[Ebb Carbon] Carbon Removal Purchase Application

General Application

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

Company or organization name

Ebb Carbon, Inc.

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

San Carlos, CA

Name of person filling out this application

Matthew Eisaman, Ben Tarbell, Todd Pelman, Dave Hegeman

Email address of person filling out this application

apps@ebbcarbon.com

Brief company or organization description

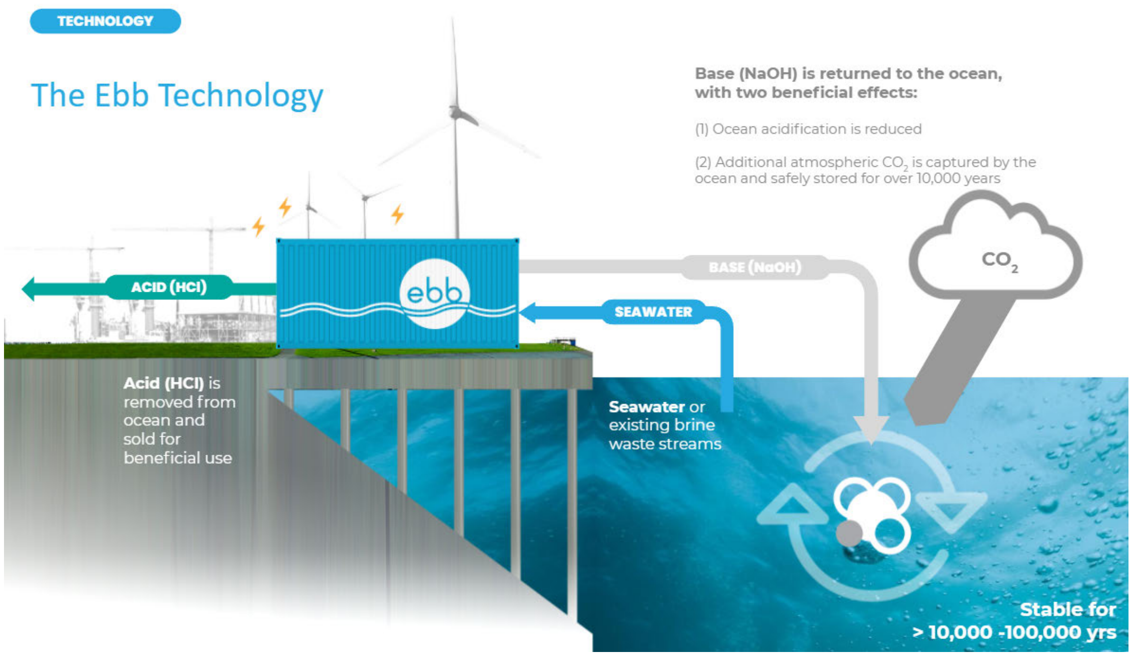
Ebb Carbon reverses ocean acidification while capturing CO_2 as oceanic bicarbonate

1. Overall CDR solution (All criteria)

a. Provide a technical explanation of the proposed project, including as much specificity regarding location(s), scale, timeline, and participants as possible. Feel free to include figures.

Overview

Ebb Carbon's process captures atmospheric CO_2 and stores it for 10,000 to 100,000 years while reversing ocean acidification. With our process, low-carbon electricity pumps acid out of the ocean and the less acidic seawater left behind converts atmospheric CO_2 to a form that is safely and naturally stored in the ocean (see summary figure below).



First we summarize Ebb Carbon's performance on each of Stripe's 2021 target criteria, and then explain the process in more detail.

Physical footprint. Our first modular unit will fit 50t(CO_2)/y capture capacity into a standard twenty foot equivalent (TEU) shipping container measuring with a footprint of 160 ft^2. The second and third units, which will be responsible for most of the CO_2 removal to satisfy our commitment to Stripe, will fit a 200t(CO_2)/y system in a TEU and within five years we expect to be able to achieve a capacity of 500t(CO_2)/y per TEU module for a footprint of 3.125 t(CO_2)/y per square foot, equivalent to about 336,000 t(CO_2)/y per hectare without stacking equipment. Stacking TEUs would reduce this footprint even further.

Capacity. ***In principle:*** Imagine we use Ebb Carbon's technology to establish a preindustrial pH distribution in steady-state with a near-preindustrial 350 ppm atmospheric CO_2 concentration. Accounting for the exchange timescale between the surface ocean and deep ocean, the steady-state rate of atmospheric drawdown from that point forward would be around 44 GtCO_2 yr^{-1}, which is roughly equal to modern emissions from human activities. ***In practice:*** Our ability to find offtake partners for the HCl byproduct may provide a constraint on capacity. However, we have identified new uses for dilute acid that will allow us to at least reach the tens of gigatonnes of CO_2 per year scale. Our ability to physically deploy Ebb modules quickly enough may also limit scale. Assuming our long-term goal of a 500t(CO_2)/y per TEU module goal described above, 0.5 Gt(CO_2)/y would require the cumulative deployment of 1 million TEUs.

Cost. Over the next five years, we expect to reduce CapEx via economies of scale, engineering refinements, and increased uptime; and reduce OpEx as industrial colocation and larger scale enable cost sharing and access to lower-cost and lower-carbon-intensity electricity. Our techno-economic assessment predicts a price below \$100/t(CO_2) in 5 years.

Durability. Ebb's process stores atmospheric CO_2 as oceanic bicarbonate for 10,000 - 100,000 years. See explanations and citations of this range later in the application.

Verifiability. We will directly measure the rate of NaOH generation. Local and regional data and models of ocean currents will be utilized to verify the CO_2 drawdown in space and time as the returned NaOH disperses in the ocean. These models will be ground-truthed by initial field tests with frequent sampling of the seawater chemistry in the vicinity of NaOH return.

Additionality. Every mole of acid that Ebb Carbon removes from the ocean, resulting in CO_2 drawdown, is additional relative to the baseline scenario without Ebb's technology.

Safety and compliance. pH measurements at the point of NaOH dispersal will provide feedback to the electrochemical unit to keep the steady-state maximum pH change well within safe bounds (maximum, local pH change < 0.4 pH units). Ebb systems will most likely be deployed at existing, permitted coastal facilities that treat waste effluent from desalination and wastewater treatment plants. The communities and stakeholders who will be affected by Ebb Carbon's process include: employees, local coastal communities, the aquaculture, fisheries, and tourism industries, and the organisms comprising marine ecosystems. We are engaging these communities, soliciting feedback and concerns, and adjusting our design and deployment plan accordingly. We expect Ebb Carbon's technology to be safe for marine life and beneficial to many of the industries and communities that rely on coastal ecosystems, and we are performing tests to verify this before deployments occur. When colocated with an existing industrial facility like a desalination plant, Ebb's process would likely fall under existing permits and actually reduce the environmental impact of the plant by reducing the salinity of its effluent. We have started discussions with government agencies to understand any additional permitting requirements.

Net-negative lifecycle. For the early deployments used to satisfy our commitment to Stripe, the ratio of CO_2 emissions to gross CO_2 capture will be 13%. This includes emissions due to grid electricity use and shipment of HCl byproduct to offtake partners. This also assumes an emissions intensity of 0.075t(CO_2)/MWh achieved by operating during times of low carbon intensity at the balancing-authority level, resulting in a capacity factor of 45%. Later deployments using, e.g., offshore wind with an emissions intensity of 0.012t(CO_2)/MWh would have an emissions-to-capture ratio of 3%. See our answer to question 4 below for more details.

Detailed description

The increasing atmospheric CO_2 concentration is changing the climate and acidifying the oceans, potentially increasing the vulnerability of marine calcifiers to dissolution [1]. Ebb Carbon uses low-carbon electricity to electrochemically pump acid out of the ocean. This restores the ocean chemistry such that the remaining ions in the ocean react with atmospheric CO_2, safely locking it up for 10,000 – 100,000 years as bicarbonate, the ocean's most abundant form of carbon storage. For every thousand tonnes of CO_2 that Ebb captures, the pH of the surface ocean in a 1.6km^2 area is increased by 0.1 pH units, helping to reverse ocean acidification.

At a more detailed level (see summary figure above), electrical energy converts brine (aqueous NaCl) into acidic and basic output streams: hydrochloric acid (HCl) and sodium hydroxide (NaOH). Our input can be seawater or any briny effluent, e.g. from water recycling or desalination facilities. The acid is prevented from returning to the ocean and may be sold for beneficial use. The base is controllably returned to the ocean, increasing oceanic pH and alkalinity, resulting in the reversal of ocean acidification and the reaction of atmospheric CO_2 with NaOH to capture and store CO_2 as bicarbonate, HCO_3^-.

The NaOH returned to the ocean reacts quickly with naturally occurring seawater bicarbonate, increasing carbonate concentrations and opposing the ongoing carbonate ion decreases from ocean acidification [2]:

$$NaOH + HCO_3^- \rightarrow Na^+ + H_2O + CO_3^{2-}.$$

On the timescale of the 1-12 months required for air-sea gas exchange [3], atmospheric CO_2 dissolves into seawater and reacts with carbonate, increasing bicarbonate ion concentrations and returning the seawater pH to nearly, but slightly above, the pre-NaOH-addition value:

$$CO_2 + CO_3^{2-} + H_2O \rightarrow 2HCO_3^- .$$

To have a meaningful impact on climate change, Ebb Carbon must scale to >1Gt(CO_2)/year, meaning that offtake partners for the HCl must be scaled. We have identified a number of promising directions that could scale to much greater than 1Gt(CO_2)/year.

Ebb Carbon's electrochemical technology that produces acid and base from salt water is known as bipolar membrane electrodialysis, which employs a stack of ion-selective membranes between electrodes. There are three membrane types: anion exchange membranes (AEMs) pass only negatively charged ions, cation exchange membranes (CEMs) pass only positively charged ions, and bipolar membranes (BPMs) separate water into hydrogen (H^+) ions and hydroxide (OH^-) ions. These membranes are arranged in a repeating pattern (AEM, BPM, CEM, AEM, BPM, CEM…) with a typical unit having 50 to 200 AEM-BPM-CEM triplets. The brine, acid, and base flow between the membranes, and when a voltage is applied at the electrodes, the transport of Na^+ in one direction and Cl^- in the other, combined with the separation of H^+ and OH^-, results in aqueous acidic HCl and basic NaOH outputs.

We have a small demonstration unit of this process in our lab and are currently commissioning and testing the first 50t(CO_2)/y system intended for deployment. Our work to date has focused on validating our ability to mitigate ocean acidification and capture CO_2 at the gigatonne scale without unintended consequences.

[1] B. Figuerola , et al., Front. Mar. Sci. 8, 584445 (2021).

[2] D.A. Wolf-Gladrow, et al. Tellus B, *51*(2), 461–476 (1999).

[3] D.C. Jones, et al., Global Biogeochemical Cycles, *28*(11), 1163–1178 (2014).

b. What is your role in this project, and who are the other actors that make this a full carbon removal solution? *(E.g. I am a broker. I sell carbon removal that is generated from a partnership between DAC Company and Injection Company. DAC Company owns the plant and produces compressed CO_2. DAC Company pays Injection Company for storage and long-term monitoring.)*

Ebb Carbon is a full-service carbon removal solution. We sell carbon removal credits and valuable byproducts. We are developing the technology, and the projects and partnerships that deploy the technology to reverse ocean acidification, convert and sequester atmospheric CO_2 into bicarbonate, and facilitate beneficial use of the byproducts.

c. What are the three most important risks your project faces?

Risk 1. A market for voluntary carbon credits may not scale and policy incentives available to others in the industry may remain inaccessible to us.

Risk 2. Scaling the technology that works in the lab--we may not be able to reduce costs or maintain efficiencies as we scale in real-world operating conditions. Risk 3. Our approach is new commercially. It may take time to convince stakeholders that our process is beneficial to the marine environment, has no negative unintended consequences, and is significantly carbon negative on a lifecycle basis.

d. If any, please link to your patents, pending or granted, that are available publicly.

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

2. Timeline and Durability (Criteria #4 and Criteria #5)

a. Please fill out the table below.

	Timeline for Offer to Stripe
Project duration *Over what duration will you be actively running your DAC plant, spreading olivine, growing and sinking kelp, etc. to deliver on your offer to Stripe? E.g. Jun 2021 - Jun 2022. The end of this duration determines when Stripe will consider renewing our contract with you based on performance.*	March 2022 - September 2024
When does carbon removal occur? *We recognize that some solutions deliver carbon removal during the project duration (e.g. DAC + injection), while others deliver carbon removal gradually after the project duration (e.g. spreading olivine for long-term mineralization). Over what timeframe will carbon removal occur?* *E.g. Jun 2021 - Jun 2022 OR 500 years.*	CO_2 removal starts immediately and reaches equilibrium within 1-12 months.

Distribution of that carbon removal over time *For the time frame described above, please detail how you anticipate your carbon removal capacity will be distributed. E.g. "50% in year one, 25% each year thereafter" or "Evenly distributed over the whole time frame". We're asking here specifically about the physical carbon removal process here, NOT the "Project duration". Indicate any uncertainties, eg "We anticipate a steady decline in annualized carbon removal from year one into the out-years, but this depends on unknowns re our mineralization kinetics".*	50 tons in 2022 150 tons in 2023 Remainder in 2024 Removal rate in 2022 will depend on when equipment is first placed in service and uncertainties around commissioning timelines and capacity factors.
Durability *Over what duration you can assure durable carbon storage for this offer (e.g, these rocks, this kelp, this injection site)? E.g. 1000 years.*	>10,000 years (lifetime of excess alkalinity in the ocean)

b. What are the upper and lower bounds on your durability claimed above in table 2(a)?

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

c. Have you measured this durability directly, if so, how? Otherwise, if you're relying on the literature, please cite data that justifies your claim. *(E.g. We rely on findings from Paper_1 and Paper_2 to estimate permanence of mineralization, and here are the reasons why these findings apply to our system. OR We have evidence from this pilot project we ran that biomass sinks to D ocean depth. If biomass reaches these depths, here's what we assume happens based on Paper_1 and Paper_2.)*

The durability of Ebb Carbon's CO_2 storage is essentially equal to the residence lifetime of excess alkalinity added to the ocean. The simplest calculation is to divide the total alkalinity (TA) concentration (3×10^6 Tmol alkalinity) by the approximately 33 Tmol /yr TA input into the ocean through rivers (Cai et al., Continental Shelf Research, 28, 1538– 1549, 2008). This gives a residence estimate of about 100,000 years, as supported by the conclusions of Renforth et al., Rev. Geophys. , 55, 636-674, 2017). However, there are reasons to believe that the removal of alkalinity is proportional to the degree of supersaturation rather than the concentration. This, in turn implies that excess alkalinity might have a residence time of around 10,000 years, shorter than the residence time of alkalinity.

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

The durability risks of Ebb's process are quite low. Once the additional alkalinity added to the surface ocean has been converted to bicarbonate by equilibration with atmospheric CO_2, this bicarbonate is stable for at least 10,000 years. One possible risk would be if the acid pumped out of the ocean is accidentally released back into the ocean, but this risk is mitigated by making sure that the acid is used in processes where return to the ocean is not a concern. One may also worry that the added alkalinity could be pulled out of the surface ocean where gas exchange with the atmosphere occurs and into the deep ocean before it has equilibrated with atmospheric CO_2. However, this is not a concern as equilibration time is much faster than the time to exchange to the deep ocean [1, 2].

[1] D.C. Jones, T. Ito, Y. Takano, and C.-W. Hsu, Spatial and seasonal variability of the air-sea equilibration timescale of carbon dioxide. Global Biogeochemical Cycles, 28(11), 1163–1178, 2014.

[2] K. Matsumoto, Radiocarbon-based circulation age of the world oceans. Journal of Geophysical Research: Oceans, 112(9), C09004, 2007.

e. How will you quantify the actual permanence/durability of the carbon sequestered by your project? 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.)*

Once the alkalinity has reacted with atmospheric CO_2 to form bicarbonate, the storage will last for at least 10,000 years, as described in the previous answers. Direct measurement of the alkalinity added to the ocean will be accomplished by direct measurement of the rate of NaOH generation. A pH measurement at the point of NaOH dispersal will be used to keep the steady state maximum pH change well within safe bounds. Local and regional models will model the CO_2 drawdown in space and time as the added alkalinity disperses in the ocean. These models will be ground-truthed by initial field tests with frequent sampling of the seawater chemistry in the vicinity of the NaOH dispersal.

3. Gross Capacity (Criteria #2)

a. Please fill out the table below. **All tonnage should be described in metric tonnes here and throughout the application.**

	Offer to Stripe (metric tonnes CO_2) over the timeline detailed in the table in 2(a)
Gross carbon removal Do not subtract for embodied/lifecycle emissions or permanence, we will ask you to subtract this later	294 tCO_2
If applicable, additional avoided emissions e.g. for carbon mineralization in concrete production, removal would be the CO_2 utilized in concrete production and avoided emissions would be the emissions reductions associated with traditional concrete production	N/A

b. Show your work for 3(a). How did you calculate these numbers? If you have significant uncertainties in your capacity, what drives those? *(E.g. This specific species sequesters X tCO_2/t biomass. Each deployment of our solution grows on average Y t biomass. We assume Z% of the biomass is sequestered permanently. We are offering two deployments to Stripe. X*Y*Z*2 = 350 tCO_2 = Gross removal. OR Each tower of our mineralization reactor captures between X and Y tons CO_2/yr, all of which we have the capacity to inject. However, the range between X and Y is large, because we have significant uncertainty in how our reactors will perform under various environmental conditions)*

Each modular Ebb Carbon system will fit in a twenty-foot equivalent unit (TEU) shipping container and capture CO_2 at a gross rate of 200t(CO_2)/y at 50% capacity factor. This assumes that, based on known seawater chemistry, 0.8 mol(CO_2) is captured per mol(NaOH) dispersed. The offer to Stripe of 294 t(CO_2) assumes a more conservative current density (75% of that assumed for the nominal capacity rating) and 45% capacity factor based on a grid-tied system operated during times of low carbon intensity at the balancing-authority level. (As Ebb Carbon scales past the pilot stage, capacity factors will match that of local zero-carbon energy-supply contracts.)

Uncertainties: Capacity factors and carbon intensity of electricity at the final selected site,

equipment uptime, efficiency of the system in field conditions, timeline of scaling HCl offtake partnerships.

c. What is your total overall capacity to sequester carbon at this time, e.g. gross tonnes / year / (deployment / plant / acre / etc.)? Here we are talking about your project / technology as a whole, so this number may be larger than the specific capacity offered to Stripe and described above in 3(b). We ask this to understand where your technology currently stands, and to give context for the values you provided in 3(b).

<1 t(CO_2)/yr

d. We are curious about the foundational assumptions or models you use to make projections about your solution's capacity. Please explain how you make these estimates, and whether you have ground-truthed your methods with direct measurement of a real system (e.g. a proof of concept experiment, pilot project, prior deployment, etc.). We welcome citations, numbers, and links to real data! *(E.g. We assume our sorbent has X absorption rate and Y desorption rate. This aligns with [Sorbent_Paper_Citation]. Our pilot plant performance over [Time_Range] confirmed this assumption achieving Z tCO_2 capture with T tons of sorbent.)*

The assumed Faradaic efficiency and current density values for the electrodialysis units are based on vendor specifications and also our past experience measuring the performance of these systems (see for example, C.-F. de Lannoy et al., 70, 243-253, 2018). The 45% capacity factor at emissions intensity of 0.075 t(CO_2)/MWh assumes a grid-tied system operated during times of low carbon intensity at the balancing-authority level and is based on J. A. de Chalendar et al. PNAS, 116 (51) 25497-25502, 2019. Given these numbers, the rate of NaOH generation can be calculated. To calculate the rate of CO_2 capture, we assume 0.8 mol(CO_2) per mol(NaOH), which is based on calculations of seawater chemistry assuming a starting (prior to NaOH addition) pH of 8.1, salinity = 35, temperature = 18 °C, and starting dissolved inorganic carbon (DIC) concentration of 2390 μmol/kg. Actual values will range from 0.7 - 0.92 mol(CO_2) per mol(NaOH), depending on local seawater chemistry.

e. Documentation: If you have them, please provide links to any other information that may help us understand your project in detail. This could include a project website, third-party documentation, project specific research, data sets, etc.

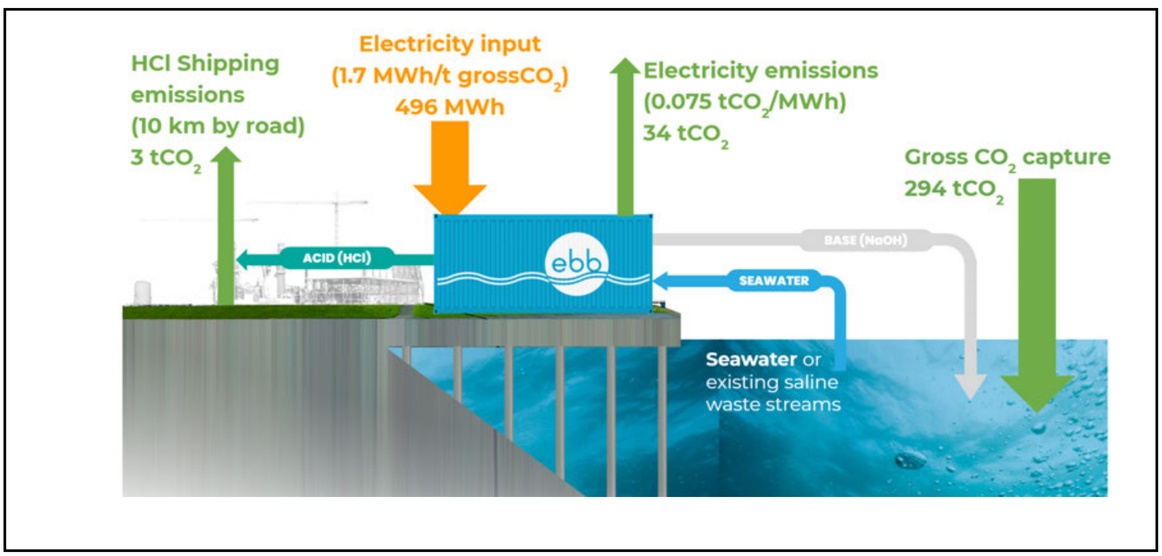
Matthew Eisaman, This is CDR talk: https://www.youtube.com/watch?v=950SLzuAuCo

4. Net Capacity / Life Cycle Analysis (Criteria #6 and Criteria #8)

a. Please fill out the table below to help us understand your system's efficiency, and how much your lifecycle deducts from your gross carbon removal capacity.

	Offer to Stripe (metric tonnes CO_2)
Gross carbon removal	294 tCO_2
Gross project emissions	37 tCO_2
Emissions / removal ratio	0.13 (This assumes grid electricity with emissions intensity of 0.075t(CO_2)/MWh for first deployments. Later deployments using, for example, offshore wind with 0.012t(CO_2)/MWh would have a ratio of around 0.03)
Net carbon removal	257 tCO_2

b. Provide a carbon balance or "process flow" diagram for your carbon removal solution, visualizing the numbers above in table 4(a). Please include all carbon flows and sources of energy, feedstocks, and emissions, with numbers wherever possible *(E.g. see the generic diagram below from the CDR Primer, Charm's application from last year for a simple example, or CarbonCure's for a more complex example).* If you've had a third-party LCA performed, please link to it.



To additionally inform the above analysis, a third-party LCA has been commissioned and is underway.

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

Electricity consumption and fossil fuel emissions from transport of the acid byproduct will dominate GHG emissions of Ebb's process by orders of magnitude, especially in early years when the electricity source is not entirely carbon-free. Therefore, for now our estimate of the CO_2 emissions process only includes these two contributions. We are currently having a third-party LCA conducted that will include additional details such as the emissions from the manufacturing, delivery, and installation of all components and materials.

d. Please justify all numbers used 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 assumptions behind the gross CO_2 capture rate is explained in 3d. To calculate CO_2 emissions from the electricity needed to power the process, we first calculate the required power using the voltage measured for our system (see e.g., C.-F. de Lannoy et al., 70, 243-253, 2018), and supported by vendor specifications, at the assumed current density. The emissions from this energy demand is calculated using a 45% capacity factor at emissions intensity of 0.075 t(CO_2)/MWh, which assumes a grid-tied system operated during times of low carbon intensity at the balancing-authority level and is based on J. A. de Chalendar et al. PNAS, 116 (51) 25497-25502, 2019. (Note that as we scale and have access to larger fractions of renewable electricity in the future, this emissions intensity will decrease.) The emissions from shipping HCl to a nearby offtake partner assumes a distance of 10km via tanker truck on highways using an emissions factor of 1.1kgCO_2 tanker^{-1} km^{-1}, a tanker capacity of 36.3 metric tons. The amount of HCl is calculated using mol(HCl)/mol(NaOH) = 1, based on measured data.

e. If you can't provide sufficient detail above in 4(d), please point us to a third-party independent verification, or tell us what an independent verifier would measure about your process to validate the numbers you've provided. (We may request such an audit be performed.)

N/A

5. Learning Curve and Costs (Backward-looking) (Criteria #2 and #3)

We are interested in understanding the learning curve of different carbon removal technologies (i.e. the relationship between accumulated experience producing or deploying a technology, and technology costs). To this end, we are curious to know how much additional deployment Stripe's procurement of your solution would result in. (There are no right or wrong answers here. If your project is selected we may ask for more information related to this topic so we can better evaluate your progress.)

a. Please define and explain your unit of deployment. (*E.g.* # of plants, # of modules) *(50 words)*

Ebb's core technology, the membrane stack, scales with membrane area. Analogous to the solar industry, Ebb Carbon will factory-produce membrane modules--deploying additional modules to scale. Our first unit will be 50t(CO_2)/year packaged in a shipping container. The next five systems will be 200t(CO_2)/year per shipping container.

b. How many units have you deployed from the origin of your project up until today? Please fill out the table below, adding rows as needed. Ranges are acceptable if necessary.

Year	Units deployed (#)	Unit cost ($/unit)	Unit gross capacity (tCO_2/unit)	Notes
2021	1	$36,000	< 1 t(CO_2)/y	Demonstration system in the lab. First field unit to be deployed in 2022.

c. Qualitatively, how and why have your deployment costs changed thus far? (*E.g. Our costs have been stable because we're still in the first cycle of deployment, our costs have increased due to an unexpected engineering challenge, our costs are falling because we're innovating next stage designs, or our costs are falling because with larger scale deployment the procurement cost of third party equipment is declining.*)

Costs will decrease from the 50t(CO_2)/year system to the 200t(CO_2)/year system as CapEx decreases with increasing size and engineering refinements, but also due to increasing uptime. Opex will decrease as industrial colocation enables cost sharing and scale allows access to lower-cost and lower-carbon-intensity electricity.

d. How many additional units would be deployed if Stripe bought your offer? The two numbers below should multiply to equal the first row in table 3(a).

# of units	Unit gross capacity (tCO_2/unit)
1 (and part of the capacity of a second unit, as needed depending on deployment timing)	200 t(CO_2)/unit

6. Cost and Milestones (Forward-looking) (Criteria #2 and #3)

We ask these questions to get a better understanding of your growth trajectory and inflection points, there are no right or wrong answers. If we select you for purchase, we'll expect to work with you to understand your milestones and their verification in more depth.

a. What is your cost per ton CO_2 today?

$1950/ton(net$CO_2$) (price per ***net*** metric ton **projected** at the 200t(CO_2)/y cumulative capacity scale)

b. Help us understand, in broad strokes, what's included vs excluded in the cost in 6(a) above. We don't need a breakdown of each, but rather an understanding of what's "in" versus "out." Consider describing your CAPEX/OPEX blend, assumptions around energy costs, etc.

Included

CapEx for balance of plant (pumps, etc.) and electrochemical system using quoted vendor prices for small unit volumes (unnegotiated, single unit vendor quotes for larger industrial units in analogous industries are 10x cheaper)

CapEx cost factor of 2

Retail grid electricity at $250/MWh with 45% capacity factor and emissions intensity of 0.075t(CO_2)/MWh, e.g. consistent with Bonneville Power balancing authority (these assumptions affect net/gross CO_2 ratio and amortization of CapEx)

Cost and CO_2 emissions to transport acid by road

~~$2/ton acid disposal cost~~ $2/ton(3 wt% acid) disposal cost in years 1-3, $1/ton(3 wt% acid) in years 4-5

Water use at $0.89/$m^3$

Periodic membrane replacement

Not included
R&D and other non recurring engineering (NRE) expenses

c. List and describe **up to three** key upcoming milestones, with the latest no further than Q2 2023, that you'll need to achieve in order to scale up the capacity of your approach.

Milestone #	Milestone description	Why is this milestone important to your ability to scale? (200 words)	Target for achievement (eg Q4 2021)	How could we verify that you've achieved this milestone?
1	Productization of an Ebb standard Twenty Foot Equivalent Unit (TEU) shipping container module	Allows us to scale the capacity of a single TEU from 50t(CO_2)/y to 200t(CO_2)/y	Q4 2022	First TEU produced with capacity of 200t(CO_2)/y
2	Offtake agreement established for aqueous HCl in volumes sufficient to meet CO_2 offset volume targets	The aqueous HCl produced by Ebb Carbon must be prevented from returning to the ocean	Q1 2023	Offtake agreement established
3	Integration with existing industrial process that provides a saline effluent	Provides high-volume input source to the Ebb Carbon process without the need to permit or install new intake infrastructure. Provides permitted outfall. Allows scale to access low-cost, low-carbon-intensity electricity.	Q2 2023	Ebb Carbon unit colocated with existing industrial facility

i. How do these milestones impact the total gross capacity of your system, if at all?

Milestone #	Anticipated total gross capacity prior to achieving milestone (ranges are acceptable)	Anticipated total gross capacity after achieving milestone (ranges are acceptable)	If those numbers are different, why? (100 words)
1	<1 t(CO_2)/y	250 t(CO_2)/y	Initial 50t(CO_2)/y system deployed followed by an additional 200t(CO_2)/y Ebb Carbon module that will be engineered and deployed.
2	250 t(CO_2)/y	450 t(CO_2)/y	Acid offtake agreement allows deployment of at least one additional Ebb Carbon module
3	450 t(CO_2)/y	650 t(CO_2)/y	Integration with existing industrial facility allows deployment of at least one additional Ebb Carbon module

d. How do these milestones impact your costs, if at all?

Milestone #	Anticipated cost/ton prior to achieving milestone (ranges are acceptable)	Anticipated cost/ton after achieving milestone (ranges are acceptable)	If those numbers are different, why? (100 words)
1	$1950/t($CO_2$)	$1950/t($CO_2$)	Cost is the same because this milestone will affect scaling capacity but not dominant costs of electrochemical CapEx and electricity price.
2	$1950/t($CO_2$)	$1950/t($CO_2$)	Cost is the same because this milestone will affect

			scaling capacity but not dominant costs of electrochemical CapEx and electricity price.
3	\$1950/t(CO_2)	\$1500/t(CO_2) - \$1950/t(CO_2)	Integration with existing industrial facilities potentially allows for cost sharing and access to lower-cost, lower-carbon electricity and should allow larger electrochemical units with lower capex.

e. If you could ask one person in the world to do one thing to most enable your project to achieve its ultimate potential, who would you ask and what would you ask them to do?

Beyond an economy-wide price on carbon we would ask the CEO of Goldman Sachs (or similar entities that invested early in financing wind and solar project developments) to build a team to create project finance structures and capacity to fund the expansion of deployments of CDR technologies like Ebb Carbon.

f. Other than purchasing, what could Stripe do to help your project?

Create standards that help the market filter for high-quality CO_2 removal offsets.

Encourage other companies to also buy high quality CO_2 removal offsets.

Perhaps create a market for CO_2 removal offsets that can integrate with transactions on the Stripe network.

7. Public Engagement and Environmental Justice (Criteria #7)

In alignment with Criteria 7, Stripe requires projects to consider and address potential social, political, and ecosystem risks associated with their deployments. Projects with effective public engagement tend to do the following:

- Identify key stakeholders in the area they'll be deploying

- Have some mechanism to engage and gather opinions from those stakeholders and take those opinions seriously, iterating the project as necessary.

The following questions are for us to help us gain an understanding of your public engagement strategy. There are no right or wrong answers, and we recognize that, for early projects, this work may not yet exist or may be quite nascent.

a. Who are your external stakeholders, where are they, and how did you identify them?

Ebb Carbon systems will most likely be deployed at coastal facilities that treat waste effluent from desalination and wastewater treatment plants. The communities and stakeholders who will be affected by Ebb's process include employees, local coastal communities, the aquaculture, fisheries, and tourism industries, and the organisms comprising marine ecosystems. We are engaging these communities, soliciting feedback and concerns, and adjusting our design and deployment plan accordingly. We expect Ebb to be safe for marine life and beneficial to many of the industries and communities that rely on coastal ecosystems, and we are performing tests to verify this before deployments occur.

b. If applicable, how have you engaged with these stakeholders? Has this work been performed in-house, with external consultants, or with independent advisors?

We have engaged external consultants and advisors and have started discussions with aquaculture facilities about the potential for locating Ebb Carbon systems onsite. As part of these discussions, we have tried to understand how Ebb's process can integrate with their existing operations, and also what constraints their operation may place on Ebb Carbon. We have started working with academic researchers to study the potential effects of the Ebb process on marine organisms and ecosystems to establish clear data-driven guidelines for safe operation. We have also started discussions with government agencies to understand the likely permitting requirements.

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?

To ensure safety of marine ecosystems, the Ebb Carbon process has been designed to limit the maximum local pH shift at the point of dispersal to natural ranges, i.e. < 0.4 pH units. Based on our initial discussions, this limit would mean that Ebb is safe, and probably beneficial, for marine life, and would also be beneficial to existing aquaculture operations. In most cases, this also means that when colocated with a desalination plant, Ebb's process would fall under existing permits and actually reduce the environmental impact of the desalination plant by reducing the salinity of its effluent.

d. Going forward, do you have changes planned that you have not yet implemented? How do you anticipate that your processes for (a) and (b) will change as you execute on the work described in this application?

> We are currently at a very early stage so the primary difference moving forward will be a deeper level of engagement with the stakeholders already mentioned, and also engagement with a wider array of stakeholders, including local communities, indigenous communities, the fishing and tourism industries, the offshore wind industry, and the relevant permitting agencies.

e. What environmental justice concerns apply to your project, if any? How do you intend to consider or address them?

> Environmental justice concerns apply to any technology intended to scale to Gt(CO_2)/year since deployment choices inevitably distribute the technology's effects geographically. Ebb Carbon's modular approach will allow more equitable siting of deployments compared to a large, centralized facility. Ebb is committed to the principles of justice, diversity, equity, and inclusion, and we have codified this in the "Company Pillars" section of Ebb Carbon's Founding Charter, which includes "Practice Environmental Justice" as one of our pillars. We expect Ebb's process to be safe for employees as well as safe and beneficial for marine life and local communities.

11. Legal and Regulatory Compliance (Criteria #7)

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

> While we have not sought or received any formal legal opinions regarding the deployment of our solutions yet, we have received informal opinions that our approach is permissible in California, Federal, and International jurisdictions with the required permits.

b. What permits or other forms of formal permission do you require, if any? 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.

> We expect to operate within existing permitted industrial or municipal uses of seawater intake and discharge. These permits are typically granted through public engagement with multiple constituencies and agencies. We will operate midstream within these permitted industrial process flows and ensure that discharge from our system enables the permitted process intake and discharge parameters to stay within their permitted boundaries. In all cases we will

improve, from an environmental impact standpoint, the pH and salinity of effluents from these existing processes. We will operate within industry standards and regulations regarding the safe handling, storage, transportation, and end-use of byproduct HCl.

c. 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.

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

The London Protocol is an international treaty ratified by 53 countries (not the US) that prohibits dumping of wastes in the ocean. By using only seawater and energy to affect the carbonate system, rather than mining and dissolving minerals or altering biological systems, Ebb most likely avoids potential pitfalls of contamination and biogeochemical alterations covered under the London Protocol.

d. Does the project from which you are offering carbon removal receive credits from any government compliance programs? If so, which one(s)? (50 words)

We do not expect to receive carbon credits from any government compliance programs during the delivery period to Stripe.

12. Offer to Stripe

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

	Offer to Stripe
Net carbon removal (metric tonnes CO_2)	257 t/CO_2

Delivery window (at what point should Stripe consider your contract complete?)	March 2022 - September 2024
Price ($/metric tonne CO_2) ***Note on currencies:*** *while we welcome applicants from anywhere in the world, our purchases will be executed exclusively in USD ($). If your prices are typically denominated in another currency, please convert that to USD and let us know here.*	$1950/t$CO_2$

Application Supplement: Ocean

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

Physical Footprint (Criteria #1)

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

> Typical deployment locations will be coastlines connected with existing industrial activities. Ebb Carbon's technology requires sea water intakes and outfalls, and access to electricity with a low carbon intensity. Ebb prefers to co-locate systems with other coastal facilities that process seawater such as desalination or wastewater recycling facilities because of their potential for cost reduction by shared infrastructure and reduced additional local impact. Access to road, rail, or marine shipping will be required to transport acid byproducts to end-use locations.

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.

> Ebb Carbon's technology is packaged inside of Twenty Foot Equivalent Unit (TEU) shipping containers for compactness and flexibility, and will often collate with an industrial process (e.g.

a desalination plant). Additional TEU-sized tanks may be required to manage product distribution. Plumbing and power connections will interface directly to the containers. Adequate access is required around the containers for maneuvering or transfer operations.

Our first modular unit will fit 50t(CO_2)/y capacity into one TEU measuring 20 ft(length)×8 ft(width)×9 ft (height) with a footprint of 160ft^2. The second and third units, which will be responsible for most of the CO_2 removal for our Stripe commitment, will fit a 200t/y system in one TEU, for a footprint of 200t(CO_2)/y per 160 ft^2, or 1.25t(CO_2)/y per ft^2, equivalent to 135,000t(CO_2)/y per hectare. Within five years we expect to be able to achieve a capacity of 500t/y per TEU module for a footprint of 3.125t(CO_2)/y per square foot, equivalent to about 336,000t(CO_2)/y per hectare. The need for temporary storage tanks may increase these footprints somewhat. Stacking containers could significantly reduce these footprints.

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.

We will scale analogously to how the solar photovoltaics (PV) industry has scaled. In the same way that all PV systems are constructed from ~5 Watt (W) cells packaged in ~300W modules which are integrated into systems sized 5kW to 500MW+, we will scale single membranes in module stacks of multiple membranes which can be configured into large field deployments designed around repeatable optimized system blocks. This gives us flexibility to accommodate the long tail of small systems as needed to satisfy local requirements, up to the large multi-megaton scale systems using the same core components built in a factory. As operational and system design efficiencies improve through iteration, the physical footprint will steadily decrease over time.

Assuming the 500t/y TEU module with a footprint of 336,000 t(CO_2)/y per hectare described in 2a, 100Mt(CO_2)/y would have a footprint of about 298 hectares.

Potential to Scale (Criteria #2 and #3)

4. Building large systems on or in the ocean is hard. What are your core engineering challenges and constraints? Is there any historical precedent for the work you propose?

Ebb Carbon's technology is currently designed for onshore operation to work with existing infrastructure, so core engineering challenges and constraints related to ocean systems have largely been minimized. There are still engineering challenges and constraints around process optimization, material handling, and near-ocean environmental conditions. With respect to feedstocks and product discharge in and out of the ocean, there is a precedent with existing industrial processes, specifically: industrial cooling, desalination and water treatment. Two of Ebb Carbon's co-founders studied engineering at the California Maritime Academy and have extensive experience engineering and deploying systems in the marine environment.

Externalities and Ecosystem Impacts (Criteria #7)

5. How will you quantify and monitor the impact of your solution on ocean ecosystems, specifically with respect to eutrophication and alkalinity/pH, and, if applicable, ocean turbidity?

At specific deployment sites, pH measurements at the point of NaOH dispersal will provide feedback to the electrochemical unit to keep the steady-state maximum pH change well within safe bounds (maximum, local pH change < 0.4 pH units). When colocated with an existing industrial facility like a desalination plant, Ebb Carbon's process would likely fall under existing permits and actually reduce the environmental impact of the plant by reducing the salinity of its effluent. We have started discussions with government agencies to understand the likely permitting requirements for stand-alone systems.

We expect Ebb Carbon to be safe for marine life, but to verify this we are in the process of designing mesocosm studies to assess the effects of Ebb's process on marine organisms such as coccolithophores and diatoms. We also aim to perform periodic sampling before and during deployment at Ebb locations to record any physiological responses of organisms in response to the Ebb Carbon process.