[Solid Carbon] Carbon Removal Purchase Application

General Application

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

Company or organization name

Ocean Networks Canada

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

Victoria

Name of person filling out this application

Kunal Khandelwal

Email address of person filling out this application

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Brief company or organization description

World-leading Cabled Ocean Monitoring Infrastructure and Big Data Not-for-profit

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.

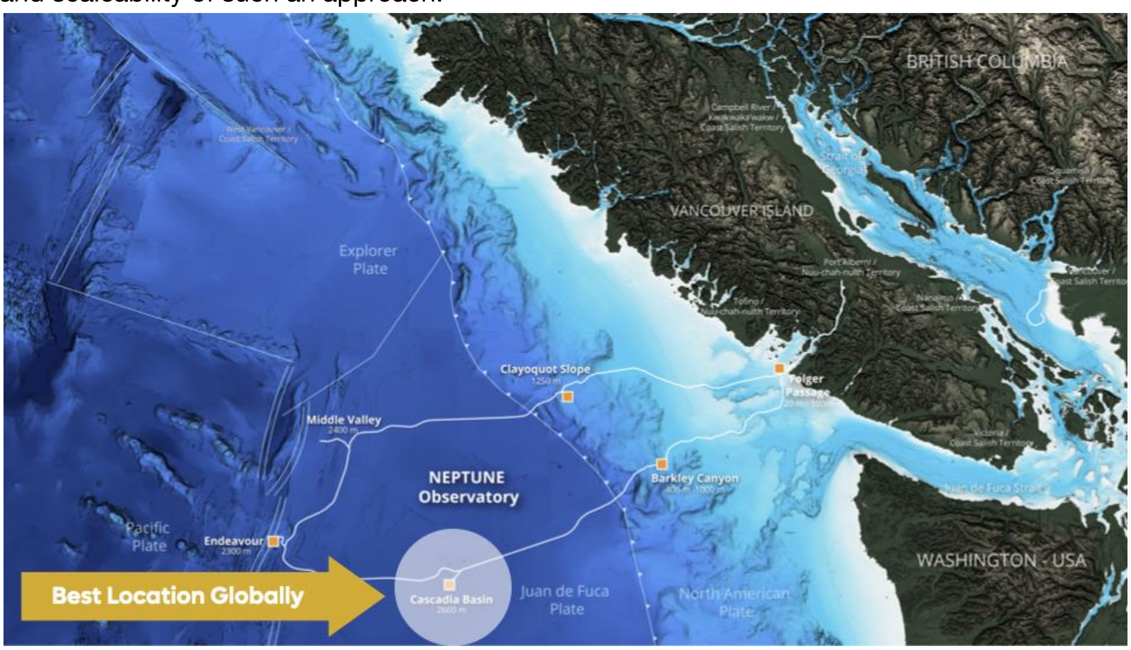
<1500 words

Solid Carbon is an offshore negative emissions technology that aims to turn carbon dioxide (CO2) into rock. Ocean Networks Canada is leading Solid Carbon along with an international team of researchers committed to advancing technology to draw CO2 from the air and inject it below the seafloor into ocean basalt. There, it will react with the basalt and mineralize into rock, providing a durable and vast reservoir for Carbon Dioxide Removal (CDR). This ambitious project follows a globally scalable systems approach that is urgently required to meet planetary climate targets.

In essence, Solid Carbon is integrating six separate, yet proven technologies into a fully integrated system that will extract CO2 from the atmosphere through (1/6) Direct Air technology, installed on an (2/6) ocean floating platform, powered by (3/6) wind, solar, and/or thermal energy, and (4/6) injects the CO2 into the subsea floor (5/6) using offshore drilling technology, where it will (6/6) react with the basalt and mineralize into stable rock.

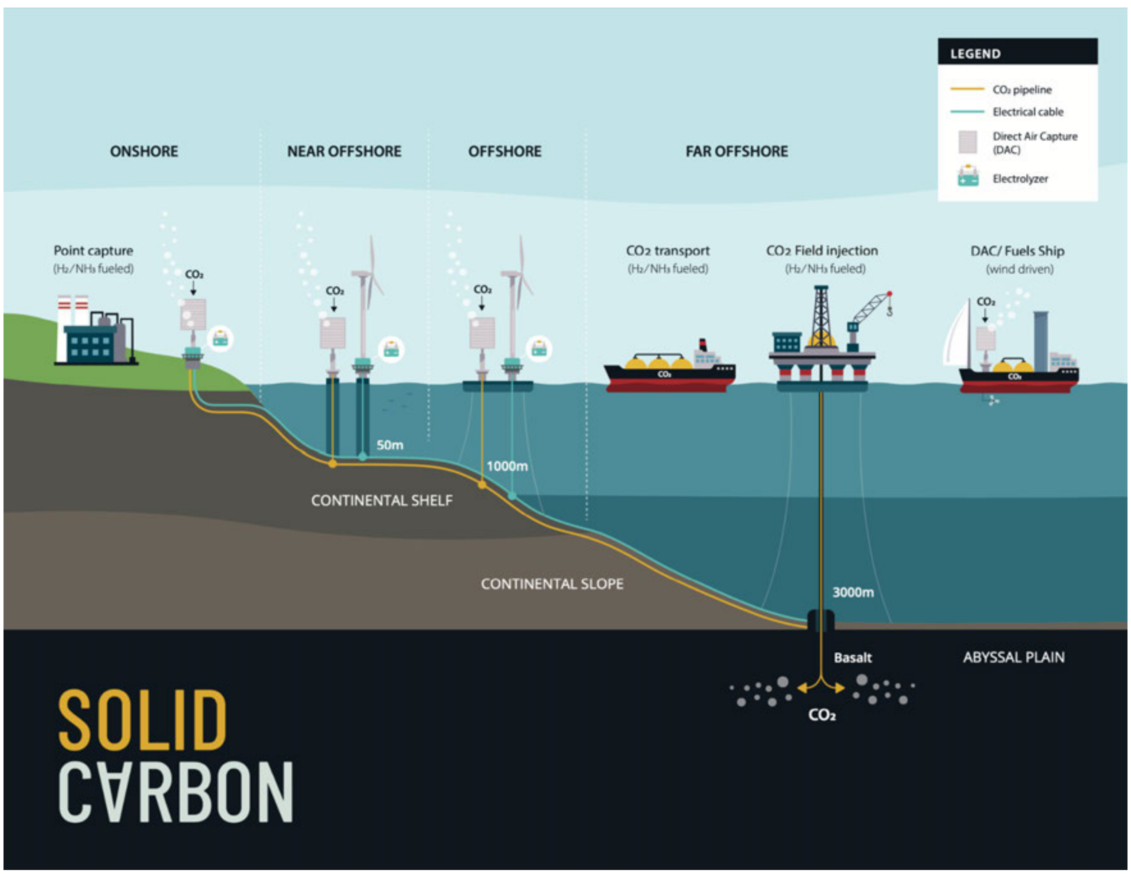
Based on the success of the Carbfix project in Iceland with onshore Basalt (where CO2 converted into carbonates within 2 years), Solid Carbon aims to build on this by demonstrating the efficacy of carbon sequestration in ocean basalt, which constitutes over 90% of basalt on Earth. We propose to design and conduct a field test of CO2 injection into ocean basalt, tracking the hydrological and geochemical impacts of permanent sequestration, and evaluate new and established monitoring approaches to ensure safety.

An offshore hydrogeological experiment will take place at Ocean Networks Canada's deep-water Cascadia Basin site using existing scientific drill ship technology. Stripe's CDR purchase agreement will help us raise the remaining funding and to proceed with a demonstration as early as 2023 or maximum by 2025 to showcase the permanence, durability and scaleability of such an approach.



Ocean Networks Canada has more than 800kms of cables having power and internet connection laid out as per the network shown in the diagram. Each of the boxes is a node that is connected to hundreds of sensors collecting real-time live data that is made available on ONC's very own Big Data Platform. The proximity of the demonstration site to Cascadia Basin node, makes it the best possible location globally for the demonstration as the sequestered CO2 could be monitored in real-time using existing infrastructure.

Solid Carbon has a rich history starting as early as 2008, when one of its principal researchers (from Columbia University) published a paper on CCS in ocean basalt in the Cascadia Basin. In 2010 , two scientific boreholes were drilled in the proposed carbon storage area, to complete the evaluation of the formation-scale hydrogeologic properties within the oceanic crust (led by University of California, Santa Cruz). In 2017, the US Department of Energy funded a pre-feasibility study led by Columbia University along with Ocean Networks Canada and University of Victoria researchers. Based on the success of this study, in 2019, ONC-led Solid Carbon received funding from the Pacific Institute for Climate Solutions for a four-year desktop study to evaluate a) Systems Engineering aspect (UVic) b) Demonstration Planning (ONC) and c) Acceptance from a social (UBC), regulatory (Columbia University) and investor (ONC) perspective. Solid Carbon was also one of the top 100 finalists in the MacArthur Foundation's 100&Change competition in 2020.



The systems engineering aspect will help evaluate the optimum way of combining the different technologies for a given set of location parameters for the ocean basalt. While the ideal solution could be to have offshore DAC on floating platforms powered by renewable energy, there could also be a pairing of onshore DAC with pipelines where the Basalt is very close to the coast. The diagram above showcases the different permutation and combinations possible

Project Lead Organization - Ocean Networks Canada (ONC) Funding Partner - Pacific Institute for Climate Solutions (PICS) Research Partners University of Victoria (UVic) Columbia University University of British Columbia (UBC) University of Calgary (UCal) University of Washington University of California, Santa Cruz GEOMAR Helmholtz Centre for Ocean Research Kiel Industry Partners Carbon Engineering Carbon180 TechnipFMC (Partnership in progress) Regulatory Partners Natural Resources Canada Environment and Climate Change Canada Department of Fisheries and Ocean Canada National Research Council Canada

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.)*

<50 words ONC with its over $500 M infrastructure consisting of over 800 km of underwater cables and observatories with thousands of sensors is well positioned to lead the demonstration of the technology in partnership with partner Universities and Industry organizations and showcase the efficacy of this solution globally

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

<300 words 1) Environmental Risk - The CO2 escapes into the ocean. This risk is very low, as proven by the results of the CarbFix experiment in Iceland. Not only is there a 300-m thick, low-permeability sediment layer called “caprock” above the basalt that

impedes any CO_2 migration to the surface, in the unlikely event that CO_2 would leak into the caprock and rise and cool, it would form hydrates still within the sediment and stay in the seafloor rather than continue to the surface. Regardless, real-time, 24/7 monitoring of the seafloor will be conducted by Ocean Networks Canada.

2) Industry Support Risk - Industry may see this as a way to continue to extract fossil fuels and pollute.

Solid Carbon is currently working with oil and gas services providers; they see the downturn in their markets and recognize the need for new -sustainable- opportunities for their organizations and workers.

3) Regulatory Risk - Carbon dioxide must be listed in Schedule 5 of Canadian Environmental Protection Act (CEPA) in order for Solid Carbon to move forward with a demonstration.

Canada has already signed on internationally, we are just awaiting domestic amendments (a procedural delay). Ocean Networks Canada is in ongoing conversations with Environment and Climate Change Canada regarding reforms to the Canadian Environmental Protection Act (CEPA); it is anticipated that the required changes are imminent.

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

Fiber optic sensor to detect CO_2 gas at high pressures.
US Patent Application # 15/032,794, Canadian Patent # 2929635

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*	*<10 words* 8 weeks between 2023-2025

on performance.	
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.*	*<10 words* 8 weeks between 2023-2025
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 words* 10,000 tonnes injection would be spaced out over 8 weeks. This would help identify the most optimized approach to injecting supercritical CO2 into the ocean basalt
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 words* Greater than 10,000 years

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

Number/range 10,000 years - 10,00,000 years

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.)*

<200 words

The basalt layer where the CO2 is being injected is 3,000+ m below sea level. At these depths, CO2 is not buoyant in comparison to the sea water. Also the basalt layer has a 300 m thick cap rock above it acting as a protective shell for the CO2. Thanks to these twin protection, the CO2 will remain as it is within the reservoir and gradually dissolve into the pore water. Pore water is naturally moving at 2-3 m/day along the fastest routes of well-connected channels and thus may reach the nearest outcrop over 50 km away in about 50 years but it is expected that most dissolved CO2 will by then have mineralized or taken another route, and whatever (if any) escaped will remain near the ocean bottom at over 2,500 m below sea level. The only path back into the atmosphere would be through volcanic eruptions that occur some 400 km away which is still highly unlikely. The ocean crust is slowly moving towards it at about 4 cm per year, thus arriving after about 10 million years

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?

<200 words

The previous section explains how the durability risk is quite low with the upper bound being 10M years. With regards to fundamental uncertainties associated with the CO2 injection into basalt, one of our teams from the University of Calgary published an article recently that talks about this in detail. Essentially, this paper shows that, because the sediment "blanket" overlying the sub-seafloor basalts will give the CO2 plenty of time to dissolve and react with the basalts, it is still reasonable to expect significant CO2 mineralization.

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.)*

<200 words

Solid Carbon has developed and is further refining a comprehensive monitoring plan to follow the outcome of the injected CO2. This includes remote sampling through geophysical methods such as seismic and electromagnetic monitoring that indirectly image the CO2 plume in the subsurface, and also direct sampling at monitoring holes capturing pore fluids. Through the use of reactive and non-reactive tracers added to the injection fluids (simulating the outcome of the CO2 left behind by mineralization and also background pore fluids freely flowing through the formation), it will be possible to calculate and thus monitor the

mineralization. In addition, the injection hole will be visually monitored by a camera and the surrounding area by acoustic sonar that would detect any ebullition. Further, insights will feedback into our reactive transport modelling to refine reservoir predictions. As the monitoring data will be streaming into the Ocean Networks Canada data archive and will thus be freely and openly accessible to the public through the Oceans 2.0 data portal, the at-a-glance overview Dashboard tool will be utilized to access the current state of the system, how much CO2 is injected, how the plume migrates below the subsurface, how much of it dissolves, mineralizes, and any associated occurrences such as injection-induced small scale seismicity, live view of the injection hole and the bubble-monitoring sonars, all as near-real-time as possible.

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	*E.g. XXX tCO_2* 10,000 metric tonnes
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	*E.g. XXX tCO_2* 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)*

<150 words

We are hoping to inject a total of 10,000 tons of CO2 that will be made available through either industrial or commercial sources and transported to the injection site

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).

 # metric tonnes CO_2/yr

It has been estimated that each well is capable of injecting 1.2 Million tonnes of CO2 with the total estimated storage capacity over 750 Gigatonnes of CO2 just within the Cascadia Basin. The demonstration that we are proposing of 10,000 tonnes in 8 weeks will help us understand key injection parameters as well as rates of mineralization. We would be able to further refine our estimates based on the results of the demonstration.

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.)*

<200 words

Estimates of global subsea basalt geosequestration are on the order of 100,000–250,000 GtCO2 (1), and the area of interest within the Cascada basin is estimated at 750 Gt CO2 (2). Further analysis linking sequestration to offshore wind capacity is soon to be published.

Well-scaled estimates of the Cascadia Basin are ongoing via reactive transport modelling, based on laboratory experiments examining the reactivity of pure basaltic minerals and intact basalt core samples and geophysical and geochemical measurements of natural carbonation reactions in Cascadia basin.

(1) Snæbjörnsdóttir, S. Ó.; Sigfússon, B.; Marieni, C.; Goldberg, D.; Gislason, S. R.; Oelkers, E. H. Carbon Dioxide Storage through Mineral Carbonation. Nat. Rev. Earth Environ. 2020, 1, 90–102.

(2) Goldberg, D. S.; Takahashi, T.; Slagle, A. L. Carbon Dioxide Sequestration in Deep-Sea

Basalt. Proc. Natl. Acad. Sci. U. S. A. 2008, 105 (29), 9920–9925.

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.

• www.solidcarbon.ca • https://pics.uvic.ca/projects/solid-carbon-negative-emissions-technology-feasibility-study • https://pubs.acs.org/doi/abs/10.1021/acs.est.1c02733 • https://www.bnnbloomberg.ca/video/we-re-looking-to-put-51-gigatons-per-year-of-co2-into-the-seafloor-geoscientist~2283677 • https://vancouversun.com/news/local-news/research-project-proposes-turning-co2-into-stone-under-the-sea

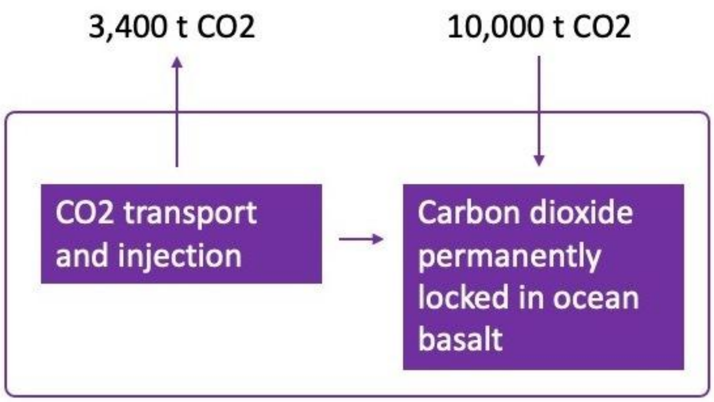
4. Net Capacity / Life Cycle Analysis (Criteria #6 and Criteria #8)

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.

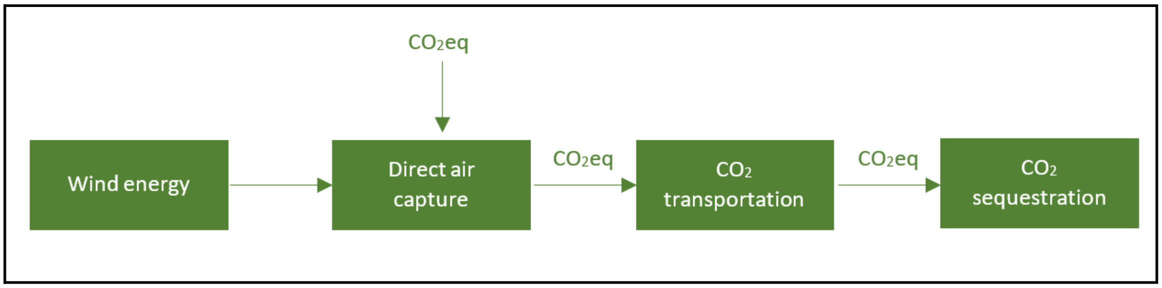
	Offer to Stripe (metric tonnes CO_2)
Gross carbon removal	10,000
Gross project emissions	3,400
Emissions / removal ratio	0.34
Net carbon removal	6,600

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.

The Demonstration



Solid Carbon Big Idea



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?

<100 words Our modelling framework plans include LCA to quantify overall GHG impact of the Solid Carbon concept. This includes both operational and embodied GHGs. Notably, Solid Carbon would use renewable energy (thus no implications of burning fossil C), and sequestration is not affiliated with hydrocarbon extraction nor utilized for C-based fuels (thus no ambiguities around offsetting and counterfactuals).

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.

<200 words The demonstration injection of 10,000 t of CO2 requires a 2-ship operation, one drill ship (D/S) and one supply vessel which we expect to make two trips to the injection site. The D/S Joides Resolution emissions number: 2,447 t CO2 Based on www.iodp.org/doc_download/2537-joides-fact-sheet-11-29-07b (PDF):

Port: estimated as 6 t/day (/0.85 kg/l) = 7,059 l/day times 2 days = 14,118 l
Transit: 40 t/day (/0.85 kg/l) = 47,059 l/day times 3 days = 141,175 l
Station: 13 t/day (/0.85 kg/l) = 15,294 l/day times 50 days = 764,700 l
TOTAL = 919,993 l = 2447 t CO2 (2.66 kg CO2 / l of diesel

The storage barge emission number: 926 t CO2
Based on ONC expedition experience with Island Tug and Barge:
Station: 7 t/day (/0.85 kg/l) = 8,236 l/day times 28 days = 230,588 l
Transit: 20 t/day (/0.85 kg/l) = 23,530 l/day time 5 days = 117,648 l
TOTAL: 348,236 l * 2.66 kg CO2 / l of diesel = 926 t CO2

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.)

<100 words

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)*

<50 words

# of injection wells per sequestration location

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	0	n/a	n/a	Procurement would support our 1st-of-kind demo
2020	0	n/a	n/a	Procurement would support our 1st-of-kind demo
2019	0	n/a	n/a	Procurement would support our 1st-of-kind demo

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.*)

<50 words n/a

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)
Number	The demo would sequester 10,000 t CO2. We anticipate a full-scale unit enabled by the demo to be >=1.2 Mt CO2/yr

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?

Our demonstration cost per ton CO2 would be equal to the cost of demonstration by net CO2 sequestered. The cost is high because for the one-off demonstration we will be chartering marine vessels that comprise more than half the cost. The return on investment of the demonstration, even at this high carbon price, is the confirmation that ocean basalt, with its

vast capacity globally, is the most durable sequestration reservoir.

From the overall technology perspective, our calculations project that for a 25 year sequestration production system that employs DAC on floating offshore platforms powered by renewables/net-zero fuels and in situ mineralization would put the cost of CO_2 in the range of \$170-\$190 per ton of CO_2. Essentially, dedicated CO_2 logistics by ship, pipeline, or co-location drastically reduce costs vs the demo.

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.

>100 words

From the overall technology perspective, this is our anticipated cost of all elements based on levelized costs (capex+opex) precedents from the literature. The main component is DAC. Because energy is sourced from integrated renewable wind, costs are mostly capex. Volatile opex costs (like natural gas) are avoided.

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	First iteration of modelling framework	A modular modelling framework allows iteration and optimization over many possible technologies and systems arrangements (DAC, logistics, wind energy, and more) - for Cascadia and beyond.	May 2022	Technical report and/or peer-reviewed publication(s) detailing modelling methodology and early system results.
2	Completion of the current feasibility	Outputs of the study are a detailed	October 2023	Provision of the drilling

	study.	demonstration plan (drilling prospectus) and characterized ($ and LCA) system architectures. These inform our next steps in Cascadia and new sites beyond.		prospectus, and system modelling results and open-source framework.
3	Undertake the Cascadia Basin demo injection	Provides validation and refinement of injection modelling and is a precondition to developing the Cascadia site at-scale.	Summer 2024	Comprehensive monitoring data acquired during and after injection will be publically available for verification

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	Est. 1.2 Mt per year per well, and 750GtCO2 capacity within the Cascadia Basin.	Similar	n/a
2	Est. 1.2 Mt per year per well, and 750GtCO2 capacity within the Cascadia Basin.	Higher accuracy on per-well capacities (as a function of injection strategy)	The feasibility study comprises detailed reactive transport modelling with best available data to refine our reservoir predictions.
3	Est. 1.2 Mt per year per well, and 750GtCO2 capacity within the Cascadia Basin.	Higher accuracy on per-well and total region capacities (as a function of injection strategy)	Data from the demonstration will be used to validate modelling and further inform reservoir capacity predictions.

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	$170-$190 per ton of CO2	Similar, but with better knowledge of technology tradeoffs	The modelling framework will allow quick exploration of potential system designs, incl. Sensitivity analysis.
2	$170-$190 per ton of CO2	TBD	We expect a higher fidelity anticipated cost/ton following additional work going into the modelling framework.
3	> $2,000 per ton of CO2	$170-$190 per ton of CO2	The higher prior cost reflects the (mainly logistics) cost of a one-off demonstration to validate the Cascadia site. A purpose-built production-scale system would converge on modelled costs.

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?

<50 words We would ask Mark Carney to showcase Solid Carbon's potential to durably store thousands of gigatons of CO2 to the financial and political G7 leaders that would help drive investments, resources to scale it globally.

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

<50 words Stripe can help introduce Solid Carbon to potential industry partners, government partners as well as philanthropic foundations that may have an interest in investing in large scale CDR

projects like Solid Carbon. Stripe could also assist Solid Carbon through advising or introducing the team to commercialization and business development experts.

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?

<100 words
Social acceptance is a key part of the ongoing Solid Carbon feasibility study. This part of the project led by University of British Columbia is conducting research to understand public perceptions (drivers of acceptability and unacceptability) of Solid Carbon and negative emissions technologies. Stakeholder groups include general publics of BC and WA, scientific experts, and local coastal communities (incl. Indigenous communities).

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

Work is in-house. Public and expert surveys have already been conducted. Most data have already been analyzed and manuscripts are being prepared for publication. Insights from these will inform forthcoming in-person engagement/interviews with local coastal communities.

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
72% of geotechnical and marine experts surveyed agreed that technologically engineered NETs will be necessary to stabilize warming. Public respondents were also supportive of the project, with only 11% of BC respondents opposed or strongly opposed (15% in Washington). The risks of most concern to participants were those of ocean pollution and impacts to deep ocean ecosystems. Further engagement with local and Indigenous communities, planned to

begin in early 2022, will aim to better understand these and other concerns and be used to suggest potential measures to mitigate any impacts.

From a public acceptance pov, one large challenge is how people think about the scale of carbon removed through different strategies/NETs and how that affects support or rethinking of technologies such as Solid Carbon. This is beyond the scope of initially planned research but key to future research including anything we might do under a new initiative.

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?

<100 words
There were no changes planned that have not yet been implemented. We might anticipate adjustments in the timing of actions for the overall technology, as well as additional outreach and stakeholder engagement activities that would occur alongside the demonstration.

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

<100 words
The current location is off the coast of Vancouver Island. From an environmental justice perspective the project should translate into economic and societal gains for the coastal population and the First Nations located in the region in the form of revenues, jobs, community investments and taxes. That said, in the global community, there is much resistance to the idea that solutions should be market driven largely because of the optics that: the countries most responsible for GHG's/the climate problem are becoming 'set' to profit from their removal or the solutions.

11. Legal and Regulatory Compliance (Criteria #7)

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

<100 words
Legal academics at Columbia University's Sabin Center for Climate Change Law have conducted a comprehensive legal analysis (see https://climate.law.columbia.edu/sites/default/files/content/Webb%20%26%20Gerrard%20-%20Offshore%20CCS%20in%20Canada.pdf).

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.

<100 words The demonstration injection would require a "disposal at sea" permit from Environment and Climate Change Canada under the Canadian Environmental Protection Act. A seabed license may also be required from Natural Resources Canada. The project team has consulted extensively with both agencies, and provides them with regular updates about the project, but has not yet formally applied for permits.

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.

<100 words There is some uncertainty as to whether a seabed license would be required for the demonstration project and, if so, whether and how such a license could be obtained. There is also some uncertainty regarding whether and how a disposal at sea permit could be obtained. Those permits are issued by Environment and Climate Change under the Canadian Environmental Protection Act. That Act does not currently provide for the issuance of permits for the sub-seabed injection of carbon dioxide. Environment and Climate Change Canada has recommended that the Act be "amended to expressly authorize the . . . issu[ance] of permits for the storage of [carbon dioxide] in sub-seabed geologic formations." A bill to make the necessary amendments is expected to be introduced in 2021/22.

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)

<50 words - As per the latest Canadian Budget (2021), CCUS projects would receive investment tax credit as stated in the link below. However the Solid Carbon demonstration which will offer the carbon removal credits will not be eligible for this tax credit. https://www.canada.ca/en/department-finance/programs/consultations/2021/investment-tax-credit-carbon-capture-utilization-storage.html

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)	6,600 metric tonnes
Delivery window (at what point should Stripe consider your contract complete?)	Completion of the 8week demonstration latest by 2025
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.*	*This is the price per ton of your offer to us for the tonnage described above. Please quote us a price and describe any difference between this and the costs described in (6).* $2,000/metric tonne CO2, for every ton of CDR purchased, will contribute towards the purchase and transfer of CO2 to the demonstration location as well as towards R&D with regards to offshore geologic injection into Basalt.

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.

> *<200 words*
> Cascadia Basin in the Northeast Pacific Ocean, about 200 km for the coast and nearest settlement.

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.

> *<200 words*
> The physical footprint is restricted to several hundred meters around the CO2 injection site, in the upper basalt rock layer, about 3,000 m below the sea surface, beneath about 300 m of sediment cap rock.

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.

> *<200 words*
> One injection site could sequester about 2 Mt of CO2/yr over about 25 years with a total storage area of a few km radius, modelled as less than 8 km diameter for 50 Mt. Thus, 100 Mt of CO2/yr would require 50 injection sites, and if spaced for maximum injection volume would require about 60 km by 60 km, or 3,600 km2 (of sub-seabed area), but would then yield a

total sequestration volume of 2.5 Gt CO_2.

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?

<200 words

Drilling and fixing an injection hole into deep ocean crust has been done many times before. Offshore wind also exists (albeit at limited depths). DAC exists, but not offshore (but could be put nearshore on land if need be). The main challenge may be adapting these precedents for an integrated and dedicated design (and manufacturing capacity) to realize the most competitive performance.

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?

<200 words

A comprehensive monitoring plan carried out by Ocean Networks Canada will track the CO_2 plume in the deep ocean crust through indirect (geophysical) and direct in-situ sampling at monitoring wells as well as the ocean floor. This will be in addition to the natural safety net that the CO_2 will be heavy at that depth so that any leaked CO_2 cannot reach the atmosphere (Rackley, S. A. (2010), Carbon Capture and Storage, Butterworth-Heinemann, pp 267. https://doi.org/10.1016/B978-1-85617-636-1.00012-2.), and once in the basalt rock, mineralization and thus durable storage in form of solid rock can occur in a timely manner (Matter et al. (2016), Rapid carbon mineralization for permanent disposal of anthropogenic carbon dioxide emissions, Science 352 (6291), 1312-1314. https://doi.org/10.1126/science.aad8132)

Application Supplement: Geologic Injection

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

Feedstock and Use Case (Criteria #6 and 8)

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

<50 words We will be injecting supercritical CO_2 which may be alternated with sea water

2. Do you facilitate enhanced oil recovery (EOR), either in this deployment or elsewhere in your operations? If so, please briefly describe. Answering Yes will not disqualify you.

<50 words - We don't facilitate enhanced oil recovery.

Throughput and Monitoring (Criteria #2, #4 and #5)

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

<500 words

The setting is porous reactive basalt occurring mostly in the sub-seafloor. The Cascadia Basin is a well-studied example. The ultimate trapping mechanism is CO_2 mineralization as solid carbonates. Additional trapping mechanisms are: stratigraphic trapping by non-porous cap rock and sediments, buoyancy trapping (depends on the site), dissolution trapping in reservoir fluids, and capillary trapping.

Sequestration infrastructure comprises one injection and one to two monitoring wells secured with casings and packers (existing ones at the site may be reused), an injection and a supply vessel with reusable transport pipes and pumps to inject CO_2 in supercritical form into seafloor basalt.

Solid Carbon has developed and is further refining a comprehensive monitoring plan to follow the outcome of the injected CO_2. This includes remote sampling through geophysical methods such as seismic and electromagnetic monitoring that indirectly image the CO_2 plume in the subsurface, and also direct sampling at monitoring holes capturing pore fluids. Through the use of reactive and non-reactive tracers added to the injection fluids (simulating the outcome of the CO2 left behind by mineralization and also background pore fluids freely flowing through the formation), it will be possible to calculate and thus monitor the mineralization. In addition, the injection hole will be visually monitored by a camera and the surrounding area by acoustic sonar that would detect any ebullition.

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

<10 words N/A

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

Unit volume/unit time - average of 200 tonnes/day for demonstration

Environmental Hazards (Criteria #7)

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

<200 words

The only major environmental risk for the project is if there is CO2 leakage. As explained previously this risk is very low, as proven by the results of the CarbFix experiment in Iceland. Not only is there a 300-m thick, low-permeability sediment layer called "caprock" above the basalt that impedes any CO2 migration to the surface, in the unlikely event that CO2 would leak into the caprock and rise and cool, it would form hydrates still within the sediments and stay in the seafloor rather than continue to the surface. Regardless, real-time, 24/7 monitoring of the seafloor will be conducted by Ocean Networks Canada.

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

<200 words

Key uncertainties for using and scaling the injection method include:

1) The physical dynamics of multiphase (water + CO2) flow during full-scale CO2 injection. Although multiphase flow is well described in sedimentary basins, injecting supercritical CO_2 into water-filled basalt has been explored to a much lesser degree. Optimizing CO_2 mineralization will involve optimizing CO_2 and water flow in the subsurface, for which such physical models are key.

2) Mineralization rates at CO2 injection rates representative of full-scale implementation. Although the CarbFix project and various experimental studies have shown that CO2 can be

rapidly mineralized at modest injection rates, full-scale injection rates shift chemical dynamics and will likely decrease mineralization rates.

Improving on both listed uncertainties is a key prediction of the efficacy of the technology at full-scale but is unlikely to prevent its successful implementation.