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 Dioxide Removal Purchase Application Fall 2022

General Application - Prepurchase

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

Company or organization name:

Ocean-based Climate Solutions, Inc.

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

Santa Fe, New Mexico, USA

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

Philip Kithil: [redacted]
Salvador Garcia: [redacted]
Dr. Ian Walsh: [redacted]

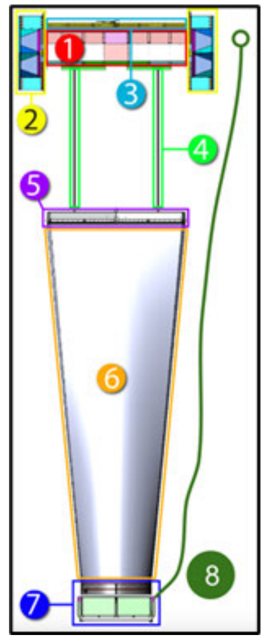
Brief company or organization description:

We produce, deploy, operate, and maintain our open ocean wave-powered upwelling pumps for marine carbon dioxide removal (mCDR) and ocean ecosystem restoration.

1. Project Overview

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.

Powered entirely by ocean waves, our upwelling pumps transport nutrient-rich deep ocean water to the sunlit surface to trigger phytoplankton growth. This process is known as "artificial upwelling." The 1.9m diameter by 500m depth pumps are spaced about one nautical mile apart and drift slowly with ambient currents in the open ocean hundreds of miles offshore.



Each Pump comprises a buoy and water outlet at 5m depth connected to the 500m flexible fabric tube, which is connected to a 1.2-tonne bottom-weight/ valve. During transport, the tube is "spooled" onto the buoy. When dropped off a ship, the bottom weight/valve sinks, unspooling the tube while priming it with seawater. When fully unspooled, the buoy rises and falls on passing waves, with this vertical force causing the one-way valve to close (wave upslope) and then open (wave downslope). The water inside the tube is elevated on each wave upslope, quickly achieving momentum and delivering a steady flow of nutrient-rich deep water to the sunlit upper ocean.

There are three main sections of the Pump (Top, Middle, & Bottom): Top: Buoy (1) with paddle wheels (2), electronic sensor compartment (3), and high-strength ropes (4). Middle: The outlet (5) and industrial-strength fabric tube (6). Bottom: Bottom-weight valve intake (7) and recovery line (8).

Once deployed, the Pump looks like this:

Analytical studies and modeling show the deep water quickly mixes and remains in the sunlit upper ocean (Kemper J, Riebesell U and Graf K (2022) Numerical Flow Modeling of Artificial Ocean Upwelling. Front. Mar. Sci. 8:804875. doi: 10.3389/fmars.2021.804875).

We're currently working with **The Ocean Researchers*** (see confidentiality addendum), a leader in Artificial Upwelling (AU) for mCDR, to test a full-scale Pump in the Canary Islands this November.

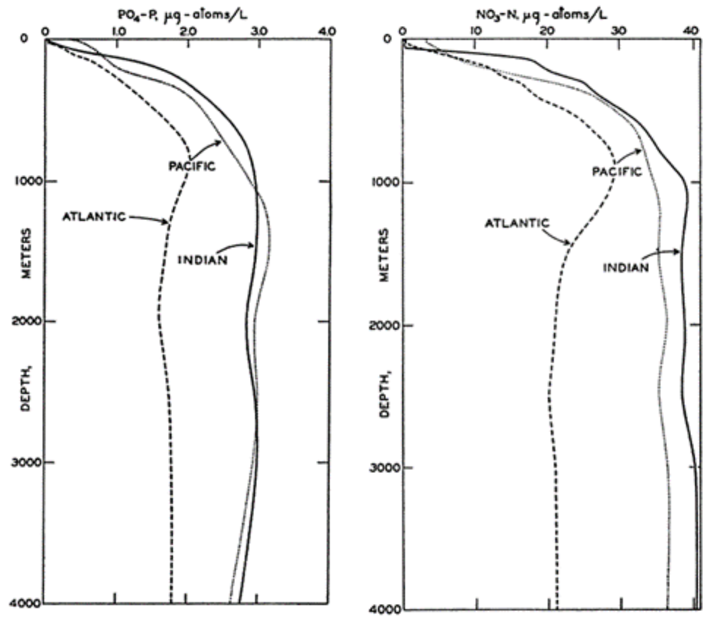
The overall objective of this test is to gain data on the mixing depths and advection rate of the upwelled water and the biological response from injecting nutrients in the sunlit upper ocean.

Onboard sensors include:

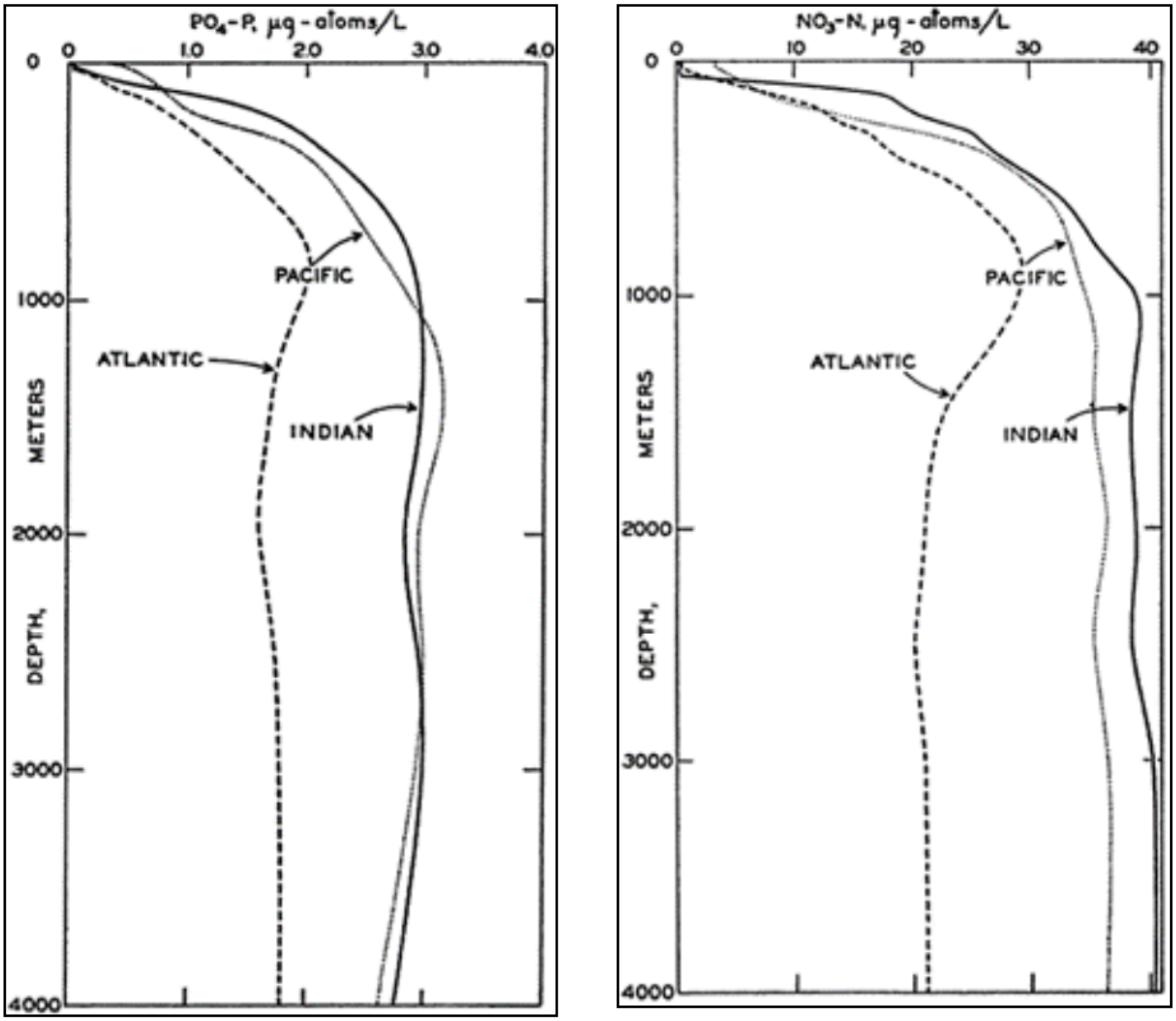
- GPS.
- Temperature (inside and outside the outlet).
- Strain gauges on the connecting ropes.
- Flow meters inside the outlet.
- Wave height/period as measured on the buoy.

All data is averaged over ten minutes, then uplinked via satellite throughout the trial, with the complete data set downloaded after we recover the Pump.

Among the assets provided by **The Ocean Researchers*** are **The Research Vessel*** and **The Sailing Yacht*** from **The Institute***. The **The Ocean Researchers*** science team includes (read names in confidentiality addendum). Our onsite team includes CEO Philip Kithil, Chief Engineer Philip Fullam, and COO Chris White, with remote participation from Dr. Ian Walsh and CRO Salvador Garcia. **(*View names in Confidentiality Addendum, throughout this document)**



These diagrams (below) provide nitrate and phosphate ratios according to depth in the Atlantic, Pacific, and Indian oceans regarding the global applicability of artificial upwelling.



The challenge with ocean upwelling is that along with nutrients, the dissolved inorganic carbon (DIC) concentration also has a regeneration profile, with low concentrations at the surface relatively monotonically increasing with depth, with the gradient controlled mainly by water mass.

To assess the biological response, we measure both the nutrients and the carbonate chemistry of the upwelled water to verify there is an 'excess' of nutrients relative to the DIC such that there is a net uptake and fixing of atmospheric CO2 into the particle pool via phytoplankton rather than simply shunting of upwelled CO2 as DIC into the fixed carbon pool. The presence of 'excess' nutrients, particularly phosphate, relative to DIC in the twilight zone is a steady-state result of nutrients having higher first-order remineralization rates than particulate organic carbon. It has been long established (Dymond and Lyle, 1985) that this dynamic drives the linkage of atmospheric CO2 to ocean upwelling on a global scale through geological time.

There are many ways to define the 'excess' relative nutrient load relative to the carbon load. Karl and Letelier (2008) used the phosphate concentration relative to nitrate and DIC to define a sequestration potential for a given depth profile (Table 1 seen below).

Table 1. Nutrient balance and net CO_2 sequestration potential for precision upwelled waters at Station ALOHA. DIC: dissolved inorganic carbon; r-P: residual phosphorus

Source Water (m)	Total nutrient concentration (μM) DIC	NO_3^-	PO_4^{3-}	Excess nutrient concentration[a] DIC (μM)	P (μM)	DIC:P (mol:mol)	Total P excess plus r-P (μM)	Total N_2 fixation[b] (μM)	Net C sequestered (mmol C m^{-3} upwelled)[c]
100	2046	0.06	0.062	22	0.058	371:1	0.111	5.6	15.2
120	2055	0.32	0.101	29	0.081	357:1	0.134	6.7	15.5
140	2070	0.79	0.137	41	0.088	465:1	0.141	7.0	5.8
160	2075	1.26	0.163	43	0.084	512:1	0.137	6.8	2.5
180	2082	1.98	0.215	45	0.091	492:1	0.144	7.2	2.9
200	2091	2.84	0.276	48	0.099	489:1	0.152	7.6	2.0
250	2100	5.58	0.461	39	0.112	348:1	0.165	8.3	15.7
300	2119	9.99	0.757	29	0.133	217:1	0.186	9.3	32.7
350	2146	14.22	1.044	28	0.155	179:1	0.208	10.4	41.2
400	2173	18.82	1.361	24	0.185	132:1	0.238	11.9	54.5
450	2164	23.35	1.667	−15	0.208	−71:1	0.261	13.0	101.1
500	2199	28.00	2.033	−11	0.283	−37:1	0.336	16.8	121.8
750	2313	40.90	2.985	18	0.429	42	0.482	24.1	141.5
1000	2337	41.58	3.006	38	0.407	92	0.460	23.0	114.9

[a]Excess nutrient is defined as concentration of DIC and r-P at the target depth that would remain in the surface if all the upwelled NO_3^- is removed during the hypothesized Stage-I bloom with Redfield stoichiometry (C_{106}:N_{16}:P_1) after correcting for the average nutrient concentration that is observed in the upper 25 m at Station ALOHA between 1989 and 2005 (DIC = 2024 μM, r-P = 0.053 μM). For example, excess DIC at 300 m is: (2119 μM – 2024 μM) – (9.99 × [106 ÷ 16]) = 29 μM
[b]Total N_2 fixed = total P × (N:P ratio); assumes a molar N:P ratio of 50 (White et al. 2006)
[c]Net C sequestered = total P × (C:P ratio) – excess DIC for that depth; assumes a molar C:P ratio of 331 (White et al. 2006)

The attraction for using this method is that the ocean's temporal and spatial variability of dissolved constituents decreases with depth. Particularly in the central gyres, a relative sparsity of data still yields volumetric/depth/time relationships that are reasonably stable. Hence, the initial conditions of the setting of a particular pump deployment in a central gyre can be reasonably assumed to be the conditions over annual time scales.

The task then is to gauge the actually delivered seawater. For that, we can use a mixing model over the volume addition:

$\text{Temperature}_{z,plume} = A * \text{Temperature}_{z,ambient} + D * \text{Temperature}_{intake}$

$PO_{4ex\ plume} = A * PO_{4z,ambient} + D * PO_{4intake}$

And

A + D = 1

Since for the oligotrophic ocean, we can assume that the available dissolved nutrient concentration in the mixed layer is low and constant, i.e.:

$PO_{4ML,ambient} = 0$

Where z here is replaced by the mixed layer depth.

Suppose we assume that the upwelled volume is dispersed into the plume and that the plume is entirely within the mixed layer. The mixed layer is equal to or less than the euphotic depth. In that case, we can presume that all upwelled water that enters the intake is dispersed within the mixed layer and is taken up over time into the biological system.

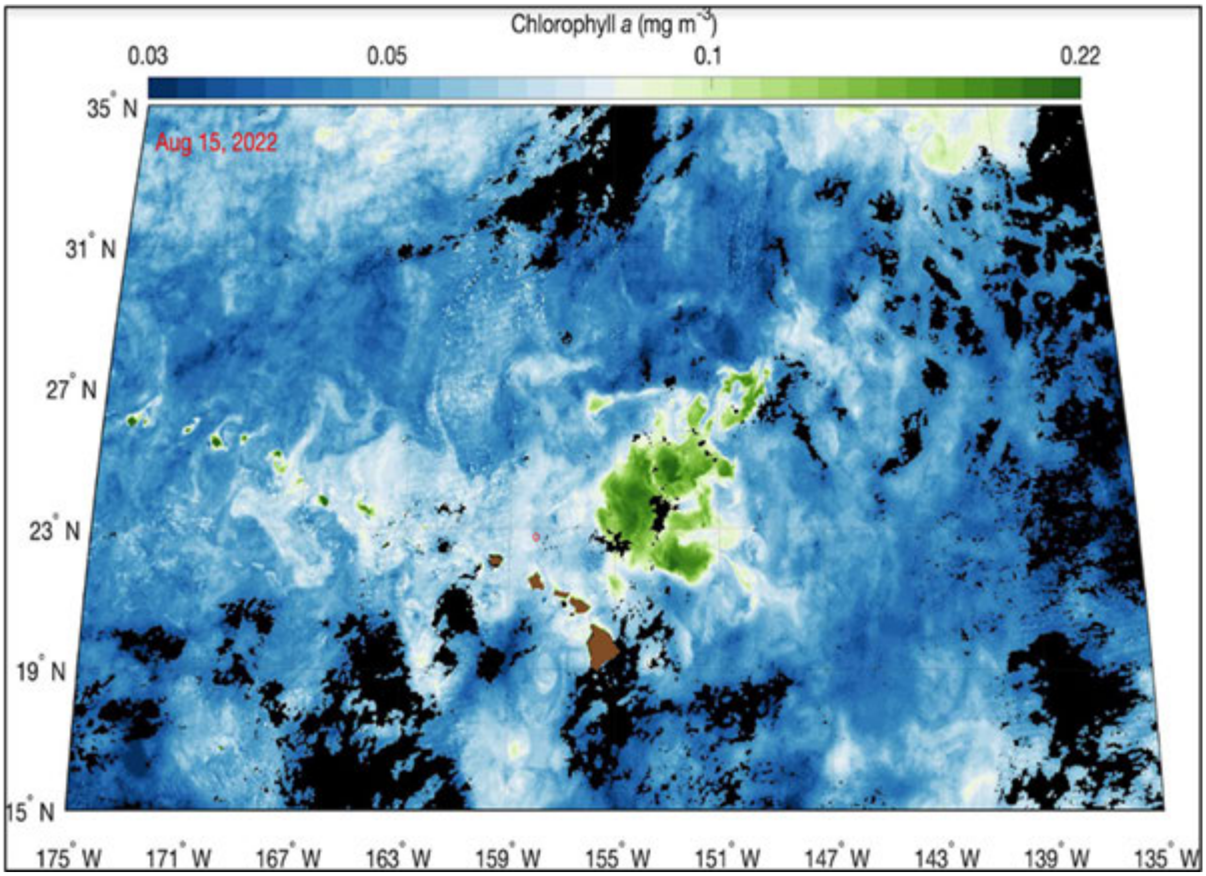
Since we know that the ambient excess phosphate is low and effectively constant, the additional phosphate added to the system will devolve to background, which will occur on the order of days. Hence, the most straightforward measurement of the net sequestration effect of a given artificial upwelling pump can be based on the temperature and nutrient load relationship at the intake depth range and the measured temperature anomaly at the surface.

If our November sea trial with **The Ocean Researchers*** can correlate flow rate at the outlet with wave height/period, in future pump versions, we may be able to determine the upwelled nutrients just from knowing the source water profiles, pump GPS coordinates, and the buoy-mounted wave sensor – saving cost and increasing pump lifetime by eliminating subsea electronics/sensors.

Karl-Letelier (2008) established that excess nutrients, especially phosphate, are found throughout the ocean deserts (e.g., North Pacific Subtropical Gyre, NPSG), which support additional blooms of phytoplankton that draw down more CO2 than is artificially upwelled. The flux of biological matter supports the entire water column ecology, with some of the dissolved organic carbon sinking to the seafloor, where it is isolated from the atmosphere for 1000 or more years.

To minimize potential negative environmental impacts, we propose one Pump per square mile as its estimated annual upwelling volume of 45 million cubic meters represents about a 10% mixing ratio – safely above the 6% needed to spur a biological response (personal communication with Ulf Riebesell) but well under natural analogs of environmental harm from excess nutrients, such as found from the Mississippi River outflow into the Gulf of Mexico causing eutrophication and dead zones (e.g., Nutrients in the Upper Mississippi River: Scientific Information to Support Management Decisions (usgs.gov).

Pumps are designed to operate on a large scale. This satellite image below shows a natural phytoplankton bloom near Hawaii in August 2022 (courtesy Prof. Dave Karl, University of Hawaii-Manoa), covering an area roughly 5 degrees in latitude by 4 degrees longitude, or ~ 75,000 square nautical miles. Based on nutrient profiles in this part of the Pacific from Table 1 in the Karl & Letelier paper, we estimate one Pump can sequester about 250 tonnes of CO2 per year. If our pumps were deployed at one square mile (roughly equal to the natural bloom area seen below), the estimated annual net export would be about 18.7 million tons.

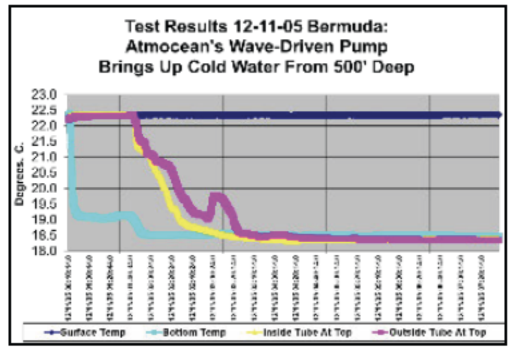


Regarding best-in-class: as far as we know, we're the only ones focused entirely on artificial upwelling for mCDR in the open ocean. We have more than 15 years of experience developing wave-powered AU technology, gaining substantial know-how and IP relating to the design, fabrication, deployment, recovery, and logistics.

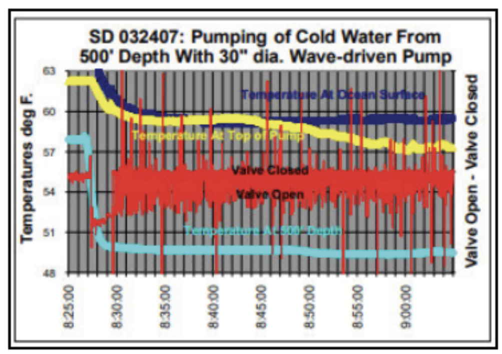
b. What is the current technology readiness level (TRL)? Please include performance and stability data that you've already generated (including at what scale) to substantiate the status of your tech.

<500 words

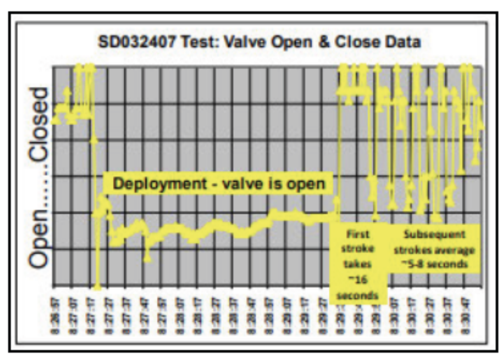
Our ocean upwelling pump is at TRL 7. Pump design and testing began in October 2005 with a 0.3m diameter, 60m depth pump deployed off TX, followed by a 0.3m diameter, 152m depth pump off Bermuda in December 2005 – with cold deep water reaching the surface in about one hour and continuing 9 hours until recovery.



In March 2007, we added accelerometers on the bottom valve on a 0.75m diameter, 152m depth pump test off San Diego, showing 14.4 minutes from the onset of pumping for the cold/deep water to reach the surface – a calculated flow rate of 0.078 m3/s. Taking wave height/period data from nearby NDBC #46258, the calculated upwelling time was 24 minutes – 61% longer than the actual - this is consistent with theories relating to the salt fountain effect by Henry Stommel –water inside an upwelling or downwelling tube gains momentum, delivering more volume than calculated from wave height/period.



In February-March 2008, we produced several 0.75m diameter by 300m upwelling pumps for extended sea trials by the University of Hawaii-Manoa, featured in Discovery Channel's "Hungry Oceans." Despite incorrect assembly and twisting during deployment, one pump operated for 17 hours and demonstrated upwelling though at a reduced flow rate (due to the twisted tube). The reduced rate from twisting is known because the upwelling time from 315m to 165m took one hour, then an additional two hours from 165m to 15m – as documented in the White et al. paper section 3(c).



With the failure of the 2009 UNFCCC in Copenhagen to address CO2 sequestration, for the next ten years, we pivoted to other applications of our wave-powered pumps, including desalination, electricity generation, and onshore aquaculture – conducting various short-term tests in Oregon, California, Bermuda, Newfoundland, and Peru.

In 2018 we re-pivoted to ocean CDR with a combination upwelling/downwelling pump, conducting three same-day proof of concept trials off San Diego and Morro Bay, CA, indicating the concept could work.

This year, funded by **The Foundation***, we built a 1.9m diameter by 100m depth upwelling pump for a 1-day trial off Port Hueneme, CA (Photo, Right). This pump incorporates much higher strength tube fabric and on-buoy instrumentation, providing 10-minute uplinked summaries of water temperature sensors, connecting rope forces, flow meters, wave height/period sensors, and GPS. Due to saltwater intrusion in the satellite modem caused by a faulty o-ring, we did not obtain operational data.

A 1.9m by 200m pump of the same design (and functional o-ring!) is now awaiting deployment in the Canary Islands under the scientific oversight of the team from **The Ocean Researchers***. This trial will commence on Nov 20 and run for about 14 days. In addition to our instrumentation above, we will install accelerometer loggers on the valve – giving us a comparable data set to the San Diego 2007 trial (but 1.9m, not 0.75m diameter). **The Ocean Researchers*** will use an array of temperature sensors and other instruments down current from the pump to characterize the mixing and advection of the upwelled plume and resulting phytoplankton bloom.

*** Names for organization provided in the confidentiality addendum.**

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?
Upwelling flow rate	0.078 m^3/s for 0.75m diameter tube.	1.39 cubic meters per second for 1.9m diameter tube.	Since drag is a cube function and surface area is square function, we expect less drag as we increase to a larger diameter (area), yielding a greater flow rate.
Nutrient profile at depth	From Karl Table 1, 500m upwelling depth.	Assumes Hawaii nutrients as per Station Aloha/HOTS	This area is believed to be among the best for upwelling.
Fossil-based electricity needed for operation	None	None	Wave powered, no fossil energy needed for operation.

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?

<300 words [193 words]

Our team member's role at the company, name, years of experience, and brief bio include:

Founder/CEO/Entrepreneur, Philip Kithil, 50: BA/MSBA Economics with six startups since 1972 and >10 patents in previous automotive safety technologies business sold in 2004 to NYSE-listed supplier.

Chief Engineer & Production Management, Philip Fullam, 50: BSME/MBA experience in designing and producing mechatronic and mechanical products.

Operating Manager, Chris White, 15: MS Oceanography/ Limnology. Experienced in technical and business operations and business development.

Consulting Ocean Scientist, Dr. Ian Walsh, 45: Biogeochemist and measurement expertise Retired head scientist at Seabird Scientific, a leader in ocean measurement devices.

Marketing Officer, Salvador Garcia, 15: BS BA & Marketing, Returned Peace Corps Volunteer (Peru). Specialized in Digital Marketing and Sales, Raised more than $20 million for start-ups.

Financial Advisor, Robert Lipstein, 45: CPA, retired managing partner at KPMG; IPO and public board experience.

Marine Operations Director, Jeff Guilliams, 20: BS. Owner 404Marine LLC, operating workboats for USN and other clients along US west coast.

We seek: CFO, HR, IT, Admin, Sales, Production, Logistics, Data Analysis, and Ocean biogeochemical modeling.

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
The Software Engineering Firm*	Engineering	Discussing Strategic Partnership, negotiations in progress.
SIOEN	Supplier of fabric for tube	Supplier
Reytek	Manufacturer of Pump	President of Reytek, Philip Fullam, is a Shareholder of OBCS and our Chief Engineer.
The Foundation*	Funded Sea Trials	Currently has option to invest.
The Ocean Researchers*	Science Partner	Leader in Scientific Analysis of Artificial Upwelling
Seaview Systems	Supplier of real-time sensors on buoy	Supplier
Ocean Visions	Engineering and Science Advisor	Funded by **The Foundation***
404 Marine	Deployment Vessel Contractor	They've been our provider for ocean operations since 2018.
Dr. Ian Walsh	Consulting Chief Scientist	Contracted

* Names for organization provided in the confidentiality addendum.

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?

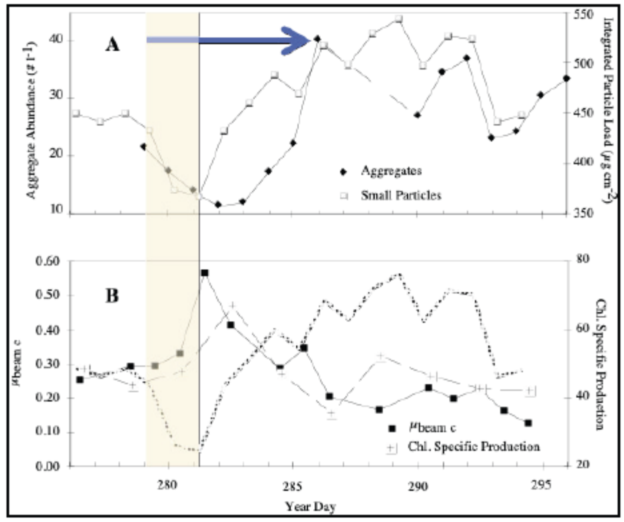
<30 words **(29 words)**

Ten years mCDR: Once funded, we estimate 6-9 months for delivery/deployment. CDR is continuous for as long as the pump is deployed. End-of-life recovery is scheduled at the 10-year deployment mark.

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.

<100 words (99 as is)

Upwelling commences upon deployment. Photosynthesis and carbon fixation occurs as upwelled water reaches sunlight.



Vertical flux from surface to depth varies depending on pathways (aggregate settling vs. heterotrophic fecal pellets) but is ~1 week. This figure (Walsh et al., 1997) indicates timing between an upwelling event (shaded portion), with a rapid initial increase in water column particulates and peak aggregate abundance afterward. Aggregate settling velocities vary, but 100m per day below the mixed layer is reasonable (Walsh et al., 1988).

Once upwelling begins, and the biological process is triggered, CDR is continuous with magnitude varying per upwelling and dispersion rates.

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	1,500 (6 new pumps)
2024	14,000 (50 new pumps)
2025	76,500 (250 new pumps)
2026	201,500 (500 new pumps)
2027	451,500 (1,000 new pumps)
2028	951,500 (2,000 new pumps)
2029	1,951,500 (4,000 new pumps)
2030	3,951,500 (8,000 new pumps)

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	Build Pumps	2Q 2023
2	Deploy Pumps	2Q 2023
3	Obtain Data	3Q 2023

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

<200 words

While we file patent applications periodically, this is not our primary IP protection strategy. Instead, we rely on our know-how accumulated since 2005, our design intricacies, supply chain, deployment techniques, purpose-built boat specifications and availability, and related intangibles, including being first in our segment of the CDR industry. Our current pending US patent is US17267200, PCT/US2019/046292.

k. How are you going to finance this project?

<300 words

We seek upfront funding from Frontier to pay our direct costs to produce and deploy the pumps. Alternatively, we can seek additional support from **The Foundation*** however, this will be a decision of their investment committee, possibly incurring delay, with less than 100% financing, and adding cost.

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.).

<200 words

No, we do not have other buyers for this project (this offer is exclusive to Frontier).

We have proposed building at least six pumps in 2023; two were offered to Microsoft's pending FY24 RFP, two to Frontier, one to **The Software Engineering Firm*** partner, and one for **The Ocean Researchers***. The pumps reserved for **The Software Engineering Firm*** and **The Ocean Researchers*** are under negotiation/discussion. Our capacity in 2023 can increase if other customers commit.

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.

<200 words

None at the moment. We are focusing on selling Pumps to generate mCDR credits for their sponsors. The 45Q tax credit does not include our methodology.

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

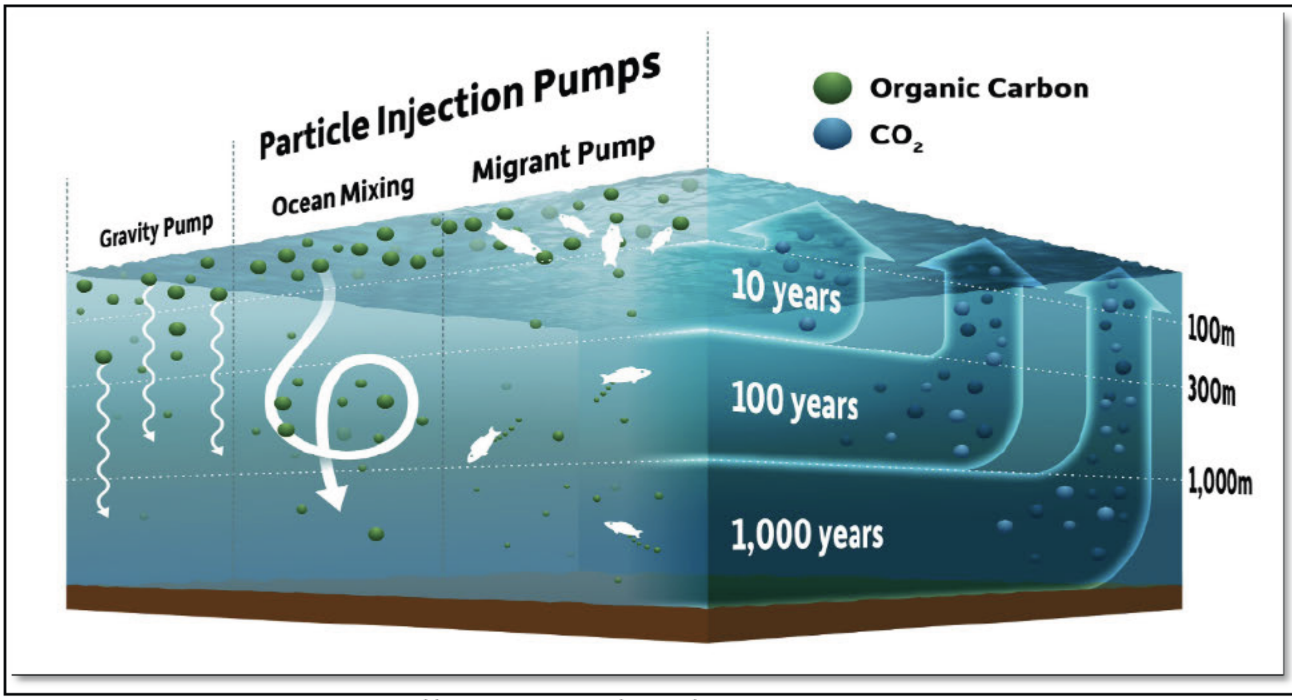
Risk	Mitigation Strategy
Technical	
We do not foresee any technical risks as we built and deployed identical pumps in 2022.	N/A
Project Execution	
1 Production facility unavailable or fully committed 2 Workforce shortage in the US – personnel not available due to tight labor market 3 Supply chain delays/parts not available 4 Deployment vessels are fully booked, causing delays in deployment 5 Permitting is denied, takes longer, or requires moving to a different location	1 Source contract production elsewhere. 2 Source workforce in Mexico or elsewhere 3 Source alternate materials 4 Source alternate vessels 5 Refile permit, move to an alternate location
Ecosystem	
We do not foresee any ecosystem risks for this project, just two pumps.	N/A
Financial	
1 Inflation causes prices to be higher than our estimate 2 Financing of upfront costs not available or expensive 3 Working capital shortfall	1 Renegotiate the contract price and/or terms. 2 Cancel the contract or renegotiate the price and/or terms 3 Layoff key staff, delay operational elements, renegotiate price and/or terms

2. Durability

. 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?

< 300 words, including number/range of durability estimate

The biological gravity pump delivers particulate organic carbon to the seafloor, where it remains sequestered for millennia. It is also well known that the average ocean circulation time from the seafloor to the surface is 5,000 years. The circulation return time of waters above the seafloor depends largely on depth, as seen in this graphic:



Picture: Dr. Thomas Weber - https://www.phys.org/news/2019-04-view-ocean-impact-climate.html

When discussing ocean CDR durability, one must consider the continuity of the carbon cycle - unlike land-based approaches, which characterize CDR as episodes - “one and done.” Ocean CDR is a continuous process, by definition, resulting in a long tail of CDR extending beyond the selected cutoff date.

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?

<200 words

Risks are relative to the uncertainty of unique ecosystem shifts that reduce sequestration. Changes in basin circulation patterns and ventilation of deep water are possible. However, they would occur over time frames that are long relative to the ability to respond to and abate risks from continuing operations.

Feedback from artificial upwelling will decrease uncertainty in models by providing more data, particularly data on perturbations in the biological system, allowing for a rapid increase in a fundamental understanding of the biological pump and oceanic ecosystem dynamics.

Negative feedback from production and release into the atmosphere of greenhouse gasses such as nitrous oxide or methane are presumed to be at low risk of occurring but will need to be monitored during the initial research phase. Ecosystem shifts, e.g., the dominance of particular phytoplankton species or genera, that arise from the dynamics of AU could be avoided by modulating upwelling parameters such as the source depth and pumping rate.

At scale, artificial upwelling will impact the thermal coupling between the ocean and the atmosphere, which could be large enough to create far-field effects that could create negative socioeconomic impacts.
Pumps will push the envelope for material functionality throughout the endeavor's lifespan, as the system's longevity is critical to the cost per ton exported. Wide-scale artificial upwelling deployment will likely create a positive feedback loop on design and material development.

3. Gross Removal & Life Cycle Analysis (LCA)

. 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	4910 tons (2 Pumps)
Describe how you calculated that value	We apply our estimated annual volume of upwelled water per pump (45.8 million cubic meters) to the values shown in the righthand column of Karl/Letelier Table 1, of 121.8 um/m3 upwelled and convert from C to CO2 equal to 245.5 tons per year. The pumped volume is based on six years of wave height/period data from buoy #51001 N of Hawaii. Please see our **OBCS Costs and Projections Frontiers*** for projection details.

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.

None to date.

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.

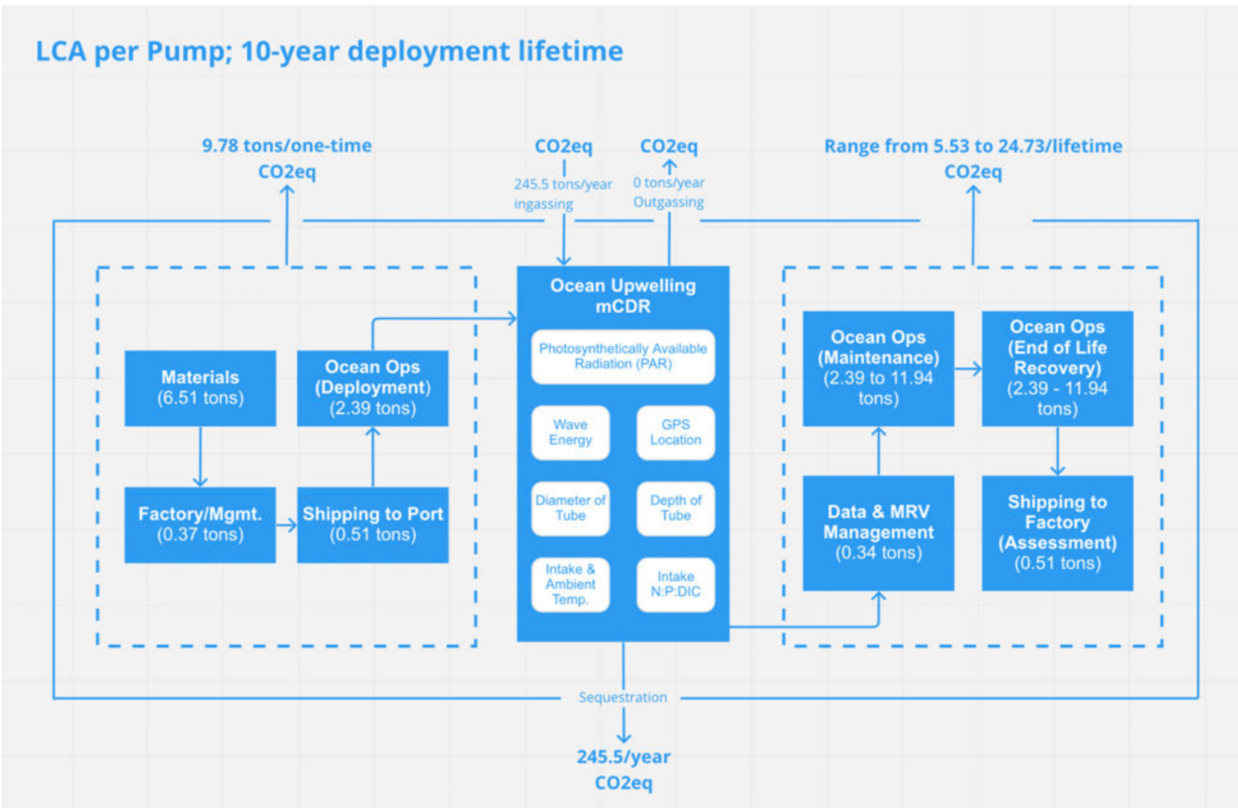
Not applicable.

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)* Range of gross carbon emissions is from **31.02 to 69.02 for the two pumps**. How we arrive to this range: We estimate 19.56* tonnes of emissions for two pumps for production, transport, and deployment. There are almost no recurring emissions as the pumps operate entirely on ocean waves (with sunlight recharging the on-buoy batteries). Post-deployment emissions can range from *11.06 to *49.46 tons over the project's lifetime of 10 years. The range is owed to the distance of the Pump relative to the port for ocean operations for maintenance and end-of-life recovery, in addition to Data & MRV Management and Shipping to the Factory for Refurbishment or Recycle/Disposal Assessment. *Details provided in **OBCS Costs and Projections Frontiers*** Excel sent as an attachment and linked to in the confidentiality addendum.	
Emissions / removal ratio Per pump, we estimate (9.78 + 5.53/(245.5 x 10 years) to (9.78 + 24.73/(245.5 x 10 years) = **Range from 0.0062 to 0.0141** (gross project emissions / gross CDR–must be less than one for net-negative CDR systems)	
Net CDR over the project timeline Per pump, we estimate (4910 - (19.56 + 11.06)) to (4910 - (19.56 + 49.56)) = Range from 4879.38 to 4840.88 tons of CDR over project lifetime. **Conservative estimate: 4840.88 tons of CDR over project lifetime.** *(gross CDR - gross project emissions)*	

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?

<100 words We base our boundary conditions on what occurs leading up to the deployment of the Pump and the carbon dioxide emissions we expect to happen over the ten-year project lifetime. After end-of-life recovery, the pumps are shipped to the factory and assessed for refurbishment or recycling/disposal, which are not assigned emissions because they would be nominal. Finally, CO2e ingassing and outgassing are driven by continuous processes over extended time periods. Given the certainty of increasing CO2 emissions, there will be a net ingassing because atmospheric CO2 increases faster than Oceanic CO2.

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.

The CO2 emissions are modeled after assumptions we've laid out in our **OBCS Costs and Projections Frontiers Excel*.** The **average** annual CO2 emissions over the ten-year project lifetime are the high range **is 6.902 tons.**

Process Step	**CO_2(eq) emissions over the project lifetime (metric tonnes)**	**Describe how you calculated that number. Include references where appropriate.**
Materials	13.02	View cell C38 on 'LCA CO2 Footprint' tab, 6.51 * 2 Pumps
Factory	0.68	View cell C61 on 'LCA CO2 Footprint' tab, 0.34 * 2 Pumps
Shipping to Port	1.02	View cell C47 on 'LCA CO2 Footprint' tab, 0.51 * 2 Pumps
Ocean Operations (Deployment)	4.78	View cell C56 on 'LCA CO2 Footprint' tab, 2.39 * 2 Pumps
MRV & Data Management	0.68	View cell C78 on 'LCA CO2 Footprint' tab, 0.34 *2 Pumps
Ocean Ops (Maintenance)	4.78 to 23.88	View cell B80, C80, D80 on 'LCA CO2 Footprint' tab, (2.39 to 11.94)*2 Pumps
Ocean Ops (End of Life Recovery)	4.78 to 23.88	View cell, C81, D81 on 'LCA CO2 Footprint' tab, (2.39 to 11.94) *2 Pumps
Shipping to Factory (Assessment)	1.02	View cell C82 on 'LCA CO2 Footprint' tab, 0.51 *2 Pumps

*** Link to OBCS Costs and Projections Frontiers Excel* made available in the confidentiality addendum.**

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.

. 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.

<300 words

Our approach to MRV at this stage in the development of AU-driven mCDR is to partner with scientific organizations to bring a set of tools to the task of measuring carbon fluxes stimulated from the pump deployments and upwelled water mass. The oceanographic community has been studying carbon fluxes and air/sea coupling for decades, pointing to understanding the ocean's role in mitigating and responding to atmospheric loading due to anthropogenic inputs (e.g., JGOFS). The recent activity demonstrates that the community is applying its expertise to MRV for mCDR (NASEM report, ARPA-e funding, NOAA, and NSF-sponsored scoping workshop). In particular, we are working with **The Ocean Researchers*** team to deploy a pump near the Canary Islands. We are also in ongoing discussions with David Karl at the University of Hawaii for deployment and MRV activities off Hawaii to take advantage of the long-term observations from HOT (https://hahana.soest.hawaii.edu/hot/) as our additionality comparison.

As a practical approach, we intend to evaluate whether we can quantify mCDR with a combination of real-time data, basic calculations, and advanced modeling. The data will encompass nutrients delivered to the euphotic zone, derived from flow rates, wave height/period data, and knowing the nutrient ratios at the inlet. Calculations will build on the approach taken by Koweek (2022). Modeling may include the work by Chickamoto et al. (2021) and Illyna et al. (2020).

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.)*

<200 words

The durability of the carbon flux in terms of deriving the net sequestration will be evaluated from the results of modeling of the ventilation time based on the depth of injection (Siegel et al., 2021) combined with the export flux relationships (Boyd et al., 2019) and data collected from the pump and downstream of the pump compared to the unperturbed water column. Essentially, the particulate flux settling through the water column increases its time to ventilation on an 'at least' basis while at the same time settling rates and shifts to less labile fractions of the organic carbon flux (Walsh et al., 1988), results in a decreasing rate of loss from the particle flux to the dissolved flux with increasing depth. For our pumping system, assuming we achieve a dispersion ratio sufficient to trigger a bloom and the nutrient injection/flux relationship described in Karl and

Letelier (2008) we anticipate a relatively rapid export under bloom conditions such that a very high fraction of the carbon stimulated by the bloom will reach the seafloor, e.g., Lampitt, 1985. MRV techniques deployed by our research partners will be pointed toward direct measurements of the particle dynamics and fluxes to verify and/or modify the models.

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 Inc ude each component from the Quant f cat on Too re evant to your pro ect	**Discuss the uncertainty impact related to your project** Est mate the mpact of th s component as a percentage of net CDR. Inc ude assumpt ons and sc ent f c references f poss b e.
Stimulated net primary production in surface plume	Low to medium (5-10%). As observed in central gyres and discussed in Karl and Letelier, 2008 for the NPSG in particular, the surface water is nutrient depleted at almost all times over a broad area such that upwelled nutrients are almost certainly entirely consumed by phytoplankton uptake and particulate carbon production.
Vertical flux of particulate carbon	Medium to High, but with rapid improvement with experience and data. (20 - 50%). This is the most significant area of uncertainty relative to sequestration, as the mode of particle production and trophic pathways need to be demonstrated. Because the initial conditions for any given pumped volume mixed into the upper water column are variable based on at least the pumped flow rates and relative velocities between the ambient mixed layer and the pump the precise pathways of production and export are likely to change with time and may reflect rapid shifts between bloom and grazing dominant systems. We will approach this by

	using a minimal flux model (Boyd et al., 2019 subtropics relationship) at the start and modify this with results from MRV and research data sets.
Degradation rate of particulate carbon and nutrients.	Medium to high, but with rapid improvement with experience and data (20 - 50%). The organic carbon degradation rate is a functional driver for predicting particulate carbon flux with depth (Walsh et al., 1988). Differences in degradation rates between carbon and nutrients have impacts on the short-term (above Redfield nutrient regeneration in the upper water column) and long-term (paleo relationships between atmospheric CO2 and upper ocean productivity (Dymond & Lyle, 1985)). The parameterization of these rates will be a focus of continuing research.
Deepwater ventilation	Low to medium with uncertainty inverse to sequestration time presuming NPSG pump location (5-10%) (Siegel et al., 2021)
Air-sea gas exchange	Low (<5%) Assumes NPSG location and 1000 year sequestration time which is >> time to surface water equilibration in the NPSG
Deepwater/sediment storage	Low: no discount assuming 1000 year sequestration time and the location of the pumps in the NPSG.

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?

Stimulated net primary production: 10%

Vertical flux of particulate carbon and degradation rate of particulate carbon and nutrients (combined): 30%

Deepwater ventilation: 5%

Air-sea gas exchange: 5%

Unknowns: 10%

Combined (quasi-summation): 50%

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.?

<200 words (192)

Absolutely, yes! Nothing like a perturbed system and control to drive new insights into how the ocean works.

This phase of MRV development should be comprehensive in terms of recruitment of scientific approaches and measurements to capture early the broadest range of actual and potential impacts as we move to scale. One goal from the early research phase is to develop a set of tools that sets the minimum data set that must be collected to allow for the periodic re-evaluation of the discount rates applied to the carbon flux pathway cost accounting (https://frontierclimate.com/writing/quantifying-delivered-cdr)

We fully anticipate that over the timescale of the build out of mCDR technologies that the evolution of autonomous vehicles, sensors and assimilation models will drive MRV costs and uncertainty down to a level that is conceptually small relative to the overall societal need to monitor carbon fluxes between the ocean and atmosphere and fluxes within the ocean.

We suggest the following as a more comprehensive guide: Boyd, P.W., Claustre, H., Levy, M. et al. Multi-faceted particle pumps drive carbon sequestration in the ocean. Nature 568, 327–335 (2019). https://doi.org/10.1038/s41586-019-1098-2

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)?

<200 words

We do not yet have a partner to verify the credits' delivery and registration. MRV techniques deployed by our research partners will be pointed toward direct measurements of the particle dynamics and fluxes to verify and modify the models. As our MRV technique becomes clearer we're considering registering this project with Verra's Seascape Initiative and our third-party VVB as SCS Global Services.

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.

. 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).

$273/tonne CO_2 - this does not include the uncertainty discount in the net removal volume proposed in response to 4(d).

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

Component	Levelized price of net CDR for this project ($/tonne)
Capex	$205
Opex (excluding measurement)	$68
Quantification of net removal (field measurements, modeling, etc.)	TBD
Third party verification and registry fees (if applicable)	TBD
Total	**$273**

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?
Average life expectancy of pumps	10 years	100 years	Simple one-moving part design. The average life will increase with large-scale implementation and continuous maintenance, resulting in far more CDR tonnes in future years. Also, the pumps are designed for ease of refurbishment, thus saving costs compared to building new pumps.

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

<100 words

We have excluded permitting costs in this TEA because we could do it for this project almost at no cost. We expect that permitting for long-term commercial deployments may require outside expertise at a higher cost.

The working life of each Pump directly affects the cost per ton because our costs are substantially upfront. We mitigate this by in situ maintenance or recovering and refurbishing Pumps when they reach the end of life.

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.).

<200 words

The learning rates embedded in the TEA are higher than we use, resulting in lower future costs. However, as we transition to volume production, the TEA rates may be reasonable.

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.)

<50 words

When we have Pumps deployed in the ocean providing real-time data and estimated mCDR, this would boost sales substantially and attract third-party researchers to exploit the ability to analyze perturbed and control upwelling and plume dynamics driving an MRV-based positive feedback loop.

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.

. 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.

<300 words

At this stage and for the proposed project, we have identified the following stakeholders:

1. US Army Corp of Engineers (USACE), California. We have previously obtained permits from them. Our process involved direct contact.
2. **The Ocean Researchers***. They are the global leader in artificial upwelling research. Our process involved direct contact.
3. Port Hueneme, CA: we relied on our marine contractor to coordinate with the Port Authority.

As a practical matter, because our project is located far offshore, away from shipping and most commercial fishing, we have very few relevant external stakeholders to engage with.

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.*

<300 words

Regarding the USACE, California: we completed the permit application and the final report independently.
Regarding **The Ocean Researchers***: we communicate with them directly.
Regarding Port Hueneme: our marine contractor was the main point of contact, and that is how we engaged.

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?

<100 words

Regarding the USACE: we were satisfied with the professional competence and turn-around time of approximately three months. We do not need to modify this project based on this favorable experience.

Re **The Ocean Researchers***: this process is ongoing. We eliminated the biogeochemical argo (scientific instrument) attachment method, reducing overall cost.

Re Port Hueneme: we were satisfied with the support offered by Port Authorities. We do not need to modify this project based on our experience.

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?

<100 words

We are too early stage to answer the question regarding changes to our process.

Regarding the public engagement strategy: We envision a significant educational effort at all levels of society because of where our pumps are deployed, the open ocean (specifically the North Pacific Subtropical Gyre). We believe our technology will be shown to have the most significant benefits and the fewest detrimental effects of any CDR process – land or ocean.

7. Environmental Justice

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.

. 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.

<200 words

Our deployment of the Ocean Upwelling Pumps project for Frontier Climate does not subject poor and marginalized communities to the unfair exposure or harm associated with resource extraction, hazardous waste, and other land uses associated with Environmental Justice while operating in the open ocean. Our key stakeholders for this project are the US Army Corps of Engineers and **The Ocean Researchers*** researching the environmental impact and carbon sequestration efficiency of our ocean carbon removal methodology. With that said, the pumps are currently manufactured at Reytek LLC, a key stakeholder in manufacturing, which pays entry-skill laborers assembling the pumps at about $20/hour in Albuquerque, NM. The project will create at least three temporary jobs for manufacturing and one part-time job in data analysis for MRV.

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

<300 words

Our methodology is unique in that traditional environmental justice concerns are not an issue. However, given the geographic location of our pumps for this project, the open ocean near Hawaii, there is a possibility, albeit extremely low, that our pump could cross paths with a large shipping vessel. Thankfully, our pumps are bright yellow and large enough to be viewed on radar (as a small boat) and will have a transponder that alerts ships to stay away. In addition, our team will constantly monitor the pump's location and operation status. In regards to opportunities for positive impact, the news that our pumps are deployed for carbon removal will serve as an excellent opportunity to educate the public (especially those in contact with the North Pacific Subtropical Gyre) about Ocean Upwelling for mCDR, how it brings nutrients from the deep ocean and contributes, as has been researched, to increasing biological productivity through the growth of phytoplankton, the base of the ocean food chain.

In a broader sense and over longer time frames, our co-benefits include enhancing fish populations, restoring the ocean ecosystem, cooling the ocean to reverse events such as the heat "blob" that is disrupting the NE Pacific, re-oxygenating the upper ocean, all combine to work towards greater environmental justice across all demographic and social groups.

8. Legal and Regulatory Compliance

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

<100 words

NASEM 2021 Ocean CDR report provides AU legal opinions, as does this more recent report: Romany M. Webb, Korey Silverman-Roati, and Michael B. Gerrard, "Removing Carbon Dioxide Through Artificial Upwelling and Downwelling: Legal Challenges and Opportunities," Sabin Center for Climate Change Law, May 2022.

Whether AU constitutes marine "pollution" under UNCLOS or "dumping" under the London Convention and Protocol is unclear. Resolution LC/LP.1 (2008) covers "ocean fertilization activities." Some argue that "ocean fertilization" could include AU. The Resolution is nonbinding, and subsequent decisions only apply to "putting matter into the sea from vessels, aircraft, platforms, or other man-made structures." Some scientists (Brent K., et al. Governance of Marine Geoengineering. Waterloo, ON: Centre for International Governance Innovation; 2019.) say AU is not covered because it transfers materials and is not "additional."

The US Army Corps of Engineers permitting office for Southern California issued our permit for our trial deployment in May 2022, so we are confident in a favorable decision. If our deployment site is beyond the 200 nm EEZ, then US regulatory procedures do not apply; instead, we will be under UN Law of the Sea, London Convention, and London Protocol.

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.

<100 words

If our project is located in US waters (out to 200nm), we will need a permit from the US Army Corps of Engineers, as specified in the Rivers & Harbors Act. This involves their consultation with several other agencies – US Coast Guard, US Navy, California Coastal Commission, NOAA, and others. We've already received a permit from USACE in March 2022 for our trial deployment in May and thus have some experience and a roadmap for the process.

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?

<100 words

Existing international agreements have attempted to regulate particular ocean CDR techniques, notably nutrient fertilization, but there are still significant gaps (NASEM Ocean CDR Report 2021, pg 39). We have not recently engaged with these regimes (UNCLOS, CBD, others) as they are unsure what to do about AU. However, as we scale, we intend to seek their consultation and follow any requirements they require to obtain authorization.

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.

<100 words

The legal status of artificial upwelling pumps, either within or outside the EEZ, is uncertain. Please see: Romany M. Webb, Korey Silverman-Roati, and Michael B. Gerrard, "Removing Carbon Dioxide Through

Artificial Upwelling and Downwelling: Legal Challenges and Opportunities", Sabin Center for Climate Change Law, May 2022.

To deploy our project in US waters off California, we will seek to renew our permit granted in March 2022 by the US Army Corps of Engineers under their Nation Wide Permit No. 5 procedure.

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.

<50

No, we do not intend to receive tax credits during the proposed delivery window, as these do not yet exist for our mCDR methodology. To our knowledge, the 45Q credit only applies to land-based CDR.

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) Assuming maximum end-of-life recovery distance carbon emission: 4,840.88 tons of CO2 over 10 years.
Delivery window 10 years
Levelized Price ($/metric tonne CO_2) ($279/metric tonne CO_2)

Application Supplement: Biomass

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

Feedstock and Physical Footprint

1. What type(s) of biomass does your project rely on?

50 words Artificial upwelling stimulates a natural ecosystem response similar to a natural vertical mixing event. The biomass that is produced is, therefore, a product of the natural system of phytoplankton, heterotrophs, and the microbial loop that derives from the ambient conditions stimulated by the addition of a proportion of upwelled waters and the associated nutrients.

0. How is the biomass grown (e.g., kelp) or sourced (e.g., waste corn stover)? Do you have supply agreements established?

<200 words. Phytoplankton need light, nutrients, water column stability, and relatively little grazing pressure to trigger a bloom which leads to increased vertical flux of organic carbon out of the upper ocean and down to the sediments. Artificial upwelling delivers nutrients to the surface water, stimulating a natural ecosystem response similar to a deep mixing event. Within the North Pacific Subtropical Gyre, for which we have a long and data rich timeseries of productivity and carbon dynamics representative of the Gyre as a whole from the HOT site (Karl papers) nutrient enrichment due to upwelling will most likely trigger a two stage bloom in which the first stage diatom bloom reduces the nitrate concentration to a minimum and a second stage bloom of nitrogen fixing diazotrophs reduces the phosphate and iron to the normal local minima (Karl and Letelier, 2008). We do not yet have supply agreements.

0. Describe the logistics of collecting your waste biomass, including transport. How much carbon emissions are associated with these logistics, and how much does it cost? How do you envision this to evolve with scale?

<200 words With the stimulation of the natural community response to the addition of nutrients via upwelling, the biomass produced via photosynthesis, consumption by higher trophic layers, and through the microbial loop can take many different pathways, including increasing biological stock mass (e.g., more fish), regeneration within the upper mixed layer (e.g., more heterotrophic bacteria), or settling to the deep interior of the water column and the sediments resulting in a net sequestration flux. We do not harvest or recover or collect any biomass as part of the sequestration process; there is no ‘waste’ biomass that has to be disposed of, there is no logistical support required, and no net carbon emissions or economic costs associated with the subsequent flows of fixed carbon after the upwelling stimulated phytoplankton growth. As we scale by

adding pumps within the North Pacific Subtropical Gyre (NPSG), we may vary the spacing of pumps to optimize parts of the system. However, in any event, we do not need nor intend to collect material apart from continuing research to understand the ocean as a system and measurement, reporting and verification requirements.

0. Please fill out the table below regarding your feedstock's physical footprint. If you don't know (e.g. you procure your biomass from a seller who doesn't communicate their land use), indicate that in the table.

	Area of land or sea (km^2) in 2022	**Competing/existing project area use (if applicable)**
Feedstock cultivation	Our incremental areal need is the surface expression of the pump itself. Our perturbed volume, i.e. the surface mixed layer into which the upwelled water volume mixes, will extend downstream of the pump over a distance corresponding to the time in which the nutrient concentration relaxes to the ambient level which is likely to be on the order of one to two weeks. Note that the downstream patch is not needed to be exclusionary and other marine activities can be performed in the patch.	N/A
Processing	Same as above, processing occurs within the boundaries of the downstream patch and the MRV volume. No additional area required.	N/A
Long-term Storage	No additional area is required for the gravitational and biological pathways to depths below 1000 m and ultimately the sediments.	N/A

	Area of land or sea (km^2) in 2022	**Competing/existing project area use (if applicable)**
Sequestration Process	Our initial spacing is one Pump per square mile (~2.589 km^2) of open ocean.	Not applicable

Capacity

0. How much CDR is feasible globally per year using the biomass you identified in question 1 above? Please include a reference to support this potential capacity.

<100 words (as is 99)

4.9 gigatons of mCDR annually is potentially feasible assuming 20 million $mile^2$ of suitable ocean and one Pump per $mile^2$ and taking the estimated net export of 245.5 tonnes per year from Karl and Letelier, 2008, Table 1 (net export attributable to the biological gravity pump) after the initial LCA is considered. There may be additional net export due to upwelling trace minerals (i.e., iron) and additional atmospheric absorption of CO_2 via the Solubility Pump (the upwelled 500m depth water was last exposed to the atmosphere hundreds of years earlier when the CO_2 concentration was less than 300 ppm).

Additionality and Ecosystem Impacts

0. What are applications/sectors your biomass feedstock could be used for other than CDR? (i.e., what is the counterfactual fate of the biomass feedstock)

<100 words

If we consider the possibility of upwelling nutrients without causing a sequestration response then because our method of AU does not divert other biomass resources from other locations or processes, and relies on natural system functions to drive sequestration, the alternative to loss from the upper water column would be an increase in heterotrophic biomass, with some increase in the dissolved nutrient load in the photic zone due to high grazing pressure. Note: AU is considered a way to restore fisheries (e.g. https://ocean-artup.eu/objectives). The most likely end state will be an increase in carbon sequestration (generating credits) and heterotrophic biomass (including fish).

0. There are many potential uses for waste biomass, including avoiding emissions and various other approaches to CDR. What are the merits and advantages of your proposed approach in comparison to the alternatives?

<200 words

Four main advantages to our approach:

1. There is no need to collect, bundle or store biomass; therefore, there are no costs in the effort, capital, operation, and maintenance of the mentioned activities. By simply enhancing the natural system, we increase the vertical carbon flux through the particles resulting in a net flux of carbon that is small relative to the induced productivity but is large compared to the undisturbed system. The bulk of the additional flux of nutrients will end up in the biological stocks, likely cascading upwards into the fisheries. However, this linkage will still need to be demonstrated while presupposed in previous research efforts (Dr. Ulf Riebesell, other refs).
2. No exposure to energy costs over the deployment period apart from the anticipated low net cost per ton from offset credits, research, and MRV costs.
3. Artificial upwelling technology has spillover applications for other mCDR techniques, particularly iron fertilization and macroalgae production, as well as applications in restoring ocean ecosystems and providing refuges for endangered species because it can provide quasi-continuous nutrients fluxes to the surface to increase productivity.
4. Suppose we consider not deploying artificial upwelling systems in the NPSG. In that case, the long-term depletion of phosphate in the surface mixed layer would likely continue, mainly if the driving mechanism is the increased stratification within and the expansion of the areal extent of the NPSG with a resultant loss of net primary productivity in the NPSG.

0. We recognize that both biomass production (i.e., growing kelp) and biomass storage (i.e., sinking in the ocean) can have complex interactions with ecological, social, and economic systems. What are the specific, potential negative impacts (or important unknowns) you have identified, and what are your specific plans for mitigating those impacts (or resolving the unknowns)?

<300 words

Increase in oxygen uptake through regeneration of nutrients and organic carbon with depth will decrease oxygen concentration in the water column and increase the volume of the oxygen minimum zone. The increase in AOU (apparent oxygen utilization) can be used to check the net organic carbon flux as it results from oxidation of fixed organic carbon due to increased organic carbon flux stimulated by artificial upwelling. Monitoring this will be a signal to noise ratio problem until sufficient pumps are deployed and the net carbon flux through the water column integrates over enough time to impact the current levels. Mitigation will be a function of optimizing the spacing of pumps within the NPSG to reduce negative feedbacks as they are identified from observation/model/research functional loops.

There are specific risks to higher trophic level dynamics due to the impact of deployment of pumps altering higher trophic behaviors, particularly as the result of fish congregating around the pumps. This behavior alteration may have cascading impacts along various axes, from predator/prey interactions to changes in human fishing methods. Mitigation will depend on the actual impact and would involve spacing changes on the low risk side to cessation of pumping on the high risk side.

Negative feedbacks from production and release into the atmosphere of greenhouse gasses such as nitrous oxide or methane are presumed to be at low risk of occurring. However, they will need to be monitored during the initial research phase. Ecosystem shifts, e.g. the dominance of particular phytoplankton species or genera, that are associated with nitrous oxide and methane production that arise from the dynamics of AU could be avoided by modulating upwelling parameters such as the source depth and pumping rate.

One potentially negative impact is decreased ocean pH, worsening ocean acidification. We think this is more likely at depth than in the upper ocean. Our mitigation plan is to monitor this during our initial pump deployments and increase our pump spacing if needed to reduce or eliminate the impact. A potential second mitigation plan will be to coordinate our pump locations with ocean alkalinity enhancement (OAE) locations, thereby nulling the slight negative impact from upwelling.

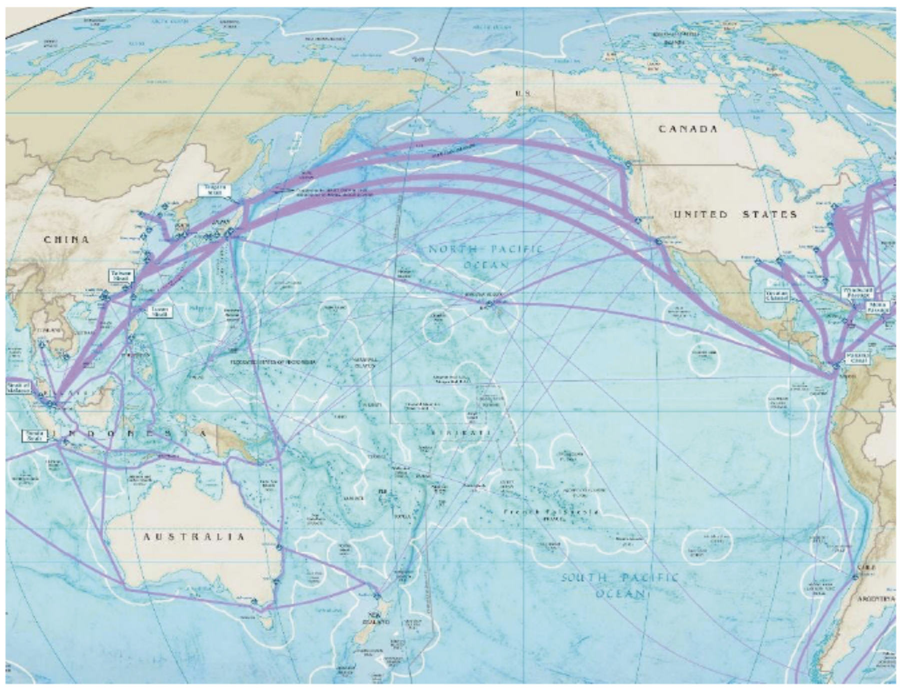
Application Supplement: Ocean

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

Physical Footprint

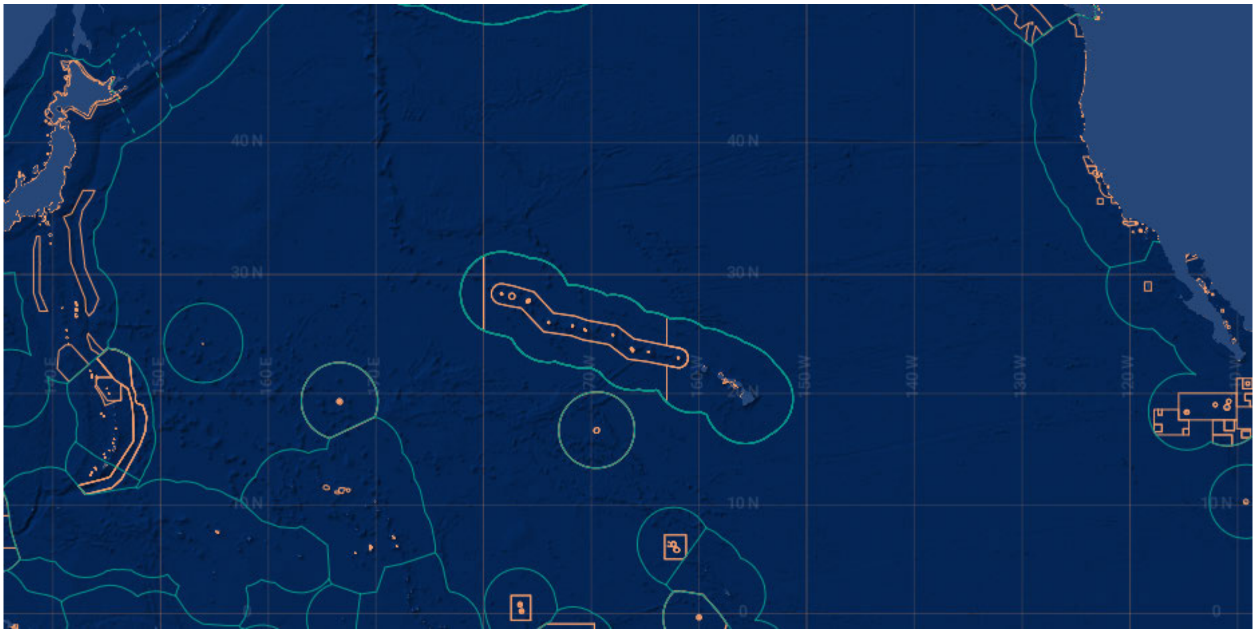
1. Describe the geography of your deployment, its relationship to coastlines, shipping channels, other human or animal activity, etc.

<200 words

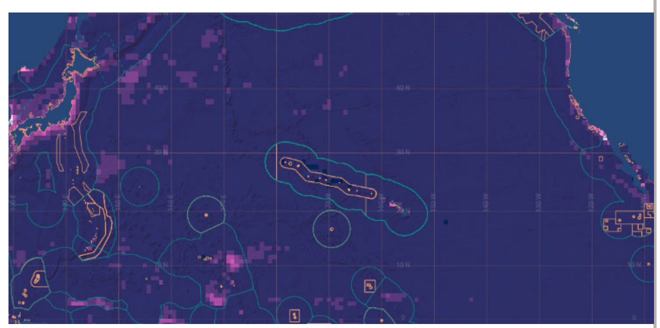


Our deployments will be in deep water/open ocean, in the subtropical and mid-latitude North Pacific. As seen in this image of shipping lanes [Pacific Ocean major ports map (ontheworldmap.com)](), this vast ocean region sees considerable ship density on the great circle routes above 40 degrees latitude but far less ship density across the subtropical and tropical latitudes (grey overlay). We also point out the relative surface footprint of one pump vs. one typical containership: 6 m^2 / (30m x 200m) = 0.001, implying a low risk of interference.

Further insights are provided by the following maps of the North Pacific showing fishing vessel activity across this region (source Transparency for a Sustainable Ocean | Global Fishing Watch), with EEZs outlined in light green and MPAs in orange:



Fishing vessel presence (all types) (last 90 days, per 8,000 km^2 grid cell)



Fishing activity by drifting longliners (hours per 32,000 km^2 grid cell size)

Encounter events (a fish transfer vessel and a fishing vessel within 500m for 2 hours, more than 20nm from a port).

With these maps in mind, we suggest this vast open subtropical and tropical North Pacific is well suited spatially for our pump technology.

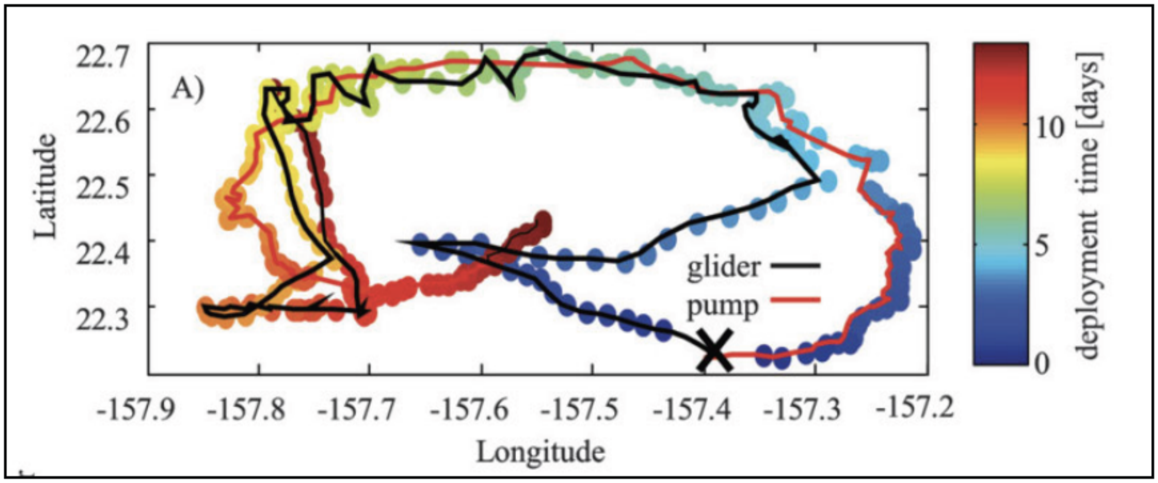
0. Please describe your physical footprint in detail. Consider surface area, depth, expected interaction with ocean currents and upwelling/downwelling processes, etc.

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

<200 words

Our surface area is approx—2 m by 3m. The depth of the 1.9m diameter flexible fabric tube is 500m. Each pump is free-drifting, essentially following the weighted average-at-depth ocean current velocities.

White et al. shows the drifting trajectory of a single 300m depth pump during their 2008 trial (0.1-degree lat or long = ~6nm).



Upwelling volume is a function of wave height and period. We have compiled six years of hourly data from data buoy #51001 north of Hawaii, as seen here. Nominal upwelling = (WVHT x (3600/APD)) for WVHT=3m or lower. Upwelling with water column momentum includes the 60.9% additional flow based on our San Diego test 032407 for a 0.75m diameter x 152m depth pump. We expect a higher ratio for the 1.9m diameter by 200m depth upwelling pump scheduled for a ~10-day trial at PLOCAN in the Canary Islands next month.

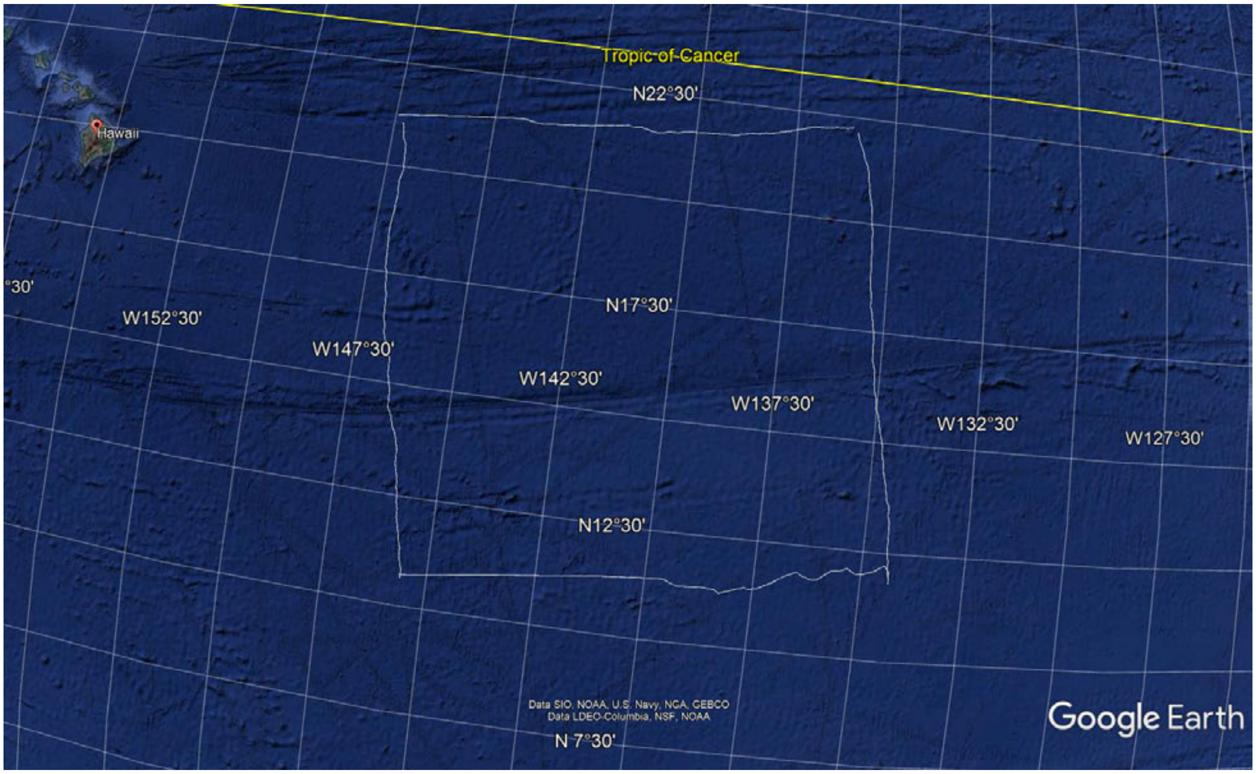
Calculation of Annual Pumped Volume Achievable In Ocean Waves							
	Nominal Pumped Volume (m^3) Data Buoy 51001 - Hawaii						
	2016	2017	2018	2019	2020	2021	Average
Nominal Upwelling	29,151,914	27,513,432	28,978,977	28,557,144	27,540,959	29,066,176	28,468,100
Upwelling with water column momentum	46,909,763	44,273,201	46,631,481	45,952,688	44,317,496	46,771,797	45,809,404

0. 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).

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

<200 words (41 as is)

To achieve 100 million tons per year, assuming 245.5 tons/pump/year, will require about 407,000 pumps which at one per square mile is an ocean rectangle of 638 miles by 638 miles, or equivalent – as visualized in this Google map image:


Tropic of Cancer
N22°30'
Hawaii
°30'
W152°30'
N17°30'
W147°30'
W142°30'
W137°30'
W132°30'
W127°30'
N12°30'
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Data LDEO-Columbia, NSF, NOAA
N 7°30'
Google Earth

Potential to Scale

0. 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?

<200 words (184 as is)

The primary challenge is vessel availability and capability to efficiently deploy thousands of pumps, many 100's of miles offshore, at low cost.

The Logistical Challenge

	Fishing Boat	Custom High Speed Workboat	Container/Roro Ship
Boat Capacity	2	10	5,000
Boat Speed (knots)	10	15	20
Deployed Pumps per year	60	1,000	250,000
Years (If only 1 ship)	66,000	4,000	16
Deployment Cost/Pump	$10,000	$800	$50

Note: 600 nm round-trip, 67% weather window

Further details are found in this slide from our presentation to Ocean Exchange. This analysis assumes 1 Gigaton CDR/year with 4 million pumps deployed in the open ocean beyond the Hawaii EEZ, requiring an average of 600nm roundtrip for deployment.

The "Custom High-speed Workboat" is now undergoing final naval engineering by our boat construction partner in Lima, Peru.

The "Container/RoRo (=roll-on, roll-off) ship" assumes typical vehicle transport vessels such as those operated by Wallenius-Wilhelmsen, the global leader in this category.

Historical precedent applies the knowledge base of fishing vessels, which routinely offload gear in mid-ocean, with the volume capabilities of larger vessels as we step up from our Custom Workboat and then to the RoRo category. The important enabler is for the vessel to set a speed such that conveyor-belt offloading each pump into the ocean achieves the desired spacing (once offloaded, the pumps self-deploy as the heavy bottom-weight sinks, causing the flexible fabric tube to unspool off the buoy).

Externalities and Ecosystem Impacts

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

<200 words We believe the primary adverse effect will be slightly worsening ocean acidification at depth due to the additional carbon flux. Prof. Ulf Riebesell from GEOMAR-Kiel has looked at this: "Artificial up/downwelling would … enhance deep ocean acidification … [but] surface ocean acidification more or less the same."

0. 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?

<200 words Once we characterize the severity of these impacts at each depth, we can identify strategies for mitigation. One mitigation is to spread out the pumps, which will lessen the severity as the biological impacts "mix down." Another might be coordinating our pump locations with other CDR strategies, such as OAE.