

General Application

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

Company or organization name

Carbix Corporation

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

Quincy Massachusetts

Name of person filling out this application

J. Quincy Sammy

Email address of person filling out this application

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Brief company or organization description

Carbix is transforming CO2 into building materials.

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.

Carbix is developing mineral carbonation reactors, utilizing industrial/emitter flue gas CO₂e and Direct Air Capture CO₂ (DACC) with calcium sulfate, calcium and magnesium silicate feedstocks, to create building material products that permanently store CO₂. Our first prototype

reactor (X-1) is operational with a minimum/maximum capacity currently at 30mt (lo output) to 45 mt(hi output) of carbonate-aggregate (fine-coarse) annually. The carbonate-aggregates produced from batch reactions are synthetic calcite, dolomite and magnesite. Gross ton CO₂ permanent sink rate is estimated to be 12-15 metric tons which makes each batch of carbonates up to 40% CO₂ by average batch sample weight. We plan to increase prototype capacity in the short term to 45 metric tons annually by implementing robotic architecture (RA's - robotic arms) and enterprise software/programming for autonomous operation of the X1 prototype along with hiring engineer-technicians.

Our proposed commercial R/D pilot reactor capacity is 100,000mt of CO₂ permanently stored annually, primarily as carbonate-aggregates and possibly other industrial materials. For Phase 1 of the R/D pilot, we have an offtake agreement LOI with Everest Energy Partners, Dallas Texas for 10,000 -15,000mt annually of carbon negative, carbon-neutral ready-mix concrete for use in Everest's operations and to cap old, abandoned O&G wells that are leaking methane. In Phase 2, the remaining amount (85000-90000mt) will be through proposed offtake agreements (in-work LOI's) with multi-national cement/concrete plants (90,000mt) and smaller producing cement/concrete plants in the USA-North America, Asia nexus and Africa, that we have approached to initiate R/D, commercial pilots.

A compelling advantage to adopting the X1 reactor iterations at commercial cement and concrete plant scale (1MMT+) is that wet and dry flue gas CO₂ from a point-source emitter waste stream and/or DACC equipment, can be directly injected into the reactor for carbonation, without having to pass through sorbent or membrane filtration steps of gas trapping and heat exchange for release of captured CO₂. Direct injection of plant flue gas CO₂ would still require removal of SO_x and NO_x, VOC's (volatile organic compounds) and PM (particulate matter) from the upstream flue gas prior to CO₂ injection into the reactor.

The X1 reactor and iterations has a USPTO provisional patent titled, Photolytic One Step Reactor with Energy Recovery. The basic reactor is comprised of:

- a. Venturi Nozzle and injector ports for efficient fluid (H₂O and H₃O) and pressurized gas (CO₂, N₂, Air) dispersion. Material: Stainless steel and other metal alloys with coatings for corrosion resistance.
- b. Internal Axial Flow Turbine-Mixers, operating from 500-1800 rpm powered by a variable speed/programmable electric motor. Power for the electric motor can be supplied by renewable sources.
- c. Electric, contact-less heating bands and elements. Power for the heating bands can also be supplied from renewable sources.
- d. UV-C/B/A light source to enhance reaction kinetics, purify water and for TOC monitoring in aggregates. Power for the UV arrays can also be supplied from renewable sources.

We are utilizing existing energy recovery devices, like regenerative braking and energy efficient electric motors. We are also developing pressure recovery devices, waste heat to power through thermo-electric generators (TEGs), and waste heat for environmental conditioning through heat exchange/pumps.to reduce/offset total energy consumption of the

reactor and reactor arrays as part of continued technology development..

Link to short video of the X-1 prototype 2, operation:

<https://drive.google.com/file/d/1NsNMeAy85FsbONgolJZc4aWinclL7G/view?usp=sharing>

Phase 1 Pilot, Dallas Texas – Everest Energy 10,000-15,000mt carbonate-aggregates and oxides. Overview: Located outside of Decatur Texas, Everest Energy has apportioned 2 acres of undeveloped land for a reactor pilot plant with annual throughput of 15,000 mt of carbonate-aggregates and oxides.. Everest Energy is the off-taker for carbon aggregates and oxides (clean clinker) for ready mix concrete meeting API Class C, ASTM C33/C150, and other applicable technical standards. CO₂ is permanently stored in the final concrete product / ready mix of well casings and precast, foundations for light infrastructure operations; and well-caps for sealing abandoned wells and sites leaking methane gas (CH₄). Even at the end of the concrete product life-cycle, which can be up to 100+ years, CO₂ remains permanently bound (>1000 years) in the form of synthetic calcite, dolomite or magnesite, which is the composition of fine and coarse aggregates.

Equipment & Infrastructure:

Two X-2 reactors, totaling just under 1.0m³ in volume will be produced for the pilot site. As a reference, the X1 prototype is .014m³. CO₂ infrastructure will initially consist of O&G, CO₂ emissions (purchased or provided), concentrated and compressed for storage tanks at 900psi. The CO₂ is transported by truck to the reactor pilot site. A reactor habitat will be constructed to house both reactors, along with power grid connection, battery back-up / power pack (30kW minimum), and water infrastructure supply. Initial recycling efforts with the X-2 reactors is estimated to be 60% water recovery rate for year one of the pilot operation. At year 2 of the pilot operation, we will add DACC equipment to increase on-site production and sourcing of CO₂, reducing our CO₂e inputs from transport of emitter CO₂.

Primary power is sourced through a Power Purchase Agreement (PPA) for wind and solar power from grid connection. Estimated \$p/kWh is 0.10¢ - 0.15¢. Renewable power farms in West and North-West Texas provide power for annual operations.

Feedstock Minerals

We are trialing 3 blended mineral feedstocks to produce aggregates and oxides that will meet existing ASTM standards for composition, and compression strength testing. The majority of minerals used are also commonly used in conventional cement and concrete making. To create these three blends some admixtures and mineral separation is required. CKD aka cement kiln dust is waste material or waste oxides recovered from cement kilns. The high CaO (calcium oxide) composition of CKD is highly reactive with CO₂ for carbonation. Each blend will also receive an additive mixture of 3.5% limestone to meet ASTM C150 standards for limestone content.

Blend 1: 77.90%-Gypsum (Desulfurized-CaO):	Blend 2: 89.16% - CKD (Cement Kiln Dust)
14.20%-Feldspar	10.02% - Feldspar
4.45%-Wollastonite	0.82% - Olivine-Forsterite

3.37%-Olivine-Forsterite

Blend 3: 90.00%- Wollastonite; 7.45%- Feldspar; .80%- Gypsum (Desulfurized-CaO)

Low Volume, Alternate Product Development at the intersection of Food & Health

We will also begin development of agriculture, food and medical grade calcium and magnesium carbonates, which are products and by-products of Blend1 and Blend3. General selling price range per ton of ag/food/medical grade carbonates and oxides is \$50-\$150 p/ton. However, alternate products could be carbon neutral. Estimated production at 100 metric tons would comprise 0.60 -1.0% of total volume of the Decatur pilot annual output.

Mineral Sources

Gypsum is sourced from the Fredericksburg Area, in Texas and Norman, Oklahoma. Wollastonite's primary source is Hermosillo Mexico, with alternate supply chains originating in Shandong, China and Aheim, Norway. Feldspar is sourced from North Carolina, with an alternate supply chain in Tehachapi Area-California, and western Nevada. Forsterite-Olivine supply chains also originate in China and Norway.

Phase 2: Cement/Concrete Plant R/D Commercial Pilot

In this phase of development, the reactor technology for Phase 1 is scaled by 9 units to reach 85000-90000mt.of carbonate production. Here's why we're focused on cement plant flue gas to create carbonate-aggregate products.

- 1. Emissions from calcination of limestone accounts for .507t/CO₂ released into the atmosphere per ton of clinker (Portland Cement) produced. Approximately 2.7Gt of CO₂e is released from calcination of CO₂.*
- 2. Annual global GHG (CO₂e) emission estimate from cement and concrete plants is estimated to be 5.0-6.0Gt (c2019), comprising nearly 8% of annual GHG's emitted.*
- 3. Cement comprises up to 80% of the embodied emission in concrete products.*
- 4. Cement plants are low-cost sources of emitter CO₂, potentially \$0 p/ton to source.*

At a global, commercial scale, adoption of the Carbix reactor technology and process, could eliminate, up to 2.7Gt per year of cement plant CO₂e emissions if adopted as standard technology and process for CCUS. Our goal for a commercial reactor facility is 1.4MMT of annual carbonate through-put per reactor array per cement plant. We estimate that 0.5Gt of CO₂ with current blends of mineral feedstock can be captured annually by year 2040. The physical footprint of a Carbix reactor array for a cement plant is approximately 2 acres, preferably on-site of the cement plant or adjoining it.

Potential Location for R/D commercial pilot:

Tehachapi-Area in Eastern California is a potential site for the use of cement plant flue gas CO₂. Emitter flue gas is piped via a short run CO₂ pipeline to an onsite reactor array. Prior to injection, the flue stream is scrubbed for SO_x and NO_x from conventional processes like limestone scrubbing of SO_x to create flue gas gypsum. The major goal of the R/D pilot phase is matching wet flue gas flow rates from a portion of the flue gas emissions exhaust into the reactor array.

Mineral Feedstock

Blends 1 -3 will be used from Phase 1 of the pilot.

Mineral Sources

Feldspar source is located in the Kern Mountains, California, and is actively mined. Gypsum is sourced primarily from western Nevada with alternate supply from North Carolina. CKD comes directly from the cement plant. Wollastonite is primarily sourced from Mexico with alternate supply from Aheim, Norway and China. Olivine-Forsterite sources are also from Norway and China.

- 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 CO₂. DAC Company pays Injection Company for storage and long-term monitoring.)

My role is to develop a team that will complete these phases and beyond. Pilot off-taker is Everest Energy Partners. We plan on listing carbon credits on puro.earth. Linde Chemicals may be a vendor source for emitter CO₂ for Phase 1. We have not finalized a cement plant site for Phase 2.

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

- 1. The ability to secure project financing for large scale plant operations in a rolling 6mos time-frame to support multiple pilots; and acquire bankable data from prototype operations. To overcome this challenge, we have initiated CFD/FEA analysis to begin modeling reactor-cement plant facility CO₂ exhaust flow to reactor array capacity.*
- 2. Recycling water, filtering and purifying it efficiently and quickly enough to match high-throughput daily volume of several thousand metric tons of CO₂ and feedstock per day.*
- 3. Integrating DAC bolt-on or DAC plug/play technologies for backup source of CO₂ during plant down-times, idling, or reduced production cycles*

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

Link to USPTO provisional patent documents. May not yet be searchable online.
[Intellectual Property](#)

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

- a. Please fill out the table below.

	Timeline for Offer to Stripe
<p>Project duration</p> <p><i>Over what duration will you be actively running your DAC plant, spreading olivine, growing and sinking kelp, etc. to deliver on your offer to Stripe? E.g. Jun 2021 - Jun 2022. The end of this duration determines when Stripe will consider renewing our contract with you based on performance.</i></p>	<p><i>X-1 prototype is active now.</i></p> <p><i>Phase1-Nov2021-Nov2022</i> <i>Phase 2, 2021-2022 (tbd)</i></p>
<p>When does carbon removal occur?</p> <p><i>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?</i></p> <p><i>E.g. Jun 2021 - Jun 2022 OR 500 years.</i></p>	<p><i>X-1 Proto: 6/2021 – 6/2022</i> <i>Phase1: 11/2021-11/2022</i></p>
<p>Distribution of that carbon removal over time</p> <p><i>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</i></p>	<p><i>For 2021: X1 Prototype: 0.15%. For Phase 1, 16.56%. Total CO₂ stored as carbonates-aggregates in 2021 is 16.71%.of projected annual capacity of 3,935 MT, gross CO₂ stored.</i></p> <p><i>By 2022, X1 Prototype:0.15%. For Phase 1, 82.84%. Total CO₂ stored</i></p>

<p><i>anticipate a steady decline in annualized carbon removal from year one into the out-years, but this depends on unknowns re our mineralization kinetics”.</i></p>	<p><i>as carbonate-aggregates in 2022 is 83% of projected capacity.</i></p> <p><i>Phase 2 not included.</i></p>
<p>Durability</p> <p><i>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.</i></p>	<p><i>>1000 years CO₂ storage as synthetic calcite, dolomite, and magnesite</i></p>

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

1000yrs – 5000yrs.

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.*)

CO₂ is permanently stored as a carbonate-aggregate unless, re-heated at high temperatures > 2400F; immersed in concentrated (90%+) acidic aqueous environments like H₃O (hydronium) and H₂CO₃ (carbonic acid); or immersed in concentrated biologics. These temperature conditions, biologic and acidic concentrations rarely overlap simultaneously in the natural and built environment. The proposed product use is concrete, where extreme temperatures, pressure, concentrated-biologic, and concentrated acidic-aqueous environment may not overlap.

Environmental conditions referenced above may exist in weak-diluted conditions in the built and natural environment. Weathering of concrete, can deteriorate the cement bond from dilute acidic, biologic, and abrasion/mechanical compression attacks over time. The carbonate-aggregate component that stores CO₂ will generally remain in-tact even at the end of product life and disposal. Coatings, cleaning, surface treatment of concrete, layering/covering, have generally improved concrete lifecycles..

References regarding permanence and weathering:

1. Utilization of mineral carbonation products: current state and potential, Caleb M. Woodall , Noah McQueen , Hélène Pilorgé and Jennifer Wilcox , Department of Chemical Engineering, Worcester Polytechnic Institute, Worcester, MA, USA.

2. Carbon dioxide sequestration by mineral carbonation, Huijgen, W.J.J. Thesis, Energy Research Centre of the Netherlands, The Netherlands, ISBN: 90-8504-573-8

3. Concrete Information-Types and Causes of Concrete Deterioration, Portland Cement Association, Multiple authors

- 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?

For Phase 1 & 2, gas leakage of CO₂ will be mitigated by reactor habitat construction and HVAC systems. We assume a minimum of 1% gross leakage rate of CO₂ back into the atmosphere.

We manage CO₂ leaks now with the use of proprietary, mini-hvac, and UV-C water purification system. Excess CO₂ from the X1 reactor prototype, is infrequently vented into a series of low pressure inter-connected water tanks. We use raw mineral sorbents, such as olivine forsterite, potassium and potassium bi-carbonates, sodium chloride (NaCl) and baking soda (NaHCO₃) of varying amount, in an aqueous slurry inside the water tanks to passively trap waste CO₂ before venting the water tanks through a charcoal filter. The carbonated water is recycled for use in the X-1 reactor.

In phase 2, we will manage venting excess CO₂ or any bypass exhaust gas, from the cement plant into an enclosed onsite reactor habitat, constructed over water pools. Depending on exhaust throughput from plant cycling, overflow CO₂ is vented into water / gas storage pools, if reactor array throughput is exceeded, Later, overcapacity CO₂ gas and water are injected into the reactor for carbonation.

- 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.)

Monitoring permanence/durability during the reactor production cycle of carbonates is accomplished by; (a) digital logging of all feedstock inputs, mineral -chemical assay by weight, per batch, (b) batch sampling product for CO₂ uptake is performed by 3rd party laboratories with XRD and thin section petrology analysis, (c) downstream sampling of final concrete product in application environment can be performed annually to measure/monitor permanence/durability with XRD and Petrology analysis.

Additionally,

CO₂, O₂, O₃ meters and other relevant gas sensors and feedstock-product weight sensors are in place and they are calibrated; the energy use of the Production Facility can be quantified and the emissions from the process calculated; the emissions from the extracting and transporting of the raw material are estimated and calculated and digitally logged daily/hourly.

SDS/MSDS listings of the raw material used in the carbonation process is made available annually along with changes to primary mineral composition-chemical assay.

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	<i>X-1 Prototype – 12MT, Phase 1 – 3923MT, Gross t/CO₂ ~ 3935MT</i>
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	<i>Not finalized at this time.</i>

- b. Show your work for 2(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 tCO₂/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. $X \cdot Y \cdot Z \cdot 2 = 350 \text{ tCO}_2 = \text{Gross removal}$. OR Each tower of our mineralization reactor captures between X and Y tons CO₂/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)

X1: The 12t/CO₂ stored, is based on the stoichiometric potential for CO₂ gas feedstock carbonation with mineral feedstock, wollastonite (CaSiO₃). Estimated gross losses/uncertainty for CO₂ uptake, is 5% (buffer) due to mineral composition variances and reactor operations. Reactor conditions and unscheduled maintenance may vary CO₂ uptake per batch, resulting in a lower uptake range. Range after losses/uncertainty may be, .38 - .42 t/CO₂ per ton Wo. We derived an average R_{CO₂} of 2.2 mass units of Wo needed for uptake of 1 mass unit of CO₂, or 0.45t/CO₂ per t/Wo. Volume of the X-1 prototype is 0.014m³, ~4GL or 14L. Approximate mass of aqueous slurry per batch, per hour carbonated is estimated ~10lbs/4.5kg; 30MT of carbonates per year. Operating hours of 5,840hrs per year. 12MT is the gross CO₂ removed.

Phase1: The carbonation potential, R_{CO₂}, was calculated from the total molar concentration of Ca, Fe²⁺, and Mg²⁺ in specific elemental mineral-chemical assays, and impurities, of blended feedstocks: gypsum (calcium sulfate) desulfurized, feldspar-anorthic, forsterite-olivine, wollastonite, and cement kiln dust. We also use a modified Steinour equation to approximate the maximum potential for CO₂ storage in minerals based on elemental oxide composition. Volume of two reactors for Phase1 ~ 1m³, with 10,000MT annual carbonate – oxide throughput. Operating hours~5,840 annually. 3923MT is the gross CO₂ removed.

- 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).

If all phases are completed, total overall capacity would average 26,237t/CO₂ with 100,000MT of carbonate output annually. Currently the X1 prototype capacity is estimated at 12t/CO₂ with 30MT of carbonate output annually.

- 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 tCO₂ capture with T tons of sorbent.*)

Between July-Dec 2020, we created 2 prototype reactors, including the X1, which is operational now. The first prototype was a benchtop type reactor for initial data gathering of

low pressure, low heat, and aeration of mineral slurries for carbonation. These baseline tests were conducted over a month, resulting in 2 samples that achieved CO₂ uptake by weight of 3% and 30% respectively; however, the sample product were polymorphs of magnesite and salt carbonates, specifically Northupite and Trona. XRD and thin section petrology study was performed by Bureau Veritas.

We will be producing new sample batches of synthetic aggregates in the X1 at higher pressure, temperatures, with direct mixing-agitation, and UV-C (172nm) + water filtration treatment of recycled reactor water. We have physically measured and filled the reactor with water, and mineral feedstocks, to determine weight per batch, and carbonation throughput at varying temperatures and pressures, during pre-carbonation testing of the X1 Reactor. As we continue sample batch testing through spring to produce concrete product samples for compression testing, we will generate, XRD and thin section petrology studies to verify the permanence, and percent of CO₂ uptake as a synthetic calcite and synthetic calcite polymorphs with the mineral feedstock Wollastonite.

- 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.

1.Link to IP, X1 reactor public demos, Case Study of Micro-Reactor, White papers on mineral carbonation; CO₂ to cement/concrete, Thermo-Gravimetric Analysis with MonteCarlo methods; with a Process, Industry and Technology Overview deck and short demo videos:

<https://drive.google.com/drive/folders/10NFy7TMO8V2P4nZpeGzy4HE3aj7GSJqU?usp=sharing>

2. Link to Mineral Feedstock Assay, Logistics, and Initial LCA for the pilot project in Decatur Texas (preliminary)

[LCA Carbix-Pilot 1.pptx](#)

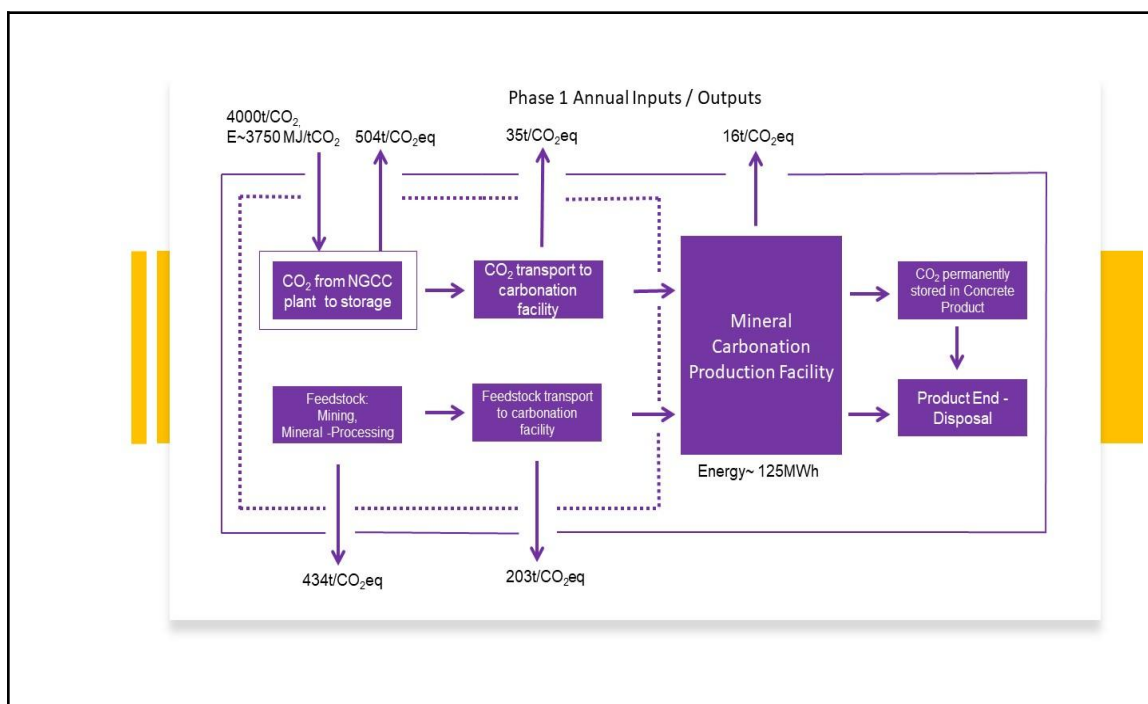
4. Net Capacity / Life Cycle Analysis (Criteria #6 and Criteria #8)

- 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	3935t-CO ₂

Gross project emissions	1200t-CO ₂
Emissions / removal ratio	0.304
Net carbon removal	2753t-CO ₂

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



- 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?

Active boundaries are assigned CO₂ emission factors, expressed as kgCO₂e/MT, to the following activities:

- mining of feedstocks: 1. gypsum, 2. feldspar, 3. wollastonite and 4. olivine.
- feedstock transport to a processing facility for: 1. crushing and grinding to specific particle size: 2. transport to production site: 3. Loading and short haul to production facility.

c. storage, compression and transport of captured flue gas CO₂ which is modeled as originating from a Natural Gas Combined Cycle plant with carbon capture equipment.
d. water and power emissions from production, Excluded are: a) habitat construction; b) and product transport to construction site.

- d. Please justify all numbers used in your diagram above. Are they solely modeled or have you measured them directly? Have they been independently measured? Your answers can include references to peer-reviewed publications, e.g. [Climeworks LCA paper](#).

The emissions factors and boundaries were modeled using conversion factors and models from agencies like the DOE, NRE. LCA analysis from various peer reviewed papers like Climeworks LCA Paper were also used.. Distances, feedstocks, and mineral sources are modeled on actual pilot location, mining sites and actual vendor locations. The actual, X-1 prototype data was also used to initially model Phase 1 volume and throughput; however, more detail modeling of the reactor operating at larger scale is forthcoming. A portion of LCA data was also generated via LCA modeling software and referenced databases, OpenLCA, GREET19, and Ecoinvent. In addition, emissions factors from US EPA, UK/EU LCA – Conversion Factors for commercial reporting, Cefic-EU/Mackinnon LCA emission factors.

Link to methodology of data sets used:

[Stripe Carbix LCA Methods.pdf](#)

Short list of literature review. If requested, further research info can be submitted.

1.. Life-Cycle Assessment for Carbon Dioxide Utilization. Lessons learned from and for LCA

André Bardow, Institute of Technical Thermodynamics, RWTH Aachen University

2. Carbon capture and utilization: preliminary life cycle CO₂, energy, and cost results of potential mineral carbonation

HH Khoo1, J Bu, RL Wong, SY Kuan, PN Sharratt, Institute of Chemical and Engineering Sciences, 1 Pesek Road, Jurong Island, 627833 Singapore*

- 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)

Phase 1 would result in deployment of 2 reactors. The key difference is pressure capability. Reactor 1 processes calcium silicates at pressure under 600 psi, which is 90% of the feedstock. Reactor 2 operates at 2200psi for processing forsterite and sulfates. Forsterite is 3% of feedstock.

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

Year	Units deployed (#)	Unit cost (\$/unit)	Unit gross capacity (tCO ₂ /unit)	Notes
2021	1 (X1 prototype)	\$21,000	12t-CO ₂	<i>Prototype costs contain initial non-standard designs and lack economies of scale. Design standard will lower costs of Phase 1 reactor.</i>
2020				<50 words
2019				<50 words
...				

- 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.)

Our costs have stabilized for the X1 proto, and we will be expecting further costs drops on successive iterations for Phase 1 due to standardizing designs and software, as well CO2 supply chains, and mineral feedstocks at large scale with cement plants.

- 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)
2	<p>3800t-CO₂ Unit 1</p> <p>200t-CO₂ Unit 2</p>

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 CO₂ today?

X1 prototype is \$1750 p.ton based on 12 -t CO₂ sink rate. Based on the total product weight of 30t of carbonates, cost drops to \$700 p.ton.of carbonate. For Phase 1, we estimate reactor costs per ton CO₂ to drop to \$50/tCO₂, assuming \$200,000 is the cost of both reactors with gross CO₂ sink rate of 4000t. Phase 1 reactor cost per 8397t carbonate output annually is \$22 p/ton.

- 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."

Included in the cost is total hardware and supplies (consumables) including S&H. OPEX, rent-lease, feedstock and CO₂ (COGS) are not included.

- 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	<i>Phase 1 Reactor Design</i>	<i>The X2 design will result in lower costs, automation, and standardized modular design.</i>	Virtual design to be completed by 7/2021. Physical construction to begin depending on funding-financing.	<i>Design review (CAD/CFD) and proofing with physical iteration.</i>
2	<i>Phase 2 Site Acquisition and Reactor</i>	<i>The X2 modular design is for a reactor array that can be co-located with a cement plant to harvest flume CO₂ gas, exhaust heat, and lower cost mineral feedstock.</i>	2Q, 2022 – 4Q 2022	<i>Contract/agreement with a MNC cement/concrete company and proof of physical installation.</i>
3	0.5 MMT-CO ₂ Scale reactor	The X3 design (CAD/CFD) will enable deployment or reactor	Q4-2022	<i>Design validation with CFD/CAD and</i>

	array.	modules on-site cement plants with a capability of 1 million metric tons p.yr CO2 sequestration/ utilization. We will be focusing on replacing amine based CO ₂ with direct injection to the reactor array.		<i>installation agreement or offtake agreement from a cement/concrete ready mix produce.</i>
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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	12tCO ₂	20tCO ₂	<i>Benefit from learning curve of reactor operations, being efficient with managing LCA, software/hardware automation to increase through-put.</i>
2	28000t-CO ₂	30-35tCO ₂	<i>We expect the range to increase since CO2 volume is onsite with improvement in rate of</i>

			<i>carbonation efficiency and CO₂ uptake. The full production of a reactor array can then be analyzed and iterated.</i>
3	<i>500,000t-CO₂</i>	<i>500,000t-CO₂</i>	

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	<i>\$1750</i>	<i>\$50t/CO₂ Phase 1</i>	<i>Reactor scaling to increase volume of carbonates results in lower price per ton CO₂.</i>
2	<i>\$50t/CO₂ Phase 1</i>	<i>\$40t/CO₂ Phase 2</i>	<i>Lower increase in cost per reactor due to material changes in the reactor array.</i>
3	<i>\$40t/CO₂ Phase 2</i>	<i>\$7t/CO₂ Plant Scale.</i>	<i>Scale of reactor volume, closer feedstock supply, material improvement to match plant output of 1MMT CO₂ per year with a reactor array.</i>

- 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?

I would ask that person to look at the potential to disrupt CO₂, perhaps not today, but in year 5 at an industrial setting (cement plant scale) across the planet. Then to look beyond cement and concrete, and into product development using CO₂ and other feedstocks to produce net zero and net negative emission products.

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

I think Stripe's continued advocacy and investment in the CO₂ removal space should continue beyond this current round of purchases. Referral to interested corporates/industry players would be especially beneficial to developing future agreements for CO₂ reduction.

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?

Anyone that benefits from CO₂ reduction and especially those that live in communities that have been physically – physiologically impacted by CO₂ emissions.

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

<100 words

- 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

- 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?

In work.

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

In terms of EJ, we would look to hire either as interns or direct hires, people living in communities that have been negatively impacted by pollution, not just CO₂, but also water pollution. We believe this would help accelerate awareness to the myriad of health issues related to emissions.

11. Legal and Regulatory Compliance (Criteria #7)

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

Currently, during pre-planning, we are consulting contractors and agencies to discussing permitting and high volume CO₂ storage.

- b. What permits or other forms of formal permission do you require, if any? Please clearly differentiate between what you have already obtained, what you are currently in the process of obtaining, and what you know you'll need to obtain in the future but have not yet begun the process to do so.

We do not have a complete list, but will provide once finalized.

- 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.

International agreements and drafting international contracts.

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)	2753t/CO ₂
Delivery window (at what point should Stripe consider your contract complete?)	Nov21-Nov22 is the project duration and should be considered complete by Nov2022, unless otherwise noted.
Price (\$/metric tonne CO ₂) <i>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.</i>	\$73 p.ton based on Net CO ₂ sequestered and utilized.

Application Supplement: CO₂ Utilization

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

Feedstock (Criteria #6 and #8)

- How do you source your CO₂, and from whom?

CO₂ is initially sourced from Natural Gas plants equipped with CCS for the X1 and Phase 1. We are currently in discussion with vendors for X1 proto phase, and Phase 1 and do not have a firm answer on supplier. DAC CO₂ may be an option for Phase 2, but is too costly to implement in such a short timeframe.

- What are alternate uses for this CO₂ stream?

CO₂ streams have multiple uses in production of industrial chemicals, among which are CO and O₂ for industrial use and hospital use. CO₂ has traditionally been used in Food & Beverage and in some recreational activities. However, given the large volume of emissions we believe the cement and concrete industry has the volume for application of CO₂ in building materials.

3. Do you have a pathway towards sourcing atmospheric CO₂ so as to achieve carbon removal?
(e.g. Future coupling of process to direct air capture)

Our pathway to using DAC, begins in Phase 2 as an enrichment stream for flue gas exhaust CO₂. We do have a partnership with a DAC startup developing DAC systems for the O/G industry. As well, notable DAC companies like Climeworks and Carbon Engineering are options for sourcing DAC as well for enrichment of the CO₂ stream to increase the uptake rate per batch.

Utilization Methods (Criteria #4 and #5)

4. How does your solution use and store CO₂? What is the gross CO₂ utilization rate? (E.g. CO₂ is mineralized in Material at a rate of X tCO₂ (gross) / t storage material).

Based on calcium silicate blends, CO₂ is stored permanently based on reaction conditions noted in the LCA links. Reactions for calcium silicates generally involve pressure up to 600 psi, temperatures up to 200C. See link for uptake rates per mineral and mineral blend.

https://drive.google.com/file/d/1dYJLmOR1YKoBUe99zaen1_UjA_4rGNpt/view?usp=sharing

Olivine-forsterite requires higher pressures near 2200psi (Reactor 2). Average reactor residence times for calcium silicates is estimated to be 15mins to 1 hour depending on particle size, and same for olivine-forsterite. Carbonates are permanently stored in concrete products.

5. What happens to the storage material (e.g. concrete), and how does that impact its embodied carbon storage over time? How do you know?

Environmental conditions referenced above may exist in weak or diluted conditions in the built and natural environment. Weathering of concrete, can deteriorate the cement bond from dilute acidic, biologic, and abrasion/mechanical compression attacks over varying time scales of decades to hundreds of years.. The carbonate-aggregate component that stores CO₂ will generally remain in-tact even at the end of product life and disposal. Coatings, cleaning, surface treatment of concrete, layering/covering, have generally improved the life-cycle of concrete. Product can be physically tested via XRD and petrology tests as well to monitor for extreme environment exposure. Refer to 2c on durability.

6. How do you ensure that the carbon benefits you are claiming through a CO₂ utilization process are not double counted? (E.g. If sourcing CO₂ from a DAC system, or selling your product to a user interested in reducing their carbon footprint, who claims the carbon removal benefits and how could an independent auditor validate no double counting?)

Each project or offset agreement/purchase are typically listed on an exchange, like puro.earth. We intend to sell all of our carbon credits via exchange to create a carbon credit repository of sorts, so that the public can view carbon credits by project/pilot site and amount of credits. Independent auditing can be performed annually and the result shared publicly and with purchasers.