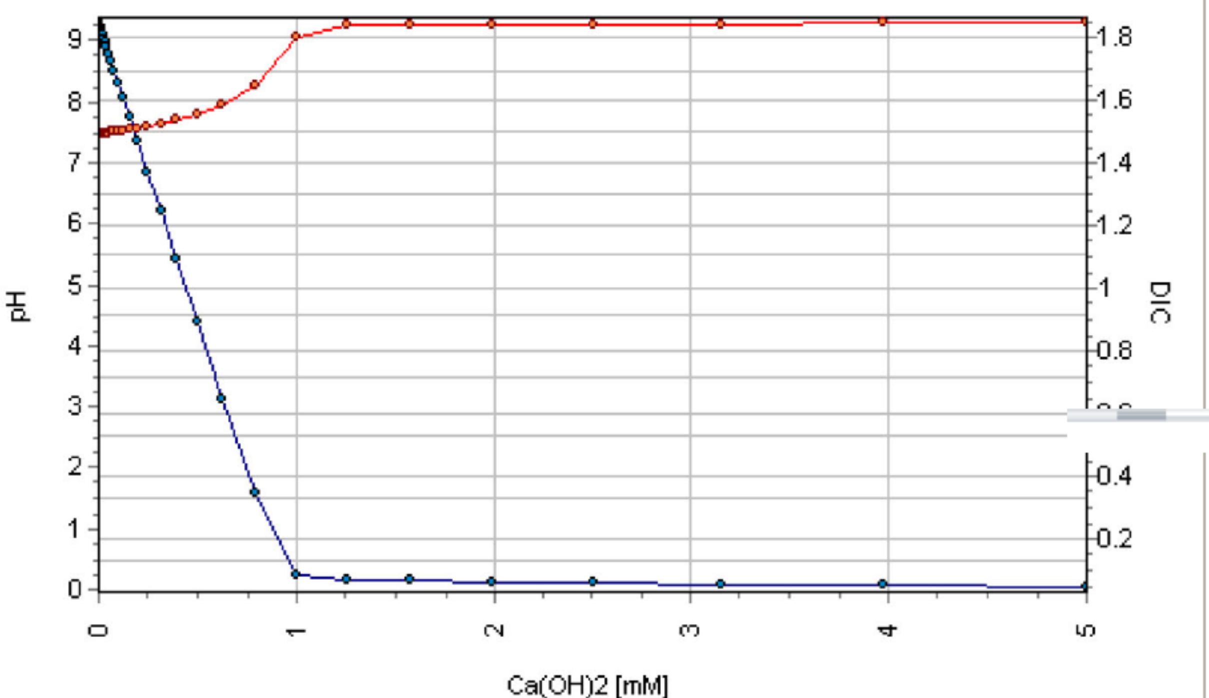


Figure 2: Simulated (using Aqion software) equilibrium pH (red) and DIC (blue) as a function of added $Ca(OH)_2$ concentration. The equilibrium DIC concentration when no $Ca(OH)_2$ is added is smaller than the natural DIC concentration (~2.3 mM) because seawater is naturally supersaturated.

Following precipitation, the $CaCO_3$ is fed to a circulating fluidized bed (CFB) calciner, which facilitates the thermal decomposition of $CaCO_3$ into CaO and CO_2. In the CFB calciner, $CaCO_3$ particles are fluidized in an oxygen/natural gas mixture that combusts, providing energy for the calcination reaction. Since the natural gas is oxy-combusted, the products of the combustion reaction are water vapor and CO_2, which mix with the products of the calcination reaction, CaO (solid) and CO_2 (gas). A cyclone separates this mixture's solids and gases into two output streams from which heat is recovered to increase process efficiency. Then, cooling induces condensation of the water vapor in the output gas stream, which leaves pure CO_2(which originated in both the seawater and via combustion), which is captured, compressed to a supercritical phase, and injected into the subsurface for permanent storage.

The CaO from the solid output stream of the calciner is fed to a third reactor, a steam slaker. In the steam slaker, CaO reacts with steam to form $Ca(OH)_2$, releasing significant amounts of usable heat. This heat dries the $CaCO_3$ removed from the precipitation reactor and heats steam for electricity generation. The regenerated $Ca(OH)_2$ is then used in the precipitation reactor to facilitate continuous, alkalinity-conserving precipitation of $CaCO_3$ from seawater.

A calcium loop schematically describes the entire process (see Fig. 1) in which calcium from $Ca(OH)_2$ is added to seawater and later regenerated by calcination and slaking of $CaCO_3$ precipitates, thereby removing DIC from the seawater. Ideally, the added mass of calcium equals the precipitated mass of calcium as $CaCO_3$. However, inefficiencies in recovering and processing the $CaCO_3$ precipitate may lead to a situation where the regenerated calcium mass is smaller than in the precipitated $CaCO_3$. Importantly, this situation does not necessitate an external makeup of $CaCO_3$ because the natural supersaturation of seawater in calcium and carbonate ions implies that it is possible to precipitate a calcium mass greater than the one added as $Ca(OH)_2$ (see Fig. 2). In this way, our process eliminates the need for an external material supply chain.

Our DOC approach has distinct advantages over alternative CDR approaches. Compared to terrestrial biomass methods, our method does not compete with agriculture over arable land. Compared to DAC, as argued above, the higher concentration of carbon in seawater, compared to air, may result in smaller CDR plants and lower removal costs. We now compare our proposed technology with alternative ocean-based CDR methods.

The monitoring, reporting, and verification of our CDR method are much simpler than marine biomass or ocean alkalinity enhancement methods, which do not generate a measurable CO_2 output stream. In our process, the removed CO_2 mass and the effluent seawater alkalinity are measured precisely within our plants. From these data, oceanographic simulations of ocean currents and the sea-air carbon flux can predict the reabsorption of atmospheric CO_2. These predictions can be tested and verified by local pH and DIC concentration measurements at different locations away from our DOC plants. Furthermore, our process does not require adding any minerals or organisms from external sources to the seawater, thus is not expected to have adverse ecological effects. On the contrary, since the effluent seawater is less acidic than the influent seawater, a positive environmental impact is expected due to local mitigation of ocean acidification. This differentiates us from ocean alkalinity enhancement methods which add minerals, sometimes containing traces of toxic heavy metals, to the seawater, thereby changing the chemistry of the seawater and potentially damaging marine ecosystems.

Finally, our proposed technology is also differentiated from other ocean-based technologies because it is not electrochemical, which leads to a few advantages:

1. Our proposed CDR plants do not require expensive membranes and electrodes, which degrade quickly in the corrosive marine environment.

2. Heat is our plants' primary energy source, which is cheaper than electricity.

3. Our method does not generate hydrochloric acid that needs to be handled and does not require any external feed of minerals such as mine tailing, simplifying supply chains and scaling.

4. Our process does not rely on seawater conductivity and can be adapted to operate in brackish or fresh bodies of water such as lakes and rivers, enabling greater deployment flexibility.

These multiple advantages allow for numerous deployment strategies that can reach multi-gigaton CDR scale in aggregate. One of them is locating the CDR plants near offshore or coastal CCS hubs, significantly reducing CO_2 transportation costs. These locations correlate with cheap natural gas prices and are ideal for our CDR process.

Another synergetic deployment strategy is repurposing abandoned offshore oil and gas (O&G) platforms, which can by itself exceed a gigaton CO_2/year CDR. There are over 10000 thousand offshore O&G drilling platforms worldwide. When these platforms' O&G fields become depleted, the platforms should undergo expensive decommissioning. In the Gulf of Mexico, for example, there are about 3000 abandoned offshore platforms awaiting decommissioning. Carbon Blue's technology provides a profitable alternative - conversion to CDR facilities capable of removing hundreds of kilotons of CO_2/year. In addition to the financial benefits for O&G companies, retrofitting offshore platforms has numerous advantages for CDR:

1. These offshore platforms connect to depleted O&G reservoirs that can store the removed CO_2 permanently and cost-effectively.

2. In many cases, pipes, previously used to transport the produced fossil fuels, connect the offshore platforms to the land. These pipes can transport natural gas to the platform and provide energy for the CDR.

3. Repurposing abandoned platforms significantly reduces construction costs and improves CDR economics.

Most importantly, since there are more than 10000 offshore platforms, and each can support CDR at a scale of hundreds of kilotons CO_2/year, the aggregate scale of CDR that existing platforms can support reaches multi-gigatons of CO_2/year. This type of offshore deployment is in addition to the vast potential of coastal CDR plants implementing Carbon Blue's technology.

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.

The TRL of our proposed technology is 4, as determined by the component of the plant that is the least technologically ready, the precipitation reactor. Except for the three main reactors of our proposed CDR plant: precipitation reactor, CFB calciner, and steam slaker, all the equipment is commercially available so that it does not limit the TRL of the process.

Furthermore, although not prevalent in the chemical industry, numerous pilot-scale plants of different processes include CFB calciners and steam slakers. Public reports, including ones by Carbon Engineering (Keith et al., Joule 2018), present performance data of CFB calciners and steam slakers, so they do not present significant uncertainties, and their high TRL is high (6-7).

In contrast, a reactor that precipitates $CaCO_3$ from seawater does not exist. Therefore, the precipitation reaction is the TRL-determining component of our process. However, we have verified the validity of the scientific principles that underlie the function of the precipitation reactor in a lab, which makes it a TRL 4. We present these experiments and their results below. In addition, we are currently executing more advanced experiments that investigate the precipitation dynamics in a prototype reactor.

We used Mediterranean seawater in our experiments to account for the seawater's natural $CaCO_3$ precipitation inhibitors. We mixed the seawater with saturated $Ca(OH)_2$ solution to prepare seawater solutions whose final $Ca(OH)_2$ concentrations are 0.5, 1, and 1.5 millimolar. We measured the pH and DIC concentrations of the three solutions (all continuously stirred) and a control without $Ca(OH)_2$ after 1, 2, 4, 8, 24, and 48 hours. After an hour, the DIC concentrations of the three solutions, but not of the control, decreased. The DIC reduction in the 0.5 mM $Ca(OH)_2$ solution (from an initial value of 2.3 mM) was ~64%, while in the 1 and 1.5 mM $Ca(OH)_2$ solutions, the reduction was 90%. The pH of the solutions (initially 8.3) increased to 8.8, ~9.6, and ~9.6 in the 0.5, 1, and 1.5 mM solutions, respectively. These results are consistent with phreeqc simulations, which imply that the similarity between the 1 and 1.5 mM solutions arises due to the effect of $Mg(OH)_2$ precipitation.

After two hours, the pH of the 0.5 mM solution started to decrease, and its DIC concomitantly increased, likely due to the reabsorption of atmospheric CO_2. A similar change in the one mM solution began only after 4 hours, probably due to the formation of $Mg(OH)_2$ crystals. These crystals dissolve as CO_2 is reabsorbed and release hydroxide ions that buffer pH changes. Similarly, precipitation of additional $CaCO_3$ due to the addition of carbonate ions (from reabsorbed CO_2) buffer changes in DIC concentration. Therefore, the DIC increase and pH reduction starts only after all the previously formed $Mg(OH)_2$ is dissolved. The 1.5 mM solutions did not show any DIC or pH changes during the experiment, probably due to the initial formation of a large amount of $Mg(OH)_2$. The results of this experiment validate the potential of DIC removal by adding $Ca(OH)_2$, thus rendering our technology TRL 4.

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?**
Electricity consumption/tonne CO_2	0.36MWh(e)/tonne CO_2	0.25MWh(e)/tonne CO_2	Scaling efficiency improvements of equipment and improved schemes for heat recovery from the slaker and calciner
Seawater DIC precipitation rate	<30 min for 50% precipitation	2 min for 50% precipitation	Mineralization processes using similar technology achieve such precipitation rates.
CDR plant land area	$200m^2$/ktonne/yr	$25m^2$/ktonne/yr	Scaling efficiency improvements and increased flow velocity can increase the precipitation rate in the reactor. Reactor stacking can reduce the required land area.

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?

We are a team of dedicated people with diverse backgrounds and complementary expertise. The key members of the team are:

1. Iddo Tsur, co-founder and CEO. Iddo holds a BSc in physics from the Hebrew University and is a graduate of the Talpiot Program, Israel's top program for training military officers for R&D leadership positions. Iddo has a decade of management experience in multimillion-dollar interdisciplinary R&D projects.
2. Dr. Dan Deviri, co-founder and CTO. Dan holds three Bsc degrees, two in chemistry and physics from the Technion, one in molecular biology from The Open University of Israel, and a Ph.D. in theoretical physics from the Weizmann Institute of Science, all with the highest honors. Dan has a proven track record in research and problem-solving, has published multiple high-impact scientific papers, and won international research awards.
3. Dan Peled, VP of Engineering. Dan holds a Bsc in environmental engineering from the Technion and has more than a decade of experience as a water engineer. In his previous role, Dan Peled was the CTO of Rotec, a desalination company specializing in desalination projects with high recovery rates, where he led the construction of numerous desalination plants around the globe.
4. Dr. Josh Steinberg, Head of Carbon Management and MRV. Josh holds a Ph.D. in geology from the Hebrew University and served as the Chief Scientist of the O&G company Ratio Energies, being involved in all stages of multi-billion dollar O&G projects, along with supervising geothermal energy, CCS, and carbon management ventures.

Our team, together with partnering organizations, covers all the skills required to execute the project.

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**
Royal Haskoning DHV	Precipitation reactor scale up consulting	Confirmed project partner
Israel Oceanographic and Limnological Research	Examining the ecological impact of Carbon Blue's process on the marine environment	Discussing potential collaboration
Geo-sequestration company	Permanently storing the removed CO_2 in geological formations	Yet to be approached

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

Beginning of construction by mid-2023, commissioning and operation by mid-2024, and permanent removal of the proposed amount by the beginning of 2025. We don't expect decommissioning in the near future.

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.

CDR will start in Q3 2024.

CDR occurs uniformly over the lifetime of a plant, per plant capacity.

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	0
2024	300
2025	647
2026	647
2027	647
2028	100000 (commissioning of large scale project)
2029	100000
2030	600000 (commissioning of commercial scale project)

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	Continuous operation of the prototype precipitation reactor	Q4 2022
2	Full design and purchase agreements for CDR plant components	Q2 2023
3	Permits for construction of CDR plant	Q3 2023
4	Continuously operating CDR plant	Q3 2024

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

We submitted a provisional patent application for the entire CDR process. By March 2023, we will apply for a patent based on the results obtained from experiments with the prototype precipitation reactor. In addition, we will develop unique know-how and, as R&D continues, apply for additional patents whenever applicable.

k. How are you going to finance this project?

Equity fundraising, governmental and private-sector grants, pre-purchase agreements

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.).

We do not have any other CDR buyers. We will look for additional buyers in the future.

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.

We do not expect any other revenue streams from the project.

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
Technical: Seawater handling risks (Biofouling, contaminations, etc.)	Collecting data from experiments using real seawater. The R&D team continuously tests the precipitation reactor on seawater and collects data to identify and mitigate the risks.
Technical: Precipitation reactor rapid scale-up	Carbon Blue collaborates with RHDHV for technical support and design consultancy regarding the scale-up of the precipitation reactor. RHDHV has decades of experience in numerous projects that use precipitation reactors as part of their process.
Environmental risks: Marine ecology	The company promotes collaboration with an oceanographic research institute (most likely Israel Oceanographic and Limnological Research) to investigate the effect of our CDR process on marine ecology.
Project execution: Site and permits for the construction of the CDR plant	Carbon Blue promotes collaboration with industries that already use seawater to save time and minimize required permits.

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?

Geological sequestration provides durability that exceeds 1000 years (with no upper limit) and is considered the most permanent of storage options for carbon dioxide..

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 primary risks associated with durability are integrity of both the wellbores and the geological reservoir and overlying caprock. Assessing leakage potential, along with stringent monitoring and mitigation procedures from both, is standard practice for CCS and has been practiced for decades. To the best of our knowledge there have been no reported leaks from geological storage reservoirs.

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	6470 tonnes (647 tonnes/year for 10 years)
Describe how you calculated that value	The Capacity of our CDR plant would be a function of the seawater supply, the calcium carbonate precipitation rate in the reactors, and the calcination throughput. The number above is based on a conservative estimate of the capacity of two large-scale (3.2m diameter) precipitation reactors, with seawater supply of 1800 cubic meters per hour. This capacity is based on our planned scale for this project. The calciner is designed to fit the calcium carbonate throughput.

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.

To date, we've captured single grams of CO_2 as part of our experiments, which are stored in the form of calcium carbonate (without calcination). The prototype reactor we are currently developing has a capacity of one tonne of CO_2 per year.

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.

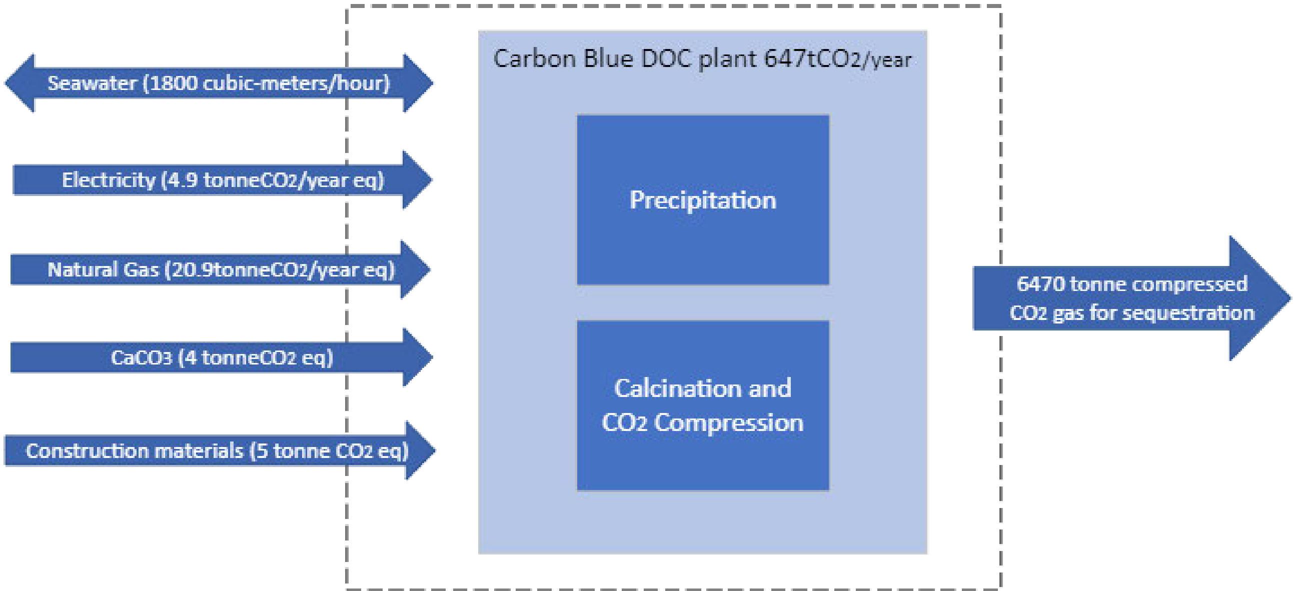
N/A

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)*	267
Emissions / removal ratio *(gross project emissions / gross CDR–must be less than one for net-negative CDR systems)*	0.041
Net CDR over the project timeline *(gross CDR - gross project emissions)*	6203

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.



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?

In the cradle-to-grave system boundaries, we account for the embedded emissions in raw materials and utilities needed for the construction and operation of the plant. We included emissions due to energy required for CO_2 compression and excluded other emissions associated with transport and sequestration, which are negligible compared to those generated due to compression. Since our CDR process is devoid of feedstock (apart from energy and seawater) or byproducts, the LCA boundaries are simple.

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.**
Electricity	49 tonne	Based on modeled mass & energy balance and solar power emissions of 21 kg CO2eq/MWh. Taken from Pehl et al., Nature Energy 2017 (https://www.nature.com/articles/s41560-017-0032-9)
Natural gas (scope 3)	209 tonne	Based on modeled mass & energy balance and scope 3 emissions of methane in the US: 22kg/GJ. Taken from IEA Methane Tracker 2022 Report https://www.iea.org/reports/global-methane-tracker-20

		22/overview GWP of Methane used to calculate CO2-eq: 28 (Source: https://www.epa.gov/ghgemissions/understanding-global-warming-potentials)
CaCO3 initial supply	4 tonne	Required for the operation of the precipitation reactor. CaCO3 GWP used: 22kgCO2eq/tonneCaCO3. Source: https://cdn.ymaws.com/www.ima-na.org/resource/dynamic/blogs/20171019_170108_21129.pdf
Construction materials	5 tonne	Based on the "Plant construction" section in Climeworks' LCA paper . Emissions calculated based on relative facility size.
(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.

> The approach presented here requires MRV methodologies to be applied in two main disciplines. First, the CO_2 will be geologically stored, a process that has well established monitoring and measuring procedures adopted from the oil and gas industry along with recent protocols published by voluntary markets (link). Second, direct ocean capture directly removes CO_2 from seawater (measurable, similar to DAC). This in turn requires that the ocean will absorb the same amount from the air as was extracted from the seawater (known as the sea-air carbon flux), and is determined by the difference in the partial pressure of CO_2 (pCO_2) in seawater and in the overlying atmosphere, and dependent on various measurable parameters such as solubility, temperature, and salinity. The governing equations behind ocean absorption are well understood and we are currently in the process of numerically modeling and establishing the MRV protocol.

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.)*

> Quantification of the amount of carbon removed from seawater will be directly measured (similar to the measured output of a DAC system). The amount of carbon that will be injected into the geological subsurface for permanent storage will also be measured and monitored (post-injection) to ensure that

the carbon is permanently sequestered. The science behind ocean absorption of atmospheric carbon is understood and we are currently modeling this process with the intent of verifying the mechanism and designing a verified monitoring protocol.

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 Include each component from the Quantification Tool relevant to your project	**Discuss the uncertainty impact related to your project** Estimate the impact of this component as a percentage of net CDR. Include assumptions and scientific references if possible.
Storage	There is little uncertainty (negligible) around this parameter as both the amount of carbon outputted from the DOC system and the amount inputted into the geological subsurface are measurable. Subsurface characterization techniques utilized for decades in hydrocarbon production are quite advanced and continuously monitor the system.
Leakage	Fugitive emissions throughout the injection process are minimal (negligible). Uncertainty in regards to storage leakage is addressed under "Storage monitoring and maintenance"
Materials	Aside from a negligible amount of initial supply of calcium carbonate, no feedstock is needed for the process.
Air-sea gas exchange	While there is little uncertainty in regards to the amount of CO_2 that is removed directly from the ocean there remains moderate (10%) uncertainty in regards to the amount of CO_2 that the ocean will in turn reabsorb from the atmosphere. While scientific understanding and initial modeling suggest that this should be a 1:1 ratio, we are adopting an uncertainty to reflect the early stage of this technology.

Energy	The amount of methane emissions from NG production varies across different countries and production facilities. In our LCA we took a conservative estimation of GHG emissions of NG production and transportation.
Storage monitoring and maintenance	Geological storage of CO_2 will require ongoing monitoring and maintenance. The facilities described in this application will only partner with a geological sequestration operator that has received all regulatory approvals and has a proven track record in subsurface characterization and engineering.

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?

> The only major uncertainty is the air-sea gas exchange, therefore we think a 10% discount should be taken.

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.?

> Most definitely. The process defined here is “first of a kind” and will establish MRV protocols for sea-air carbon flux methodology and the vast potential that we recognize in direct ocean capture.

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)?

> As the direct ocean capture technologies are not abundant or well published, the methodology and protocol are being developed internally along with a team of subject matter experts, mainly for academia (e.g., physical oceanographer, marine geochemist, carbonate/alkalinity expert, subsurface geophysicist, etc.). We intend to collaborate with third parties (e.g., Ocean Visions) to establish DOC MRV protocols that can be verified by third-party auditors and comply with voluntary markets.

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).

\$941/tonne CO_2 , including uncertainty discount

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

Component	**Levelized price of net CDR for this project (\$/tonne)**
Capex	448
Opex (excluding measurement)	465
Quantification of net removal (field measurements, modeling, etc.)[2]	12
Third party verification and registry fees (if applicable)	16
Total	941

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?**
Electricity consumption/tonne CO_2	0.36MWh(e)/tonne CO_2	0.25MWh(e)/tonne CO_2	Scaling efficiency improvements of equipment and improved schemes for heat recovery from the slaker and calciner
Seawater carbonates precipitation rate	<30 min for 50% precipitation	2 min for 50% precipitation	Mineralization processes using similar technology achieve such precipitation rates
Seawater filtration needed for the process	10um	100um	Reactor Robustness to contaminations and biological matter
Precipitation reactor maintenance	N/A	<\$500000/year	Reactor durability to corrosion and biofouling

[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.

Electricity price	$100/MWh	$30/MWh	Projected utility scale PV and wind energy prices

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

> The precipitation reactor has the most engineering and operational risks since it is the first time such a reactor is used for limestone precipitation from seawater. Therefore we are least confident in its construction and maintenance costs. The rest of our cost analysis is based on previously published data and peer-reviewed literature, so we are more confident in it.

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 NOAK CDR cost calculated in the TEA is slightly higher than our models. Most of the components of our process have a higher TRL, which allows us to reduce the process contingencies rates.
>
> There is a significant difference between "This project" cost estimation and our model, probably because of a different capital recovery factor taken, due to the finance model (primarily equity financing) of the project.

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.)

> Consensus MRV protocols for Direct Ocean Capture.

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.

We have identified several external stakeholders. These include local communities, government agencies (i.e., environmental, energy, innovation), research institutes (academia, Geological Survey, Ocean Research), environmental organizations, industries that are located offshore or along the coast, and corporations and businesses that wish to achieve climate and sustainability pledges by purchasing carbon offsets. Although it is early to form a concrete public engagement plan, we intend to follow the guidelines used in a previous CCS project (Jenkins et al., PNAS 2019). We will engage non-public stakeholders using the business-development function of the company.

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.*

Discussions have been ongoing with many of the entities listed above by Carbon Blue founders. After identifying the stakeholders, we used our professional network to engage with representatives of the relevant stakeholders successfully.

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 have been productive and helpful in designing our prototype and in the considerations needed when developing larger-scale projects and their associated timelines. One of the considerations is the need to pump seawater at a significant distance from the coast (using long pipes or at offshore facilities) to prevent damage to coastal ecology. Another is the need to limit the percentage of DIC removal to avoid excess pH increase that is detrimental to the environment.
In addition, we design experiments to analyze any potential impact of decarbonated seawater on the marine ecosystem and coral reefs.

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 view community benefit, understanding, and support as the driving force for our technology. We wish to continuously engage with global stakeholders and further promote the benefits of CDR and permanent storage. In addition, we envision continuous public outreach to local communities via newsletters and local media platforms for each of the future plants. Using these platforms, we will openly share information with the public (e.g., monitoring, CDR, environmental impact) and prompt response through open lines of communication.

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.

> Since most of our plants will be located offshore in the long term, and supply chains are minimal, there are no conflicts with local communities, marginalized or otherwise, arising from the construction of the plants. Nonetheless, the operation of the plants will have local, indirect effects on communities, which are positive. First, the plants will generate high-paying jobs that can support marginalized communities near the plants, wherever they will be. Notably, the plants will operate at the highest safety standards, which will be effective during construction and operation. Second, since our DOC process reduces the acidity of the seawater, we expect it to have a restorative effect on marine ecosystems since ocean acidification is a significant stress factor in many such ecological systems. Therefore, the restorative environmental impact of our CDR plants may benefit adjacent communities whose livelihood depends on marine ecosystems (e.g., due to fishing or eco-tourism).
>
> One point of possible concern is related to the geo-sequestration of removed CO_2, which may be on land, depending on the project. We will adhere to geo-sequestration regulations and provide local communities with complete and transparent monitoring data.

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

> Although we do not anticipate any environmental justice concerns, we plan to identify and address any concerns that will arise due to the CDR plant by forming a direct line of communication with marginalized communities in the vicinity of the plant. We will preemptively create this line of communication before any issue arises and use it to update and interact with local communities regularly. If any concern arises, we will deal with it in cooperation and consultation with the local communities. As a model for such communication, we will adopt a mechanism that proved effective in a previous CCS project in Australia (Jenkins et al., PNAS 2019).
>
> In addition to handling concerns that may arise, we will take advantage of opportunities to do good by maximizing our positive impact on the environment. Before constructing a plant, we will conduct lab research on the effect of the effluent water of the precipitation reactor on marine ecosystems grown in aquariums, representing the plant's location. We will make sure to consider the potential beneficial impact of different operation parameters on the environment when choosing the operating parameters of the plant. The positive impact of our plants on marine ecological systems is our opportunity to bring environmental justice to marginalized groups that depend on those ecological systems (e.g., via fishing or tourism).

[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

Last but not least, whenever possible, we will hire people from marginalized communities near our plants as employees, thus allowing these communities to share the prosperity generated by the CDR project, representing another opportunity for environmental justice we plan to pursue.

8. Legal and Regulatory Compliance

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

Carbon Blue is accompanied by one of the top law firms in Israel, specializing in environmental law and regulatory affairs. It is their opinion that our technology is quite similar to the regulation surrounding desalination plants and power plants that use seawater for cooling.
Some of these plants must pump their seawater from a considerable distance from the shore to prevent damage to coastal ecosystems. In our cost calculations, we considered the cost of pumping seawater at a distance of 1km from shore.

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.

Pumping and discharge of seawater back to the ocean require permits in every project stage. For our research, we use the permits of the experimentation site that we lease. We plan to apply for these permits for our pilot plant as soon as possible. Also, plant construction requires a permit which we will apply for in the next few months.
In addition, geo-sequestration of CO_2 requires a permit to do so. We have not applied for such a permit yet but intend to collaborate with operating geo-sequestration providers that will already possess the required permits.

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?

To the best of our understanding, our proposed solution complies with international law (London and Barcelona protocols), and all permits will be obtained prior to deployment, subject to the host country regulation.

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.

Regulation regarding seawater pumping and discharge varies between different countries and states. As mentioned, we recognize that the regulatory framework is similar to desalination plants and power plants that use seawater for cooling.

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.

We do not intend to receive any tax credits during the proposed delivery window for Frontier's purchase.

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))*	300 tonne
Delivery window *(at what point should Frontier consider your contract complete? Should match 1(f))*	Q3 2024 - Q1 2025
Levelized Price ($/metric tonne CO_2) *(This is the price per tonne of your offer to us for the tonnage described above)*	941

Frontier

Application Supplement: DAC

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

Note: these questions are with regards only to air capture: e.g. your air contactors, sorbents or solvents, etc. Separately, there exist Geologic Injection and CO_2 Utilization supplements. We anticipate that most companies filling out this DAC supplement should ALSO fill out one of those supplements to describe their use of the CO_2 stream that's an output of the capture system detailed here.

Physical Footprint

1. What is the physical land footprint of this project, and how do you anticipate this will change over the next few years? This should include your entire physical footprint, i.e., how much land is not available for other use because your project exists. Also, what is the estimated footprint if this approach was removing 100 million tons of CO_2 per year?

Land footprint of this project (km^2)	0.0002
Land footprint of this tech if scaled to 100 million tons of CO_2 removed per year (km^2)	2.5

Capture Materials and Processes

1. What material(s) is/are you using to remove CO_2?

We don't use any external materials for the process except an initial supply of calcium carbonate (which is regenerated throughout the process).

2. How do you source your material(s)? Discuss how this sourcing strategy might change as your solution scales. Note any externalities associated with the sourcing or manufacture of it (e.g., hazardous wastes, mining, etc.). You should have already included the associated carbon intensities in your LCA in Section 3.

Since we need only an initial and limited supply of calcium carbonate for the process, we consider it as any other construction material.

3. How much energy is required for your process to remove 1 net tonne of CO_2 right now (in GJ/tonne)? Break that down into thermal and electrical energy, if applicable. What energy intensity are you assuming for your NOAK TEA?

Current energy required: 5.25GJ(th) + 1.3GJ(e).

Assumed energy intensity for NOAK TEA: 5.25GJ(th) + 0.8GJ(e). Notably, we consider a design that can reduce thermal energy intensity to 4.5GJ(th) per tonne of CO_2. However, here we used a conservative assumption when estimating this energy.

4. What is your proposed source of energy for this project? What is its assumed carbon intensity? How will this change over the duration of your project? (You should have already included the associated carbon intensities in your LCA in Section 3).

Our proposed energy sources for this project are natural gas and electricity from a low-carbon grid.

The natural gas carbon intensity is assumed to be 6.16kgCO_2eq/GJ. This carbon intensity represents scope 3 emissions only since the CO_2 generated by the oxy-combustion of the natural gas is captured and sequestered inherently in the process.

The electricity carbon intensity is assumed to be 0.021kgCO_2eq/kWh.

5. Besides energy, what other resources do you require (if any, such as water)? Where and how are you sourcing these resources, and what happens to them after they pass through your system? (You should have already included the associated carbon intensities in your LCA in Section 3).

We require seawater for our process with a volume of ~20000m^3/tonneCO_2 After the seawater passes through our system, it is returned to the ocean with a slight increase in pH, and after some time, it reabsorbs carbon dioxide from the atmosphere.

6. Do you have experimental data describing how your system's CDR performance changes over time? If so, please include that data here and specify whether it's based on the number of cycles or calendar life.

N/A

7. What happens to your capture medium at end-of-life? Please note if it is hazardous or requires some special disposal, and how you ensure end-of-life safety.

Our capture medium contains only lime and limestone. No special disposal is needed. Most of the materials can be recycled.

8. Several direct air technologies are currently being deployed around the world. Why does your DAC technology have a better chance to scale and reach low cost than the state of the art?

Direct Ocean Capture uses the ocean as a natural "air contactor", thus significantly reducing the land area and CAPEX required for CDR.

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.

Possible locations for deployment of the proposed CDR plants include offshore platforms and coastal sites. In both cases, co-location with other facilities (e.g., abandoned offshore O&G platforms or seawater-cooled coastal power plants) can minimize the additional impact on the surroundings. Due to the requirement of natural gas to power the CDR plant and suitable locations for geo-sequestration, a preferable (but not exclusive) deployment geography include global O&G "hotspots" such as the Gulf of Mexico, North Sea, Persian Gulf, and the Gulf of Guinea.

Regarding interactions with human or animal activity, the physical footprint is small, so our plants' primary local effect will be due to the large volume of water pumped into the precipitation reactor. Such pumping can disturb local flow patterns, impacting human or animal activity. For humans, the most significant impact is the creation of no-swimming zones next to the suction pipes entry; no effect on shipping is expected. Similarly, seawater suction can harm animals. We will minimize these disturbances by pumping water away from shore (~a kilometer), where human and animal activity is less significant, and using coarse nets to block the entry of macroscopic animals into the pipes.

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.

Because the DIC concentration of seawater is relatively low, the volume of the precipitation reactors must be significant to enable DOC from a sufficient volume of water. In contrast, the calciners and slakers, which process solid minerals, are much smaller. Therefore, the number and size of precipitation reactors dictate the dimensions of the entire CDR plant.

Based on consultation with the engineering firm RHDHV, we estimate that for a 0.5 megaton CO_2/year, about 12500 m^2 of precipitation reactors of height 3.5 meters are needed. These reactors can be stacked upon each other. For example, if we consider four levels of precipitation reactors, their total surface area is 3125 m^2, with a height of 14 meters.

In addition, pipelines for pumping the water to and from the plant will effectively increase the spread of the plant. We will determine the length and orientation of these pipes for each plant based on ecological considerations. In general, if oriented correctly (influent/effluent pipes located upstream/downstream with ocean currents), horizontal pipes have a minor effect on currents. In contrast, vertical influent pipes lead to upwelling (since effluent water is always returned to the ocean's upper layer).

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.

Since the reactors used in our CDR plant are modular, the surface area of such a massive plant will be 200 times that of 0.5Mt of CO_2/year.

In contrast to a 0.5Mt plant, the extremely-large throughput of seawater needed to be pumped into the plant and returned to the ocean may impact ocean currents. There are two scenarios to consider. The first is that the plant is where ocean currents are not significant. In that case, the pumping activity of the plant can induce ocean streams directed into the influent pipes and away from the effluent pipes.

The second scenario is that the plant is amidst a significant ocean stream (e.g., the Gulf Stream). In that case, the water carried by the stream is sufficient for the requirement of the plant, so by positioning the influent and effluent pipes upstream and downstream, respectively, the effect on ocean currents can be minor. For example, the Gulf stream carries a water throughput of 480 billion m^3/hour (Introduction to Oceanography by Paul Webb), which theoretically can support CDR at a scale of ~200 Gt CO_2/year without interruption to ocean currents.

Finally, similar to the 0.5Mt plant, vertical feed pipes will cause upwelling.

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?

Two main engineering challenges are associated with deploying our CDR plants. The first is providing the seawater throughput that contains sufficient DIC to support the CDR capacity of the plant. The second, which is relevant for offshore plants, is the construction of large floating structures that can sustain the waves' large mechanical forces and the seawater's harsh chemical environment. These engineering challenges have precedents and were solved in other industrial contexts.

Cooling thermo-electric power plants require pumping large volumes of water. In such plants, residual heat needs to be removed, and the "once-through" method of cooling does that by providing large amounts of water of the same order of magnitude or even more significant than the ones we require for our CDR plants. In such cases, extremely wide pipes (meters in diameter) and large pumps transport the water.

The O&G sector solved the challenge of constructing large floating structures offshore, most notably many offshore platforms for drilling. Many of them are thousands of m^2 large, which may be sufficient for a 0.5Mt CO^2/year CDR plant or even plants of larger capacity.

Externalities and Ecosystem Impacts

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

As explained before, we expected the overall impact of our approach to marine ecosystems to be positive because the effluent, treated seawater that we return to sea is less acidic than the influent one. Since ocean acidification is one of the main stress factors of marine ecosystems, our approach can alleviate that. Moreover, our process does not include the addition of any extrinsic minerals to the seawater, which can change the chemical composition of the seawater and endanger ecosystems.

However, two potential negative impacts remain that must be considered. The first is that the pH of the effluent seawater will become too high due to the removal of CO_2 and will locally stress organisms in the vicinity of the effluent pipe. The second potential negative impact is due suction of living organisms together with the influent seawater into the precipitation reactor, which may damage these organisms. Carbon Blue has a well-formed plan to mitigate those two possible adverse impacts, which we detail below.

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?

As explained above, the only chemical change that may have an adverse ecological effect is increased pH. We will mitigate that risk by regulating the removed DIC percentage and, consequently, the pH increase. Carbon Blue is promoting joint research with the Israel Oceanographic and Limnological Research center to assess this ecological risk. The research will focus on the effect of effluent water from the precipitation reactor on representative marine ecosystems in aquariums. We will infer the optimal DIC removal percentage (determining the effluent pH) to benefit ecosystems. In all the calculations and estimations presented in this proposal, we assumed 50% DIC removal, which limits the effluent pH by 9.5.

We will mitigate the second ecological risk mentioned above by using coarse filters that prevent the entry of macroscopic organisms into the influent pipes. We expect (and will validate experimentally) that smaller organisms (e.g., plankton) will survive the passage through the reactor since the pH there is not too high (<9.5) and the residence time is short.

In any case, we will monitor the effect of each plant on local marine ecosystems by partnering with local oceanographic research centers and following the best scientific practices of the time.

Application Supplement: Geologic Injection

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

Feedstock and Use Case

1. What are you injecting? Gas? Supercritical gas? An aqueous solution? What compounds other than C exist in your injected material?

   We intend on injecting compressed CO_2 into the subsurface, deep enough to maintain supercritical conditions.

2. Do you facilitate enhanced oil recovery (EOR), either in this project or elsewhere in your operations? If so, please briefly describe.

   We do not facilitate enhanced oil recovery.

Throughput and Monitoring

3. Describe the geologic setting to be used for your project. What is the trapping mechanism, and what infrastructure is required to facilitate carbon storage? How will you monitor that your durability matches what you described in Section 2 of the General Application?

   The captured CO_2 will be transported to a geological storage facility for permanent injection. Potential storage sites can be found globally and include both depleted oil and gas fields and saline aquifers (both carbonate and clastic). Trapping mechanisms at the first stage will be structural, as stratigraphic trapping mechanisms for CO_2 have yet to be tested. Baseline surveys, prior to injection, and ongoing monitoring (dedicated monitoring wells, both shallow and deep, along with 4D seismic surveys are becoming common practice) will be maintained by the storage operator.

4. For projects in the United States, for which UIC well class is a permit being sought (e.g. Class II, Class VI, etc.)?

   Not relevant

5. At what rate will you be injecting your feedstock?

   The injection rate will depend on the storage site and the various industrial synergies (for a CCS hub approach) and will be decided on a project basis. For an independent CDR and storage site injection, the injection rate will need to match the rate of removal and compression (so as not to fluctuate reservoir pressures).

Environmental Hazards

6. What are the potential environmental impacts associated with this injection project, what specific actions or innovations will you implement to mitigate those impacts? How will they be monitored moving forward?

> Potential impacts would be on freshwater aquifers located in the subsurface. Mitigation of this would be rigorous pre-injection geological mapping and modeling, ensuring that the sealing capacity of the aquitard that separates the storage reservoir and the overlying freshwater aquifer is sufficient. This is standard practice in both O&G and CCS.

7. What are the key uncertainties to using and scaling this injection method?

> The primary concern regarding geological sequestration is economics. The technology is well established, and drilling, injecting, and monitoring techniques have become more efficient. As geological storage is the safest and most permanent solution for atmospheric CO2, incentivizing its deployment (for non-EOR projects) will allow for a deeper and more efficient understanding of its potential and durability.