Carbon Blade

Carbon Removal Purchase Application

General Application

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

Company or organization name

Carbon Blade Corporation

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

Pittsburgh, PA, USA

Name of person filling out this application

Dan Soeder, Hunaid Nulwala, Ned McMahon, Daryl-Lynn Roberts

Email address of person filling out this application

[redacted]

Brief company or organization description

A start-up with a location-agnostic, distributed DAC solution.

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 and system schematics.

Carbon Blade uses renewable energy to directly capture CO_2 from ambient air by reaction with a solution of sodium hydroxide behind gas-permeable membranes mounted on vertical "blade" devices spun by the wind. Using the wind itself to pass air eliminates the need for energy-intensive fans common in centralized direct air capture (DAC) systems. The resulting sodium bicarbonate solution is combined with sulfuric acid releasing the CO_2 for sequestration and forming sodium sulfate salt solution. This is run through an electrodialysis bipolar membrane (EDBM) that electrolytically separates out the cations and anions and regenerates the acid and base solutions which are then recycled to capture additional CO_2. The EDBM is a commercially available technology commonly used in seawater desalination plants and chemical manufacturing that utilizes modest amounts of power to separate ions.

The Carbon Blade device is a distributed solution that is designed to fit into a marine cargo container and engineered to capture one metric ton of CO_2 per day. At an estimated capacity factor of 80 percent, one cargo-container unit will capture 292 tons of CO_2 per year. Scale-up is achieved by deploying multiple units: four units will capture more than a kiloton annually, 4,000 units will capture a megaton, and four million units will capture a gigaton. The land footprint of each Carbon Blade unit is less than one acre (0.4 Ha), and installation is not permanent, requiring only a gravel pad or concrete blocks. Each unit is powered by a battery system continuously recharged on-site by hybrid renewables, including small wind turbines mounted on masts and an array of solar PV cells. This independence from the electricity grid allows for flexibility in the Carbon Blade unit's deployment location, including directly on carbon sequestration sites, eliminating the need for expensive pipelines to transport CO_2 for storage.

Our beachhead project for durable sequestration is to store carbon dioxide in the subsurface pore space of depleted oil and gas reservoirs. Conventional oil reservoirs end production by "watering out" as oilfield brines migrate upward from below to replace the oil that has been withdrawn from the pore space. Displacing these brines with CO_2 will utilize the geologic features that trapped the original oil and gas to also trap the CO_2. An economic advantage of using old oil fields is that existing wells can be employed to inject CO_2 into the ground. Given that drilling costs average around $700 per foot, this could be a substantial savings. Depleted oil fields worldwide have an enormous volume of pore space available for storing CO_2.

Conceptual Carbon Blade modular unit.

Extremely durable sequestration can be achieved by converting the captured CO_2 into solid carbonate minerals, and this is our goal. Carbon Blade is currently collaborating with the South Dakota School of Mines & Technology on a project to genetically engineer extremophile microbes that can survive in the deep subsurface to biologically convert injected CO_2 into carbonates. The microbes will utilize cations in the oilfield brine, such as Ca, Na, Mg, and Fe to create calcite, nahcolite, magnesite, siderite, and possibly other minerals from the captured CO_2. Not only will mineralization permanently sequester the CO_2 underground, but the carbonates will also fill and seal the pore space in the depleted reservoir, stopping any residual fluid migration. This will halt fugitive emissions of methane, VOCs, H_2S, and other gasses from abandoned and orphaned wells. Because the emissions are stopped at the source, this will even end methane leakage from abandoned wells that may be buried or obscured and have not been identified at the surface.

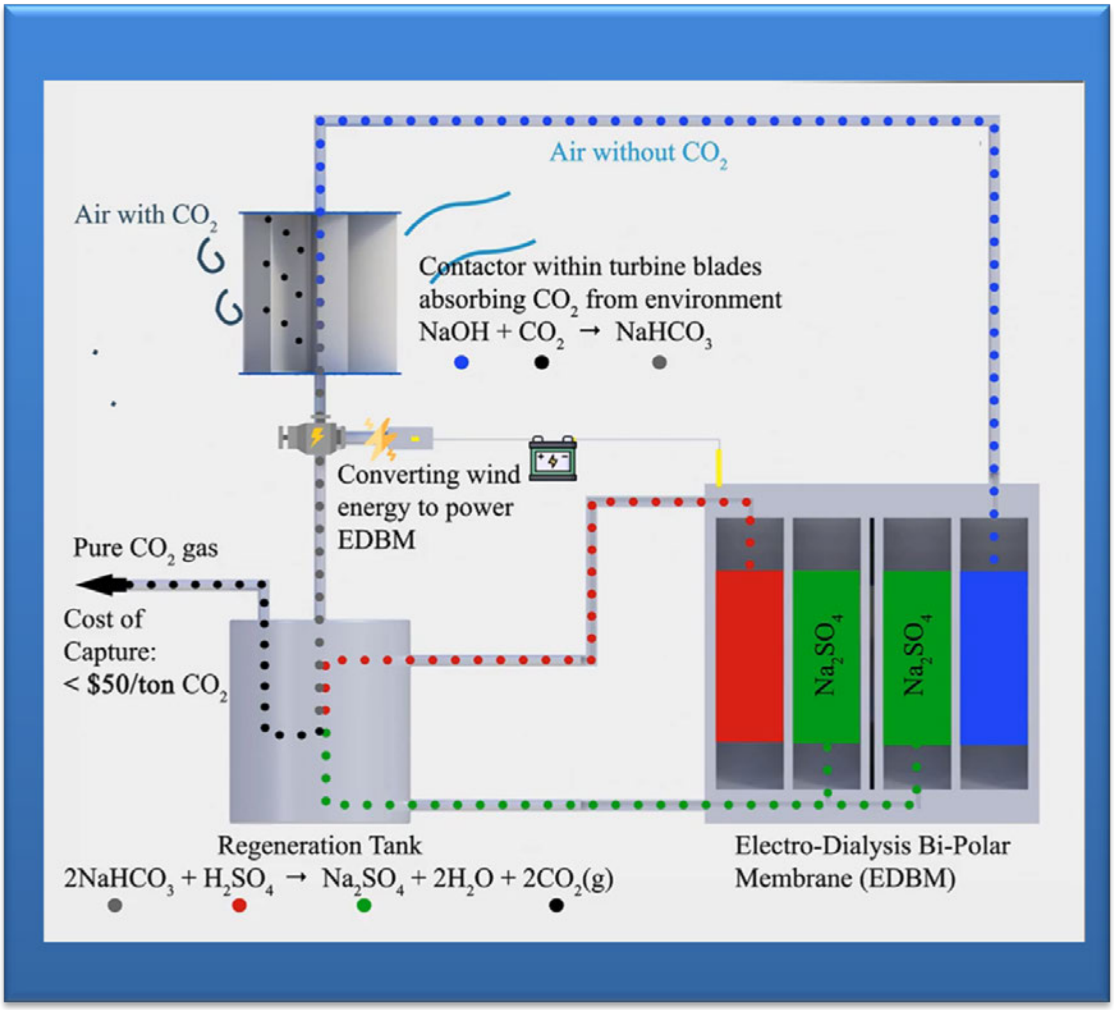
Sequestration of CO_2 as carbonates can also be done in basalt rocks, where the carbonic acid solution of CO_2 dissolved in water releases Ca and Mg ions from the rock and forms calcite and magnesite inorganically over a period of several years.

Carbfix has done this successfully in Iceland for CO_2 captured by the Climeworks ORCA DAC plant, and there are many other basalt sites, such as Hawaii or along the Columbia River in Washington where it could be applied. Adding the mineralization microbes to basalt injection should cut the conversion time down to weeks.

Another application for sequestering CO_2 is to use cations in seawater to create carbonate minerals for build-up of the land surface on low-lying South Pacific islands and atolls. Many of these islands are threatened by inundation from sea level rise and their remote location makes it difficult for any measures to be taken to raise their elevation. Using greenhouse gas from the atmosphere to raise the surface elevation is both practical and poetic, and the self-powered nature of Carbon Blade allows deployment on the most distant and isolated islands.

The broad flexibility of Carbon Blade also lends itself to the circular economy, where CO_2 can be used as chemical feedstock to manufacture chemicals, carbon neutral fuels, and durable materials. Any manufacturing company that requires a source of CO_2 can simply park a Carbon Blade unit behind their factory to supply the necessary gas. We would like to see this application in the future.

At present, Carbon Blade is in the integration and testing stage of development. We have successfully built and tested the air contactor device, and it performed well in the lab. The EDBM has also been tested for post combustion capture, and it is available from commercial sources. In fact, all components of the unit except for the air contactor are off-the-shelf, commercial items and the air contactor itself is constructed from readily-available materials. We are very confident that the device will work and successfully capture CO_2 from ambient air. We need to assemble, integrate, and balance the components so that everything operates at the same rate. For example, we don't want the capture and release chemistry to operate so rapidly that it overwhelms the ability of the EDBM to regenerate the solutions. Likewise, we don't want to produce CO_2 at a rate that will exceed our ability to inject it into a depleted oil reservoir. Once we assemble and integrate the unit, we plan to carry out a series of field tests first on a farm in West Virginia, and then on an abandoned oil or gas well in western Pennsylvania. We hope to carry out the gas well test in 2023 and begin regular DAC and sequestration of CO_2 soon afterward at an initial rate of one kiloton per year.



Schematic of direct air carbon dioxide removal operation.
The capture technology is based on a three-step reaction process:

Step 1) $CO_{2(air)} + NaOH_{(aq)} \rightarrow NaHCO_{3(aq)}$ (At the air contactor unit)

Step 2) $2NaHCO_{3(aq)} + H_2SO_{4(aq)}\ ) \rightarrow\ Na_2SO_{4(aq)} + 2H_2O + CO_{2(pure/sequestration)}$ (In the regeneration tank)

Step 3) $Na_2SO_4 + 2H_2O \rightarrow 2NaOH_{(aq)} + H_2SO_{4(aq)}$ (Transforming salt back into acid and base inside the EDBM)

The EDBM is a mature technology and an important part of the system. The EDBM contains two polymer layers; one is permeable only to anions and the other only to cations. Unlike other membrane processes, the EDBM achieves separation through a reaction in the bipolar junction of the membrane where the anion and the cation permeable layers are in direct contact. EDBM systems are commercially available from several sources and can be customized as needed. An EDBM has excellent long-term stability (up to 15 years), low potential drops, a high rate of water splitting, high perm-selectivity and excellent mechanical stability. The EDBM device splits water into hydroxide ions and protons. The produced hydroxide ion and proton are separated by migration through the respective membrane layer and combined with the counter anions. Unlike water splitting at electrodes during electrolysis, there are no gasses formed as a side product, nor are gasses used, thus simplifying the overall system. The high efficiency of the EDBM requires relatively low regeneration energy, i.e., 1.18 MJ/KgCO_2, which compares to 3-4 MJ/KgCO_2 in the case of thermal regeneration with liquid amine solvents/sorbents.

The next development stage will be the fabrication and integration of the air contactor into the EBDM system. The team will develop and fabricate a highly efficient air contactor and perform engineering analysis on this contractor with EDBM regeneration.
We anticipate minimal environmental impacts on air, water, land, biodiversity, human health, and natural resources from Carbon Blade. It is important to note that our proposed technology is NOT intended to be used for enhanced oil recovery (EOR) operations but instead is intended for sealing off depleted reservoirs. Any environmental impacts that do occur are expected to be short-term and minor. Specifically, the self-contained units are portable and do not occupy permanent land space, nor do they require external power given that they are powered by distributed renewables. The units can be placed adjacent to sequestration sites, eliminating the need to build pipelines from a disruptive, large, centralized DAC facility. At the gigaton scale, our distributed solution will spread the DAC activity over a larger land area and minimize any potential impacts to a single site.

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.)*

Carbon Blade is a CDR company focused on the direct air capture of CO_2, and will own and operate the capture units. Carbon Blade will partner with a company experienced in oilfield brine injection and oil and gas operations for sequestration and long-term monitoring of the site.

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

Risk 1: Scalability concerns. There are a few potential constraints that the Carbon

Blade approach may face. Scaling may be limited by the capability to construct a sufficient number of units. Thus, given that the DAC technology is an integration of several commercially available components, supply chain constraints with respect to the EDBM, membrane material, or solvent may hamper development.
Risk 2: Inability to engage and partner with an oil or gas company. Carbon Blade does not have the expertise or resources to sequester CO_2 in a depleted oil field. We will need to partner with a production company or service company with this expertise to assist with this fieldwork. We have not yet done so, but our early discussions with contacts in the industry seem promising.
Risk 3: Wellbore integrity problems in abandoned wells. Using existing wells can be cost efficient; however, there is a risk that these wells could have corroded casing or cracked cement which could be expensive to fix. We plan to work with our field partner to run pressure tests, cement bond logs, and video logs of candidate injection wells and install downhole pressure sensors in monitoring wells to track plume migration and ensure the permanence of CO_2 sequestration. We do not expect limits on sequestration space as there are hundreds of depleted oil fields across the United States, with thousands of abandoned wells to provide access. Utilizing large numbers of abandoned wells will eventually run into wellbore integrity and reservoir seal problems, and due diligence to fully characterize the condition of the reservoir and the wells before beginning injection may limit the rate of growth. There are other options for sequestering CO_2 in solid mineral form, such as building up the surface of low-lying coral atolls to keep them above sea level.

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

- **PCT filed: PCT/US2022/019693**

e. Who's the team working on this? What's your team's unfair advantage in building this solution? What skills do you not yet have on the team today that you are most urgently looking to recruit?

Carbon Blade is composed of a diverse group of experts from disciplines relevant to developing and deploying a scalable solution for carbon removal. These include advanced materials, chemistry and physics, fluid dynamics, mechanical design, wind turbine engineering and testing, computational mechanics, industrial engineering, energy technology commercialization, oil and gas production, and geologic storage. The team has been working together on this project for roughly a year and a half. The co-founders have all worked with one another on other projects and in other capacities prior to collaborating on the Carbon Blade technology. The founders are: 1) Hunaid Nulwala, the Carbon Blade treasurer and a PhD chemist who previously worked at the DOE National Energy Technology Lab (NETL) and Carnegie Mellon University before founding two other successful companies; 2) Daryl-Lynn Roberts, the Carbon Blade CEO who possesses an MBA from Harvard along with an B.S and M.S in engineering

from Stanford and who works as a program developer for a clean energy consulting company; 3) Ned McMahon, an engineer who owns a hybrid wind and solar power company that supplies small-scale energy solutions to places like isolated villages in Africa; and 4) Dan Soeder, the Carbon Blade secretary as well as a geologist and consultant who spent 25 years with the U.S. Geological Survey and NETL researching issues related to energy and the environment including geologic options for carbon dioxide sequestration. The team's unfair advantage is that it is composed of a seasoned group of team members that have independently developed and commercialized technologies. The team is also extremely diverse in its background/experience and work together effectively as an integrated unit. Some of the core skills that are missing on the team currently are permitting experience, sales and marketing, and Engineering Procurement and Construction (EPC) skills.

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

a. Please fill out the table below.

	Timeline for Offer to Stripe
Project duration If funded, after development, testing, and optimization in 2022, our initial CO_2 DAC and sequestration will run from 2023 to 2026.	2023-2026
When does carbon removal occur? Carbon dioxide removal will occur from 2023 to 2026 during the capture phase of the project.	2023-2026
Distribution of that carbon removal over time Carbon dioxide removal will ramp up during the capture phase of the project. Initially one Carbon Blade unit will capture and sequester 292 tons of CO_2/year, ramping up in 2025 to four Carbon Blade units. The average lifetime of one unit is estimated to be approximately 15 years. We expect to capture a total of 2940 tons	2023 = 20 T 2024 =584 T 2025 =1168 T 2026= 1168 Total= 2940

gross for this project.	
Durability Durable carbon sequestration for brine saturated with CO_2 gas will be for millennia in the geologic trap that held the original oil and gas. After CO_2 has been biomineralized to solid carbonates, the durability will be for geologic time periods of millions of years.	1000 years to geologic time periods.

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

Carbonate minerals have existed in the geologic record as limestones for hundreds of millions of years. Natural gas and petroleum stored in geologic traps has existed for similar time periods. Our upper bounds for durability are on the geologic time scale of millions of years. Carbon dioxide dissolved in water forms carbonic acid, which is mildly corrosive and may dissolve wellbore cements or corrode steel well casing. There could also be a breach in the reservoir caprock from pressure cycling during the oil production phase of the field and the carbon dioxide might find this and eventually work its way back to the surface. We expect the mineralization process will immobilize the CO_2 and stop any migration, but there could be some minor leakage (estimated <8% of what was injected) back to the atmosphere before this occurs. Therefore, our lower bounds for durability on a small component of the injected CO_2 are on the order of decades.

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.)*

Evidence in the geologic record indicates that limestones made of carbonate minerals are a stable rock type that have existed at the Earth's surface for millions of years, and in the subsurface for hundreds of millions of years. The Espanola Limestone of the Huronian Supergroup is one of the oldest limestone formations in North America, dating to about 2.3 billion years (Ga) before present (Card, K. D., Innes, D. G., and Debicki, R. L.1977: Stratigraphy, Sedimentology, and Petrology of the Huronian

Supergroup in the Sudbury-Espanola Area; Ontario Div. Mines, GS16, 99p.). The oldest limestones on Earth are stromatolites, formed by mat-like colonies of algae and bacteria that exuded and trapped fine-grained carbonate sediment. The oldest authenticated stromatolites are 3.5 Ga in the Pilbara area of western Australia. Ancient stromatolites have also been documented at 3.4 Ga in South Africa and 2.9 Ga in Zimbabwe. Converting CO2 into carbonate minerals is the most durable and stable form of sequestration.

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?

There are no fundamental uncertainties that have emerged to date regarding the capture technology or sequestration processes. The carbon capture reaction and the EDBM process have both been successfully lab tested. Biomineralization of carbonate occurs in nature on scales from single-cell calcareous algae to massive coral reefs. There is a potential risk for carbonic acid to corrode steel casing and wellbore cement, creating flow paths for carbon dioxide gas to reach the surface. We expect the engineered microbes to convert the CO_2 to solid carbonate before this can happen and we will carry out an MVA program to ensure that we spot and repair any leakage that does occur. Our beachhead plan for sequestration is to inject and mineralize DAC CO_2 in the subsurface pore space of a depleted oil and gas field, sealing abandoned wells as a side benefit. Depleted fields are typically located in relatively remote, lightly-populated rural areas. No physical or socioeconomic risks for these have been identified. Beyond Stripe, we may use our technology to seal abandoned wells within urban areas, such as Los Angeles. This will require additional risk assessments.

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.)*

We will quantify carbon sequestration by physically metering the CO_2 production from each Carbon Blade unit. We will also meter the injection of carbon dioxide-saturated brine downhole. We will install pressure sensors in selected monitoring wells in the depleted oilfield to measure the reservoir pressure response to injection and use these data in reservoir flow models to determine the size, shape, and location of the plume of CO_2-saturated brine. We will monitor the biomineralization process by tracking changes in the permeability of the reservoir rock during the injection cycle – as the

pore space becomes occluded with carbonate minerals, the permeability will decrease. We assume this will start at the distal end of the plume and work back toward the injection well.

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 Each Carbon Blade unit is designed to capture one ton of carbon dioxide per day. The CO_2 removal efficiency is 65% from air. We estimate an operational capacity of 80% per unit translating to about 292 tons per unit per year. Four (4) units operating simultaneously will remove 1,168 tons per year.	2,940 metric tons of CO_2 over 4 years
If applicable, additional avoided emissions We use 746 Kwh of energy per ton of CO_2 captured. (292*746) = 271,832 Kwh/unit/year at full operation. The 746 Kwh includes: 120 Kwh (CO_2 compression) + 373 Kwh (EDBM) + 253 Kwh (pumps, heat management, onboard control unit, etc.) If our system was connected to the grid and using fossil energy instead of renewables, we would be generating 193 tons of CO_2 to capture 292 tons. This number is based on the EPA calculator.	As the unit uses 100% renewable electricity, we save 192 tons of CO_2

https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator We are incorporating integrated renewables that generate 0.004 kg/Kwh of CO_2. Our process will be emitting 1.2 tons of CO_2/year thus avoiding 192 tons.	

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)*

1 ton/day X 365 days = 365 tons/year; 365 X 0.8 = 292 tons/year; 292 tons/year X 4 units = 1,168 tons/year.
However, we understand that ramping up the technology deployment will take time. The deployment of the first unit as well as permitting issues will need to be addressed.
20 tons/Y2023 + 584 tons/Y2024 + 1,168 tons/Y2025 + 1,168 tons/Y2026 = 2,940 tons total
Avoided emissions: 292 tons per year of carbon capture per unit = 271,832 kWh electricity per year. Powered by 100% renewable energy (wind, solar, and battery storage) annual CO_2 emissions would be 1.2 tons.
CO_2 emissions for 271,832 kWh of electricity are 246 metric tons for coal-fired and 104 tons for natural gas fired power, giving us avoided emissions of 245 metric tons for coal and 103 tons for gas. We have used the EPA calculator to average fossil fuel electricity emissions to derive the number of 192 tons of CO_2 emissions avoided.

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).

Currently, we do not have the capacity to sequester carbon. We expect to have our first prototype unit built, tested and deployed in 2023. The other three units should follow soon after, providing a combined capacity to capture and sequester 4 metric tons of carbon dioxide per day by 2025. Carbon Blade will be capturing 1,168 tons of CO_2 per year in 2025, and 2026 resulting in a grand total of 2,940 metric tons captured for sequestration by the end of the project in 2026.

The pore volume available in depleted oil and gas fields for carbon storage is enormous. To put some numbers on it, U.S. oil production in 2022 is estimated to be 11.8 million barrels per day. Since 2014, about half of U.S. production has been from conventional fields and the other half from fracked shales, but 5.9 million barrels of pore space in conventional reservoirs is still being emptied out every day. In a year, this adds up to 2,153 million barrels of conventionally produced oil. A barrel of oil consists of 42 gallons (159 liters) of liquid, occupying 5.61 cubic feet (0.159 cubic m) of volume. Thus, annual oil production in the U.S. alone frees up more than 12 billion cubic feet (342 million cubic meters) of subsurface pore volume for the storage of carbon dioxide. One ton of CO_2 at standard temperature and pressure (STP) of 25°C/77°F and one atmosphere has a density of 1.836 kg/cubic meter, and occupies a volume of 19,235 cubic feet, or 545 cubic meters. Thus, storing 2,628 tons of captured CO_2 at STP will occupy a volume of 50 million cubic feet or 1.5 million cubic meters, less than 0.5 percent of the conventional oilfield pore space emptied out in one year. If compressed to 4 atmospheres (60 psi) a ton of CO_2 will occupy a volume of 4,808 cubic feet, or 136 cubic meters. If compressed to a supercritical fluid, it occupies substantially less space (2.65 cubic meters/93.6 cubic feet per ton). Storing 2,628 tons as a supercritical fluid at depths below 2,500 feet (800 m) will only require about 7,000 cubic meters, or 246,000 cubic feet of pore space.

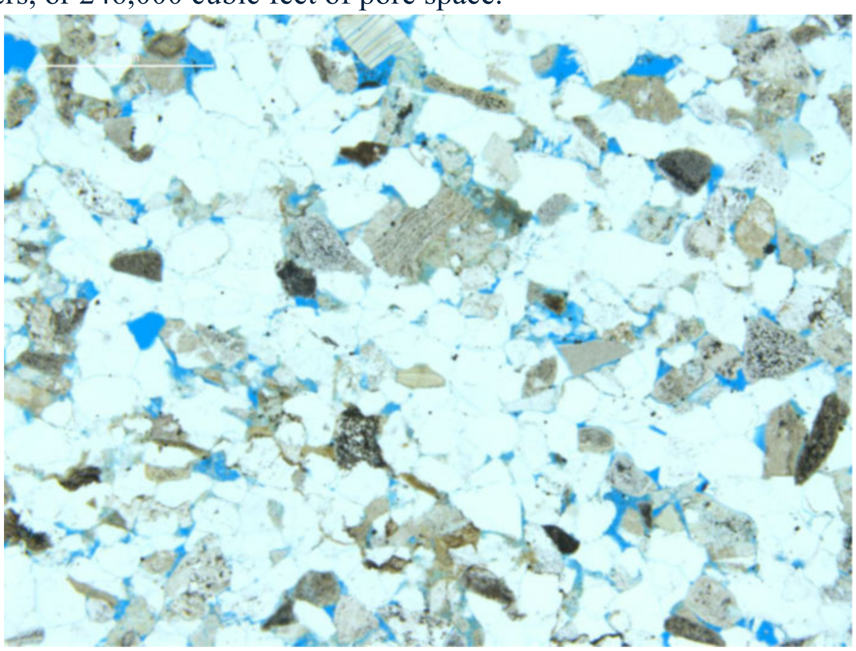


Photo of a thin section under a microscope showing blue, epoxy-filled pore space in the Frontier Sandstone of Wyoming. Scale bar at upper left is 1 mm. DOE photo.

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.)*

Foundational assumptions about the solution's capacity are based on the well-known kinetics of the chemical reactions, the molar concentrations of the acid and base, calculations of the fluid volume, circulation rate, air contact area and the acid/base rejuvenation rates. We have tested the CO_2 uptake capacity of the sodium hydroxide solution with several different iterations of the air contactor membrane, and numerous experiments with the EDBM were carried out to determine the most efficient path to regenerate the acid and base solutions. The kinetics of the carbonate mineralization have been tested inorganically by Carbfix in Iceland. See links below for references.

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.

- https://www.sciencedirect.com/science/article/pii/S0378382020309826?via%3Dihub
- https://www.carbon-blade.com/
- https://www.science.org/doi/10.1126/science.aad8132
- https://drive.google.com/file/d/1Mjc2UjgHVa5YwL144YsKy0qDbN3cG74p/view?usp=sharing

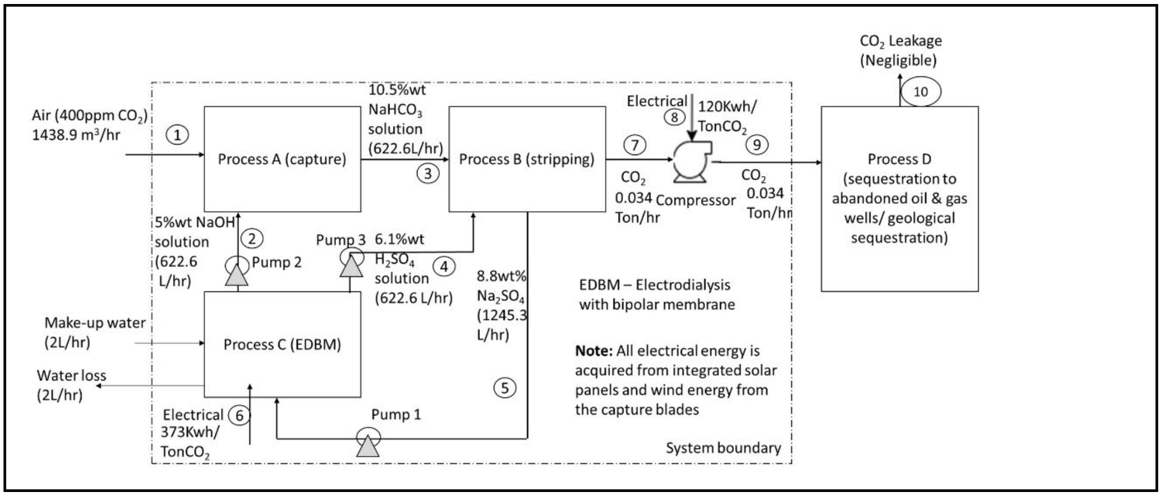
4. Net Capacity / Life Cycle Analysis (Criteria #6 and Criteria #8)

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	2,940 metric tons of CO_2 total over 4 years
Gross project emissions	Leakage and non-avoided emissions estimated at 8 percent: 2,940 x 0.08 = 235 metric tons
Emissions / removal ratio	1/19

Net carbon removal	2,940 – 235 = 2,705 tons CO_2 net removal

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 2020 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.



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?

The proposed system is a standalone/closed system with the key inputs being air and make-up water. The make-up water is needed due to evaporation. The unit generates its own electricity via integrated wind and solar tied with energy storage to regenerate the acid and alkaline solvents and operate pumps. Each unit has an output of approximately 1 ton of CO_2/day. Power requirements for the EDBM are estimated at 373 Kwh, which is supplied by the dual renewable energy generation system coupled with battery modules.

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]().

Process A is based on test data collected in the laboratory. Processes B and C are based on laboratory test data for post-combustion capture. The work was published by Dr.

Valluri of the Carbon Blade team. (https://www.sciencedirect.com/science/article/pii/S0378382020309826?via%3Dihub). Process D is outside of the system boundary; however, it is based on DOE estimates and conceptual models. [National Energy Technology Laboratory, 2015, Carbon Storage Atlas, Fifth Edition, U.S. Department of Energy, Office of Fossil Energy, Washington, DC, 114 p.]

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.

Our technology has been third-party verified for the XPRIZE submission by Dr. Venkat Shastri, the Associate Dean of Graduate Programs, and De Sanctis Professor of Engineering and Entrepreneurship at the University of San Diego. The verification of Carbon Blade's demonstration was performed on January 15, 2022. Dr. Shastri was provided with and subsequently reviewed the detailed engineering diagrams of the process, extensive lab model test data, and calculations for carbon capture and wind speed achieved in the demonstration.

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 progress.)

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

Carbon Blade consists of a self-powered, cargo-container-sized, mechanical scrubber that uses sodium hydroxide to capture CO_2 from ambient air as sodium bicarbonate and reacts this with sulfuric acid to release the CO_2 for sequestration. The unit regenerates the solutions and the design captures one ton of CO_2 per day.

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.

Year	Units deployed (#)	Unit cost ($/unit)	Unit gross capacity (tCO_2/unit)	Notes
2022	0	The first unit cost is estimated to be $1,500,000. Average cost will be below $200,000	1 ton CO_2/unit/day 292 tons/unit/year	Component prototyping has been completed. We are in the process of finalizing integration. Kilograms of CO2 have been captured and released using an EDBM type unit. We expect an initial deployment and capture to begin in late 2023.
2021	0	0	0	Testing on components completed
2020	0	0	0	Technical concept generated and detailed literature review completed. EDBM testing was carried out.
...				

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.)*

We expect our deployment costs to decrease substantially in the future. Manufacturing costs are currently high, as each unit is a one-off production. As we move into mass-production and bulk purchasing of components, the expenses of each unit are anticipated to drop dramatically.

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)
4 units	Approx. 1 ton CO_2 per unit per day 292 tons/unit/year 1,168 tons/4 units/year

	2,940 tons total in 4 years

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

We are open to purchasing high cost carbon removal today with the expectation the cost per ton will rapidly decline over time. We ask these questions to get a better understanding of your potential growth and the inflection points that shape your cost trajectory. There are no right or wrong answers, but we would prefer high and conservative estimates to low and optimistic. If we select you for purchase, we'll expect to work with you to understand your milestones and their verification in more depth. If you have any reservations sharing the information below in the public application format, please contact the Stripe team.

a. What is your cost per ton of CO_2 today?

\$1,450-\$1,680/ton CO_2 is anticipated for the first prototype unit.

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, non-levelized CAPEX costs, assumptions around energy costs, etc.

For a single prototype unit: CAPEX = \$1,500,000; annual OPEX = \$5,000: one-year cost = \$1,505,000 to capture 896 tons of CO2 during the course of this project; \$1,505,000/896 = \$1,680 per ton for the first unit. The aggregate cost for all the 4 units for a project duration of 4 years averages out to \$998 dollars per ton for a 4-year lifetime for this project. The average lifetime of a unit is estimated to be about 15 years.

c. How do you expect your costs to decline over time? Specifically, what do you estimate your cost range will be as you reach megaton and then gigaton scale? We recognize that at this point, these are speculative and directional estimates, but we would like to understand the shape of your costs over time.

We expect that the mass production of units and the ability to amortize CAPEX over time will reduce costs. The first unit is estimated to be 5X more expensive than the others. It also includes initial permitting and logistics as well as site prep costs. Each unit cost will come down significantly as economies of scale occur. It is estimated that each unit will have a total cost of less than \$200,000 with a lifetime of 15 years. Our scale-up costs do not require an engineering re-design, just the manufacture and deployment of additional Carbon Blade units. A megaton level of DAC will require about 4,000 units and the gigaton level will require four million units

d. Where are the primary areas you expect to be able to achieve cost declines? E.g., what are the primary assumptions and sensitivities driving your cost projection? What would need to be true for a long-term cost of <$100/ton to be achievable with your technology? (i.e., you are able to negotiate an x% reduction in CAPEX at scale and purchase renewable electricity at $y/kWh)

Overall, the components that comprise the unit are off-the-shelf and readily available. The novel air contactor unit is the only component that is not commercially available and is being designed/built in-house. Initially the team will deploy prototyping techniques such as 3D printing and manual fabrication to generate the first units. However, upon mass production the CAPEX are anticipated to decline substantially. For example, we foresee that industrial production techniques such as injection molding of the air contactors will significantly bring down the cost. Economies of scale will further decrease the cost of materials. Entering into long-term contracts will amortize the CAPEX costs over time, reducing the need to receive a more immediate payback. Adding telemetry to monitor performance and for security surveillance will also reduce costs. The team is optimizing the utilization of the different components to minimize the material used within the Carbon Blade unit. Specifically, we intend to test the degradation rate of the air contactor membrane and determine ways to extend the life of these membranes. The power system components are sourced from recycled thermoplastics and recycled aluminum and the battery selection is based on providing the right amount of power while at the same time minimizing the unit's carbon footprint. Our goal is to achieve a total cost of carbon capture and sequestration below $100/ton.

e. In a worst case scenario, what would your range of cost per ton be? We've been doing a lot of purchasing over the past few years and have started to see a few pieces that have tripped people up in achieving their projected cost reductions: owned vs leased land, renewable electricity cost, higher vendor equipment costs, deployment site adjustments, technical performance optimization, supporting plant infrastructure, construction overruns, etc. As a result, we'll likely push on the achievability of the cost declines you've identified to understand your assumptions and how you've considered ancillary costs. We would love to see your team kick the tires here, too.

The cost provided for the first unit build is based on a worst-case scenario. We have included the concerns and risks over supply chain issues, difficulty engaging with an oilfield partner, challenges obtaining permits, and problems with sourcing the optimal engineering company to build the unit. We have also thought about the time-cost and added an additional 6 months as a buffer in deploying the first unit.

f. 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	Small scale integrated unit	It demonstrates all the components working together at a scale of ~1-5 kg/day without the renewable integration	2022/Q4	Demonstrated in the lab scale setting and provide associated documentation.
2	Fabrication and integration of the full-scale Air Contactor capable of capturing 1tpd of CO_2.	Demonstrate operation of stacked blades and membranes with pumps and solvent circulation.	2023/Q4	Documentation of completion and verification of performance.
3	Cultivate partnerships with an engineering company and well owners and service company to deploy 1 ton/day system		2024/Q1	Provide operational reports, agreements from the engineering company. Organize a site visit to the capture site.

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	N/A	~1-5 kg/day	N/A
2	~1-5 kg/day	~1 ton CO_2 per day	Complete proof of concept for a large scale system.

3	~1 ton CO_2 per day	~1 ton CO_2 per day	Deployment of integrated system in the field.

g. 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	N/A	N/A	
2	\$1450-\$1680/ton CO_2	\$1450-\$1680/ton CO_2	
3	\$1450-\$1680/ton CO_2	\$320-450/ton CO_2	Cost of carbon capture from the first prototype unit is higher. As we scale up, the costs are anticipated to decrease significantly given economies of scale and manufacturing efficiencies.

h. 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?

We would engage individuals within state agencies responsible for plugging the 3.2 million abandoned oil and gas wells throughout the United States. It is currently estimated that states will be required to spend billions of dollars on plugging these orphan wells and the Carbon Blade solution would be more effective.

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

Stripe could connect us further with the marketplace by providing additional validation of our system. Specifically, we have a broader vision in which we can also ultimately sell/lease the Carbon Blade unit to a broader set of customers who would want to utilize CO_2 in a variety of manners.

7. Public Engagement (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 mechanisms 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 and how your project is working to follow the White House Council on Environmental Quality's draft guidance on responsible CCU/S development. We recognize that, for early projects, this work may be quite nascent, but we are looking to understand your early approach.

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

Our external stakeholders today include customers, government grant agencies, investors, supply chain partners and vendors, and policy and climate advocacy groups at the regional and national level. In terms of the initial application, the primary external stakeholders include landowners with abandoned wells on their property, leaseholders with abandoned wells on their leases, and oil & gas production companies with depleted fields and wells that are no longer productive. We are planning to partner with an oil production company or a service company like Halliburton or Schlumberger to gain access to personnel, equipment, and the expertise to inject CO_2 into depleted oil wells. The team anticipates that our demonstration project will occur on abandoned wells in a depleted field in western Pennsylvania. The target area within western Pennsylvania (Washington and Greene counties), has a large concentration of abandoned oil and gas wells. We have made contact with a major producers' group in the state to collaborate given that there are 8,840 abandoned and unplugged wells documented in western Pennsylvania. These wells frequently emit methane, a greenhouse gas more powerful than CO_2, and sometimes vent heavier hydrocarbons that can include VOCs such as benzene, a carcinogen linked to leukemia and low birth weights. Fugitive emissions from old wells may also include hydrogen sulfide, a toxic gas that can be fatal at high concentrations. Given the historical pattern of exposure to environmental hazards within this area, it will be essential for Carbon Blade to develop a robust environmental plan that monitors injected CO_2 and addresses safe disposal of the air contactor components and solvent at the end of the project.

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

The initial stage of our engagement with stakeholders has involved reaching out to community based environmental justice organizations in our network attempting to more broadly understand some of the key concerns that have been raised by relevant stakeholders. Given the early stage of development of our technology we have yet to formally engage external consultants or independent advisors and have primarily performed stakeholder engagement in-house. The founders have also been in contact with members of the petroleum industry, including industry associations and individual companies.

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?

Engagement with stakeholders has impacted the technology's design and the company's strategic approach considerably. Specifically, the team focused on the size and portability of the unit to address the early identified environmental justice concerns of placing large, centralized DAC factories in lower-income neighborhoods. Our goal for Carbon Blade units is to become a commercial technology for distributed DAC in a manner similar to rooftop solar. We envision our units being deployed in a wide scale manner so that citizens (e.g. land owners) can participate in the benefits derived from CDR, including tax credits, sales of carbon offsets, and others.

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 intend to engage with additional stakeholders and seek support from community organizations and environmental advocates as the technology becomes ready for deployment. We envision that the air contactor design will continue to evolve and stakeholder feedback will be essential to accelerate the commercialization of our technology. As an initial market our goal is to show abandoned well owners that orphan wells on their property are a liability that can be turned into an income-producing asset with DAC and sequestration. However, we will envision that stakeholder engagement will allow us to expand our focus into CO_2 utilization markets as well.

8. Environmental Justice (Criteria #7)

a. What are the potential environmental justice considerations, if any, that you have identified associated with your project? Who are the key stakeholders?

Most depleted oil fields are in lightly populated rural areas. Many landowners have made some income off royalties from the produced oil, but these have ended with the cessation of production. In some urban areas where oil fields have been depleted for a long time - as much as a century in the case of Los Angeles, property owners and residents receive zero benefits and suffer from fugitive emissions of methane, VOCs and other gasses. We hope to provide some income from carbon offsets while sealing the old wells.

b. How do you intend to address any identified environmental justice concerns?

The project team understands the importance of engaging stakeholders in the communities both where we are planning to build the units and where we intend to deploy them. It is essential to understand the historical inequities these communities have experienced in the past with the supposed "benefits" of clean energy investments. Future climate investments cannot benefit only one group in society but should be shared equitably. Additional specific consideration should be given to highlighting and communicating the potential economic benefits to frontline communities. These include jobs and the economic revitalization of an industrial sector, and for landowners, the conversion of an abandoned well from a liability into an income-producing asset. The project team will solicit input through community meetings, focus groups, technical expert panels, and online information-sharing activities. The objective of this engagement is to incorporate relevant stakeholder input and ensure that traditionally under-represented groups help optimize a solution that effectively meets stated climate goals and also provides social and economic benefits to frontline communities. Too often, stakeholders are simply briefed on the technology after it has been deployed in their community. Carbon Blade is attempting to change that narrative by iteratively incorporating stakeholder input into the technology development process.

Other areas of focus for us will be to site the factory for producing Carbon Blade modules in an industrially depressed location to help revitalize the community; to attempt to refurbish an existing factory to produce the units; to engage stakeholders including landowners with abandoned wells and leaseholders in depleted oil and gas fields; and will carefully follow all relevant ES&H policies at the manufacturing facility and in the field and hold every employee accountable for safety.

9. Legal and Regulatory Compliance (Criteria #7)

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

We have not yet received any legal opinions regarding the deployment of our solution. We intend to engage and partner with the petroleum industry on the deployment of the technology to obtain legal access to wells in a depleted oil and gas field. There is precedence within the western PA area of the Marcellus Shale developers engaging landowners. Due to this precedence as well as support within western PA we do not anticipate any major problems.

b. What domestic permits or other forms of formal permission do you require, if any, to engage in the research or deployment of your project? 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.

The U.S. Environmental Protection Agency requires an Underground Injection Control (UIC) permit for injecting waste material into the subsurface. They have delegated the issuance of these permits to the state environmental agencies. There are various classes of UIC permits depending on what is being injected. A Class III permit is required for injecting oilfield waste, typically produced water or brines. EPA recently introduced a Class VI permit for the injection of carbon dioxide. Because we are intending to inject oilfield brines saturated with carbon dioxide, we are unsure which permit is needed (possibly both). We will clarify this with regulators.

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

Some countries have injection permit requirements similar to the UIC system, while others do not. For at least the first decade of development as we ramp up from kiloton to megaton annual capture, we are planning to use domestic wells in the United States. If we move to the gigaton annual level as required by XPRIZE, we will have to go global and figure out international permit systems.

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

As described above in section b, the greatest regulatory uncertainty is the type of UIC permit we will need for the injection of CO_2 dissolved in brine into depleted oil fields.

e. Has your CDR project received tax credits from any government compliance programs to-date? Do you intend to receive any tax credits during the proposed delivery window for Stripe's purchase? If so, which one(s)? (50 words)

No, we have not received any tax credits to date. We expect to be eligible for the 45Q IRS tax credit once we start injection. We may also receive state funds for plugging abandoned wells.

10. 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*	2,705 metric tons CO_2
Delivery window *at what point should Stripe consider your contract complete?*	2023-2026
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.*	$710 USD per metric ton of CO_2 Cost of carbon capture from the first prototype unit is higher. As we scale up, the costs are anticipated to decrease significantly given economies of scale and manufacturing efficiencies.

Application Supplement: DAC

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

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

Physical Footprint (Criteria #1 and #2)

1. What is the physical land footprint of your project, and how do you anticipate this will change over the next few years? This should include your entire physical footprint, i.e., how much land is not available for other use because your project exists.

Year	Land Footprint (km^2)
2021	0
2023	0.4 Ha (one unit)
2024	1.6 Ha (four units)

2. What is the volumetric footprint of your contactor? (How big is your physical machine compared to how much you're capturing?) and how do you anticipate this will change over the next few years? These numbers should be smaller than (1) above.

Year	Contactor Footprint (m^3)
2021	0
2023	12 x 40 ft marine cargo container (480 sq feet)
2023	4 similar sized cargo containers (1920 sq feet)

2. Capture Materials and Processes (Criteria #5, #7, and #8)

1. What sorbent or solvent are you using?

The solvent is 5% sodium hydroxide solution and a 2.5% sulfuric acid solution

2. What is its absorption capacity? *(grams CO_2 per grams material/cycle)*

The unit will be passing 500 liters 5% NaOH every half hour through the contactor device with 200 m2 surface area. We will be capturing approx.38 Kg of CO2 at a wind speed of 7-8 km/hr with a capture efficiency of 65%.

3. What is its desorption capacity? *(grams CO_2 per grams material/cycle)*

Regeneration is an acid-based reaction. i.e. it is 100% desorption of CO_2 upon neutralization with sulfuric acid. The obtained salt is then passed through the EDBM system to regenerate the NaOH solution and Sulfuric acid. Based on our previous work the EDBM is extremely efficient in regeneration. The current efficiency is over 95%.

4. How do you source your sorbent or solvent? Discuss how this sourcing strategy might change as your solutions scales. Note any externalities associated with the sourcing or manufacture of it (hazardous wastes, mining, etc. You should have already included the associated carbon intensities in your LCA in Section 6)

Both NaOH and sulfuric acid are commodity materials. We do not see any potential issues arising in sourcing these materials.

5. How do you cycle your sorbent/solvent? How much energy is required?

Cycling and solvent regeneration are done using the EDBM. The energy required for EDBM-based regeneration is 1.2MJ/Kg CO_2. Based on our calculations, we can provide energy needed for regeneration using renewable energy i.e., a combination of air and solar energy.

6. What is your proposed source of energy? What is its assumed carbon intensity? What is its assumed cost? How will this change over the duration of your project? (You should have already included the associated carbon intensities in your LCA in Section 6)

The current design calls for a combination of wind power modules and PV panels with battery storage for a safety margin and to eliminate intermittency. A patented, torque-based blade and rotor design provides power at wind speeds of 5-15 mph (8-24 kph). The modular wind and solar components allow for the most efficient combination of wind and solar based on conditions at each site. The power supply for each unit will be uniform from the continuously recharging battery. Batteries may range from

LiFePo4, to carbon gel AGM or saltwater storage systems that provide adequate power and minimize our carbon footprint.

7. Besides energy, what other resources do you require in cycling (if any), e.g water, and what do they cost? Where and how are you sourcing these resources, and what happens to them after they pass through your system? (You should have already included the associated carbon intensities in your LCA in Section 6) *(100 words)*

The system is closed except for the air contactor, and we assume most water loss will be through this component due to evaporation. The high permeability membrane helps minimize the water loss and allows us to give a shape and form to the air contactor device. We estimate that approximately 1-5 liters of water per hour will need to be replaced in the system during operations but this will depend on the weather and locality.

8. Per (7), how much of these resources do you need per cycle?

We assume that we will be losing 1-5 liters of water per hour per unit.

9. How often do you cycle your sorbent/solvent?

Solvent is cycled continuously through the system as it is regenerated in the EDBM. However, we do assume an operating lifetime of the acid and base solvents of about 5 years, after which they will be replenished.

10. Does your sorbent or solvent degrade over time? Is degradation driven primarily by cycling, environmental conditions, or both?

Not applicable as we are using NaOH and sulfuric acid which does not exhibit degradation properties.

11. In practical operation, how often do you need to replace your sorbent or solvent material, if at all?

Not applicable given system dynamics. We are assuming an operating lifetime of 5 years, after which the solvents will be replaced along with the air contactor membranes.

12. Per (11), what happens to your sorbent/solvent at end-of-life? Please note if it is hazardous or requires some special disposal, and how you ensure end-of-life safety.

The process forms sodium sulfate, a salt that can be discharged into the environment. The toxicity of sodium sulfate is in excess of 5,000 mg/Kg. It has low aquatic toxicity, and natural recycling also occurs in the sulfur cycle. We believe that the wide use of sodium sulfate does not present a hazard to the environment.

13. Several direct air technologies are currently being deployed around the world (e.g. Climeworks, which Stripe purchased from in 2020). Please discuss the merits and advantages of your system in comparison to existing systems.

Carbon Engineering (CE) uses a NaOH/KOH solution that reacts with CO_2, forming sodium and/or potassium carbonates over a contactor. These react with calcium hydroxide at high temperatures to release CO_2 and generate $CaCO_3$ precipitates. Global Thermostat (GT) requires a source of steam for desorption. Climeworks uses an amine-based temperature swing system. Verdex is developing an ElectroSwing approach using quinones to capture CO_2. Susteon is working on DAC technology using a system coated with ionic liquids to regenerate CO_2 at lower temperatures (i.e. 85°C). All the above technologies are centralized systems that require external power for large fans to move CO_2 over their contractor devices and substantial power to provide heat for the regeneration of carbon sorbents.

In contrast, the trailer-sized Carbon Blade units use wind to capture CO_2 and the low power requirements of the EDBM allow each unit to be self-powered by renewables. This makes Carbon Blade location agnostic, allowing placement of units at sequestration sites, eliminating the need for expensive transport pipelines. Likewise, our unique, proposed sequestration solution of solid carbonate mineral storage in the subsurface pore space of depleted oil and gas fields is extremely durable, and will also end fugitive emissions from abandoned wells.

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?

Produced oilfield brines saturated with dissolved carbon dioxide and inoculated with biomineralization microbes.

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.

Carbon Blade is neither intended for nor suitable in EOR operations. Our process occludes subsurface pore space with carbonate minerals, halting fluid migration rather than enhancing it. We think revenue from carbon offsets and state agencies for ending fugitive emissions from abandoned wells will exceed that from EOR.

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?

Conventional oil fields tend to form in porous, permeable rocks under an impermeable seal in either structural or stratigraphic traps. Structural traps are generally folds (anticlines and salt diapirs) or fault-displaced bedding units. Stratigraphic traps tend to be facies changes or bedding pinch outs. A geologic characterization of each depleted oil field will be carried out prior to injection to assess the reservoir and trap and to determine the wells to be used for brine production, injection, and monitoring. The wells themselves will be assessed for wellbore integrity issues, and if unacceptable, either repaired or another well will be selected. The infrastructure needed to carry out carbon dioxide injection will include a pump jack to recover brine from a nearby well and a temporary surface pipeline system to transport it to the injection well. A mixing tank is required at the injection well site to saturate the brine with CO_2 and inoculate it with microbes prior to injection. A syringe pump will be used to inject the brine, and pressures will be closely monitored to ensure that the breakdown pressure of the formation is not exceeded. We will use the syringe pump to meter the injection of carbon dioxide-saturated brine downhole. We will install pressure sensors in selected monitoring wells to measure the reservoir pressure response to injection and use these data in reservoir flow models to determine the size, shape, and location of the plume of CO_2-saturated brine. We will monitor the biomineralization process by tracking changes in the bulk permeability of the reservoir rock during the injection cycle – as the pore space becomes occluded with carbonate minerals, the permeability will decrease. This will be determined by the increase in pressure when injecting at a constant rate. We assume mineralization will start at the distal end of the plume and work back toward the injection well.

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

As stated in 9b, Class III, Class VI, or both.

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

One metric ton of carbon dioxide gas at STP occupies 534.8 cubic meters, or a volume of 117,631 US gallons. If we assume a gallon of CO_2 at STP will saturate a gallon of brine, then at a production level of one ton per day, our downhole injection rate will be about 118,000 gallons of brine per day, which is a bit high. However, if we increase the CO_2 pressure to 4 atmospheres (60 psi), the injection rate drops to 29,408 gallons of brine per day to sequester one ton, equivalent to 1,225 gallons per hour, or about 20 gallons per minute (75 liters/min). This is the production rate of a good domestic water well. We will have a much better understanding of CO_2 production and injection rates once we have run some field tests of the technology and the complete system.

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?

Primary environmental threats are leakage of the acid or base solutions, and ruptures in the brine or CO_2 systems. The units will be monitored remotely using telemetry through the 4G or 5G data system and can be shut down on command if necessary. Check valves within the pipelines and tubing will stop the flow in the event of a sudden increase in the pressure gradient from a rupture. A potentially bigger concern is tampering or vandalism of these units in remote locations. The telemetry system will also include a security camera for visual monitoring, and the units will be made vandal-resistant by placing solar panels and wind turbines out of reach, attaching signage explaining what the unit is doing, and providing a polycarbonate window so the curious can see that there are no components inside the cargo container that can be easily sold if stolen. We do not anticipate any significant impacts on freshwater aquifers or surface water bodies. The brine will be recovered from watered-out oil reservoirs in the deep subsurface, far below any drinking water supplies. It will flow through a closed pipeline to the injection well where it will be infused with CO_2 and microbes and be re-injected.

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

The method can be easily scaled up by adding more Carbon Blade units to inject more CO_2 into more abandoned wells. No significant engineering or design changes are required on the basic unit for scale-up; we just need more of them. The key uncertainty we begin to run into with scaling is logistical. We intend to add telemetry to monitor the units remotely, but we don't know how often the units will need to be visited in the field. How much maintenance is required? How many people will it take to get to all the units in a timely fashion? How will repairs be carried out? Most of these issues can be characterized as "growing pains" that will be addressed as the company expands operations. We will apply best practices from other companies in addressing these issues.