# x/44

## Carbon Removal Purchase Application

# General Application

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

Company or organization name

x/44 Inc.

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

Los Angeles, CA, USA

Name of person filling out this application

Dante Simonetti

Email address of person filling out this application

[redacted]

Brief company or organization description

Low-cost, modular, electrochemical direct air capture

## 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.

The removal of $CO_2$ from the atmosphere (direct air capture: DAC) is costly because enormous amounts of energy are needed to regenerate the sorbents or solvents used to absorb $CO_2$

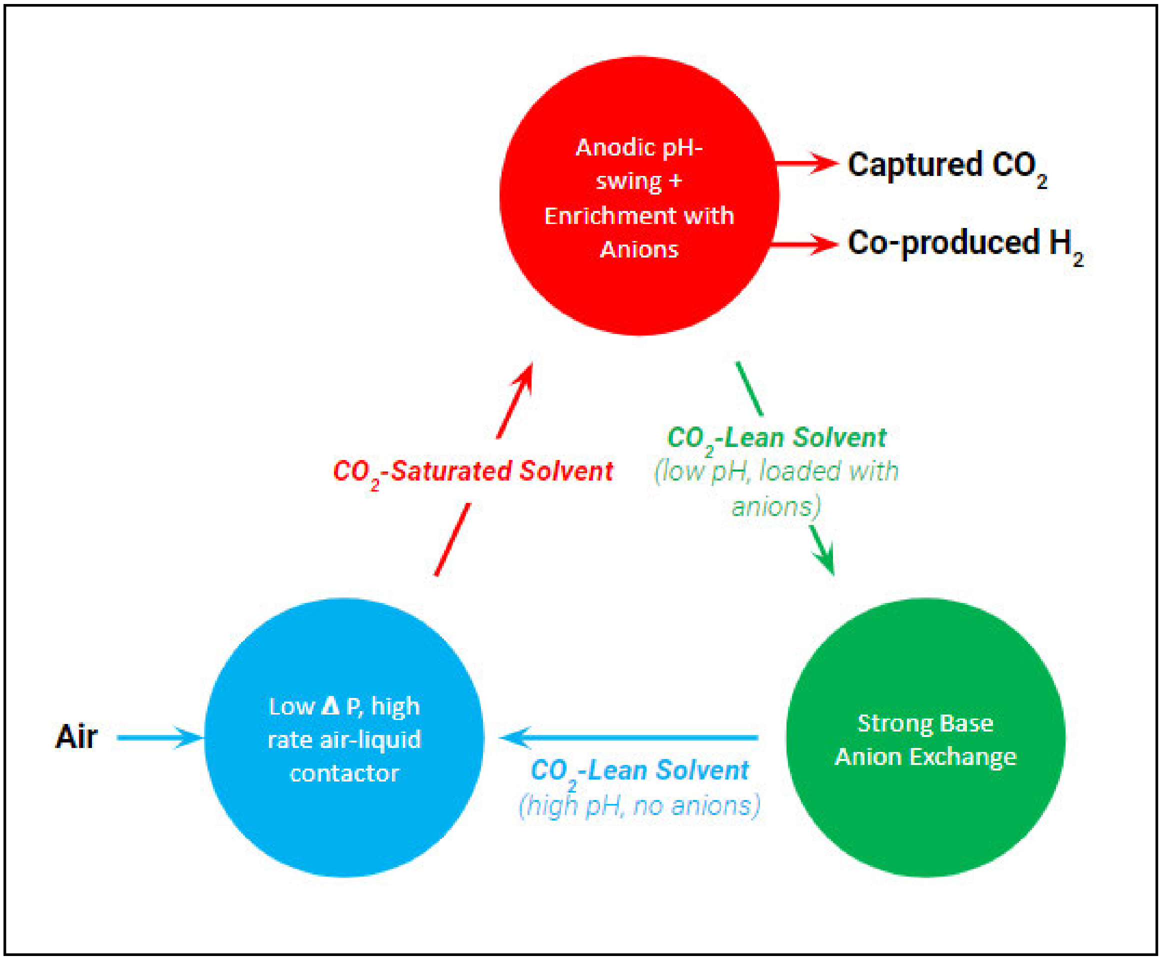
from the air (0.04 vol.%), and to compress and transport a pure $CO_2$ stream (>99 vol.% v/v) at high pressure (150 atm). These high energy requirements lead to large capital and operating costs of DAC systems and require complex (and currently non-existent) logistics infrastructure for conveying $CO_2$ to geological sequestration sites.

Significantly less energy-intensive alternative $CO_2$ utilization (e.g., CarbonBuilt's Reversa™ process) and capture (e.g., SeaChange process) technologies can be greatly enhanced by access to partially enriched/concentrated $CO_2$ (5-to-30 vol.% $CO_2$), and are greatly advantaged by distributed and flexible access to $CO_2$, e.g., which allows spatial decoupling from point-sources of $CO_2$ emissions. For these reasons, the development of low energy DAC processes that enable the modular, and fractional $CO_2$ enrichment (FCE) is foundational to catalyze the widespread adoption of $CO_2$ utilization and sequestration technologies.

x/44 is building a novel electrochemical reactor (e-reactor) to achieve DAC via FCE. The approach uses water electrolysis to generate acid and base, *in situ*, to facilitate a pH swing that regenerates $CO_2$-saturated solvents at ambient temperature and pressure, relying solely on water and electricity as inputs. In addition, water electrolysis generates hydrogen gas as a co-product, whose embodied energy (~1.2 MWh per tonne of $CO_2$ captured depending on the conversion efficiency) can be harvested to offset the projected energy requirements of electrolysis (~3.2 MWh per tonne $CO_2$) or can be sold for approximately $2000-$3000 per tonne $H_2$ (i.e. $90-140 per tonne $CO_2$). This allows for DAC at a favorable net energy intensity and in a manner that significantly reduces lifecycle emissions with direct pathways to profitability. Particularly, electrochemistry allows for flexible process operations such that the extent of the pH swing can be tuned to produce fractionally (or fully) enriched $CO_2$ streams (e.g., ranging from 5-to-99 vol. % $CO_2$), and allows the process to cycle up-and-down in its capacity, rapidly, while following renewable energy generation. This allows for the supply of atmospherically sourced $CO_2$ for downstream utilization across a range of concentrations while ensuring complete geographic freedom in system-/project-siting.

Specifically, the e-reactor can be coupled with commercially available fans and liquid-vapor contactors to bring large volumes of air into contact with the solvent, where rapid mass transfer over large surface areas enables absorption of $CO_2$ into the solvent at alkaline pH. The pH of the $CO_2$-saturated solvent is decreased in the e-reactor via proton generation at the anode. This *in situ* acidification rapidly desorbs the $CO_2$. Thereafter, the $CO_2$-lean, acidified solvent is restored to its original pH using the alkalinity (hydroxide: $OH^-$ ions) generated during electrolysis, thereby completing the pH swing. Hydrogen (gas) is generated as a by-product during the electrolysis, which can either be sold as a clean-fuel or recycled via a fuel-cell or hydrogen turbine to aid in powering the process. The desorbed $CO_2$ (between 5-to-99 vol % $CO_2$) can be coupled to industrial processes as a feedstock to ensure permanent removal.

For this project, x/44 will build its first-of-a-kind (FOAK) DAC facility at sites in California or Alabama at a capacity of 1t$CO_2$/day by Q2 2024. This first demonstration will partner with the 2021 Stripe recipient and NRG COSIA Carbon XPRIZE winner; CarbonBuilt Inc., who's Reversa™ technology durably sequesters $CO_2$ in carbonated concrete, by reaction with calcium hydroxide ($Ca(OH)_2$), also known as portlandite or hydrated lime. Taken together, this project will develop a modular, electrochemical fractional $CO_2$ enrichment technology that via the provision of low-cost $CO_2$ will catalyze $CO_2$ utilization and removal technologies. Critically, the project will move x/44's technology from TRL 3 to TRL $6^+$.




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.)*

x/44 owns its modular plants and supplies (atmospheric) $CO_2$ streams of tailorable concentrations (5-to-99 vol % $CO_2$) for industrial use. Companies capable of $CO_2$ utilization and storage, such as CarbonBuilt and SeaChange, ensure permanent removal. Specifically in this project, CarbonBuilt will utilize the $CO_2$ for carbonated concrete production.

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

1. [Technical] The greatest area of uncertainty is the performance of the scaled-up electrochemical reactors and the continuous, integrated operation of a mass contactor for $CO_2$ absorption with the electrochemical reactor for regeneration and harvesting of the partially concentrated $CO_2$ stream. While there are many adjacent technologies (i.e. electrolyzers and electrodialysis) that inspire confidence that the electrochemical

reactor can be scaled and matched with commercially available mass contactors, the engineering challenge to execute a compact, scalable design to satisfy the modular requirement of the system is a key issue to be addressed.

2. [Technical] An important risk that will be mitigated over the coming months is validating the cycle life of the solvent, and its resistance to degradation. Amines, one possible solvent class, are known to degrade in carbon capture applications via thermal and oxidative mechanisms. By eliminating the need for elevated temperature exposure and replacing it with an ambient temperature pH-swing, the thermal degradation mechanism is mitigated and the oxidative mechanism is believed to be abated. Additional quantification of the degradation mechanism and the inclusion of possible inhibitors are needed.
3. [Technical] Another major risk is the possibility of solid precipitation within the electrochemical reactor. Due to the presence of metallic cations as charge balancing counter-ions, it is possible for the desorbed $CO_2$ to form solid metal carbonates that may precipitate *in-situ* on the electrode or membrane surfaces, thereby reducing surface area and increasing the energy requirement. Proper $CO_2$ management within the reactor will be applied to minimize this risk and ensure both maximum capture efficiency and system lifetime.

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

- Patent pending (provisional patent has been filed)

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?

The team integrates scientific rigor with start-up ingenuity and industrial prowess to form a diverse, dynamic collaboration. The group is well-equipped, and has a track-record in translating benchtop outcomes into industrial pilot plants and beyond, combining ambitious, forward-looking vision with grounded, scrutinized activity to drive progress and innovation. The team draws on expertise from UCLA's Institute for Carbon Management (ICM) and is actively recruiting additional team members with experience in building electrolyzers and/or electrodialysis systems at scale to further advance the e-reactor architecture.

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

a. Please fill out the table below.

| | Timeline for Offer to Stripe |
|---|---|
| Project duration | June 2024-May 2025 |

| | |
|---|---|
| *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 2022 - Jun 2023. The end of this duration determines when Stripe will consider renewing our contract with you based on performance.* | |
| When does carbon removal occur?<br><br>*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?*<br><br>*E.g. Jun 2022 - Jun 2023 OR 100 years.* | Continuously throughout project duration |
| Distribution of that carbon removal over time<br><br>*For the time frame described above, please detail how you anticipate your carbon removal capacity will be distributed. E.g. "50% in year one, 25% each year thereafter" or "Evenly distributed over the whole time frame". We're asking here specifically about the physical carbon removal process here, NOT the "Project duration". Indicate any uncertainties, eg "We anticipate a steady decline in annualized carbon removal from year one into the out-years, but this depends on unknowns re our mineralization kinetics".* | Approximately evenly distributed over the project duration. |
| Durability<br><br>*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.* | Tens of thousands to millions of years |

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

| |
|---|
| CarbonBuilt's technology immobilizes $CO_2$ in the form of calcium carbonate ($CaCO_3$, limestone). Based on both empirical observations, and the geologic record, such mineral carbonates are known to be stable over tens of thousands to millions of years. |

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

There is extensive evidence in the geologic record of the stability of calcium carbonates in nature (e.g. the Cliffs of Dover) over millions of years, in spite of variations in both atmospheric $CO_2$ concentration and temperature. Furthermore, there is empirical evidence of the durability and structural integrity of structures formed of calcium carbonate (i.e., by lime mortar carbonation) such as Hadrian's Wall, which have demonstrated, in turn, the stability and durability of human-made carbonate materials.

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?

Calcium carbonates are thermodynamically, and kinetically, stable at ambient pressure, and over a broad range of temperatures and $CO_2$ concentrations. The $CO_2$ that is immobilized in calcium carbonates by CarbonBuilt's technology can only be removed by heating the material to ~800°C at atmospheric pressure. As such, unless exposed to an adverse event (e.g., such as a fire) CarbonBuilt's approach to $CO_2$ utilization and removal faces no risks, either physical, socioeconomic, or otherwise.

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.)*

CarbonBuilt can quantify actual $CO_2$ utilization in two ways: a) by direct measurements of inlet/outlet (gas-phase) $CO_2$ concentrations during manufacturing, and b) by post-production assessments of the manufactured concrete products whose $CO_2$ content is analyzed using thermogravimetric analysis (TGA). This approach allows proper closure of the $CO_2$ mass balance to ascertain the actual amount of $CO_2$ that is embedded in concrete products. While the durability of calcium carbonate mineral is well-known (see 2c-2d above), CarbonBuilt will additionally carry out systematic monitoring of the manufactured products using TGA over a period of 5-years to confirm that there are no changes in their embedded $CO_2$ content to further confirm permanence.

## 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<br><br>Do not subtract for embodied/lifecycle emissions or permanence, we will ask you to subtract this later | 365 $tCO_2$ |
| If applicable, additional avoided emissions<br><br>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 | Concrete: 792 $tCO_2$<br><br>Hydrogen: 140 $tCO_2$<br><br>Total: 932 $tCO_2$ |

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)*

Gross Carbon Removal

We project 1 year operation of a 1 $tCO_2$/day capacity facility:

365 days * 1 $tCO_2$/day = 365 $tCO_2$

Avoided Emissions - Concrete

CarbonBuilt projects ~1 tonne of $CO_2$ is sequestered in 50 tonnes of concrete (~2% by mass) and reports an avoided emissions to carbon removal ratio of 2.17. At 365 $tCO_2$ removal for the project, the avoided emissions are estimated as:

2.17 $tCO_2$avoided/$tCO_2$ * 365 $tCO_2$ = 792 $tCO_2$.

Avoided Emissions - Hydrogen Production

We project a co-production of ~0.09 tonnes of hydrogen gas for every 1 tonne of $CO_2$ removed. At 365 $tCO_2$ removal, there is a co-generation of ~33 $tH_2$. At 60% conversion efficiency and the high heat value of 39.38 MWh/$tH_2$, this could displace ~780 MWh of Natural Gas, or 140 $tCO_2$ ($0.18 tCO_2e/MWh_{\text{Natural Gas}}$).

33 $tH_2$ * 60% * 39.38 MWh/$tH_2$ * 0.18 $tCO_2e/MWh_{\text{Natural Gas}}$ = 140 $tCO_2$

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).

Our current bench-scale system offers a capacity of ~0.06 $t_{CO2}$ per year.

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

The foundational assumptions we incorporate in our models are a combination of direct measurements from our bench-scale system, which were independently verified by 350Solutions in January 2022, and literature-sourced values. For instance, we assume a loading of mol $CO_2$ per mol solvent consistent with literature and have measured a ratio of mol $H^+$ per mol solvent from titration-data as required for desorption (confidentially; i.e., not for public release at this time). These values, taken together with the energy requirements of a typical electrodialysis system and the efficiencies of electrolyzers, enable us to project our energy and cost targets with substantial confidence.

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.

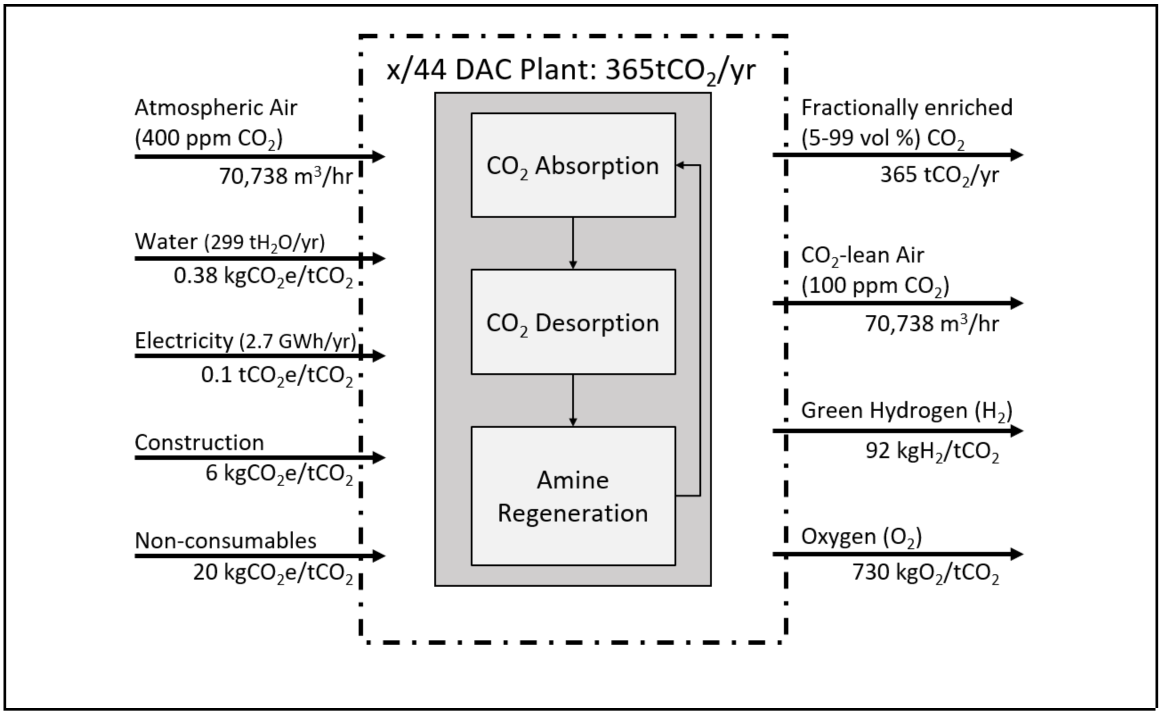
- Confidentially (i.e., not for public release at this time), 3rd-party verification completed by 350Solutions can be provided upon request

## 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 | 365 $tCO_2$ |
| Gross project emissions | 47 $tCO_2$ |
| Emissions / removal ratio | Projected: 0.13 |
| Net carbon removal | 318 $tCO_2$ |

b. Provide a carbon balance or "process flow" diagram for your carbon removal solution, visualizing the numbers above in table 4(a). Please include all carbon flows and sources of energy, feedstocks, and emissions, with numbers wherever possible *(E.g. see the generic diagram below from the CDR Primer, Charm's application from 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 boundary conditions are chosen to encompass the entirety of the system components for cradle-to-grave emissions associated with x/44's DAC plant. There is no explicit "transportation" component as the associated emissions are captured in the "construction" estimate with minimal need for transport once operational due to co-location with down-stream processes. CarbonBuilt's process flow diagram can be found in their Stripe application.

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.

All reported numbers for the system are modeled based on a combination of experimental data and literature references (as noted in 3d). Basic stoichiometry combines with the electrical efficiencies of current state-of-the-art electrolyzers to estimate the energy input per mol $H^+$ generated. Experimental titration data have determined the extent of $CO_2$ desorption as a function of pH which enables the calculation of the energy demand per mass $CO_2$ removed, with supporting reference to literature values for the equilibrium $CO_2$ loading of the solvent when exposed to air.

The carbon intensity for the electricity source was chosen to reflect the local "green" energy bundle offered by Los Angeles Department of Water and Power (LADWP). The total water consumption is determined stoichiometrically, consistent with efficiency assumptions, and the embodied emissions per ton $CO_2$ is calculated with reference to a recent study on the carbon footprint of the U.S. water sector. Both the construction and non-consumables embodied emissions are estimated in reference to Climeworks LCA, and have the greatest uncertainty at this time. Future LCA's will further refine our estimate as the system definition continues to mature.

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.

Not applicable for current estimates. Following construction and during pilot operations, the team will measure and monitor the energy consumption, the $CO_2$ intake and output, and the hydrogen production to further validate and refine these claims.

## 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)

Our current unit of deployment is a bench-scale reactor module.

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 | Bench-scale | <$5000 | ~0.06 $tCO_2$/unit | Unit is a proof-of-concept prototype to validate the desorption and regeneration approach. Serves to inform design parameters of future deployments. |

| | | | | |
|---|---|---|---|---|
| 2021 | | | | |
| 2020 | | | | |
| ... | | | | |

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.)*

| |
|---|
| N/A |

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

| # of units | Unit gross capacity ($tCO_2$/unit) |
|---|---|
| 1 | 365 $tCO_2$/unit |

## 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?

| |
|---|
| ~\$1200/$tCO_2$ (net cost with sale of hydrogen); ~\$1450/$tCO_2$ (gross cost without sale of hydrogen) |

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.

Included CAPEX: electrolyzer, fans, contactors, balance of plant, EPC & Installation, 12.5% capital recovery factor, assume 5x cost penalty for first-of-a-kind system, 10 year project lifetime

Included OPEX: land, electricity ($69/MWh), water

Additional inclusions: decommissioning costs, hydrogen revenue

Excluded: labor (included for Megaton projection), associated emissions, CarbonBuilt's (or alternative company) utilization or capture process costs.

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.

At the Megaton scale: ~$65/t$CO_2$ (net cost with sale of hydrogen); ~$155/t$CO_2$ (gross cost without sale of hydrogen)

At the Gigaton scale: We anticipate another 10-20% reduction in costs.

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)

The prices of electrolyzers (and their components), and air contactors are expected to drop considerably in the coming years as these technologies are developed, upscaled, and upsized. In addition to these ecosystem developments, we will take advantage of the modular nature of the system to "rack-and-stack" capacity to realize cost savings (Wright's Law) associated with producing small to medium volume units rather than first-of-a-kind bespoke components. For example, manufacturing a modest 1000 repeat units allows CapEx reductions by as much as 70%, for similar technological systems, e.g. hydrogen electrolyzers, when compared to building a single-plant sized to have an equivalent cumulative capacity.

Simultaneously, we continue to make enormous progress in improving our system efficiencies and unit operations for components including electrochemical reactors, ion exchange membranes, and ion exchange operations. This maturity will directly reduce the energy and water consumption and the land requirements.

As can be seen in the reported system-level costs, the design is very sensitive to the price of electricity, the price of hydrogen, and the plant efficiency (i.e. which is correlated to the price of electricity). As the price of electricity decreases with the enhanced deployment of renewable generation, this will yield further cost savings. Today, there already exist U.S projects with electricity prices in the region of ~$30/MWh for solar+storage electricity production. Since x/44's electrochemical DAC solution is powered entirely by electricity (i.e., to ensure electrification of demand, and process intensification by electrification), it is well positioned to minimize its operating expenses with clean, inexpensive renewable energy.

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.

A worst case scenario predicts a cost of ~\$530/t$CO_2$ (net cost with sale of hydrogen) or ~\$715/t$CO_2$ (gross cost without sale of hydrogen). This model assumes the following sensitivities: (1) renewable deployment stalls such that electricity costs remain constant, (2) the capital expenses fail to realize any cost reductions from existing technology, and (3) the (future) sales price of green hydrogen plateaus at \$2/kg (for net cost only). This outcome is highly improbable.

One sensitivity that cannot be incorporated into our models yet, but does reflect a risk to the deployment cost, is the system lifetime as it pertains to the cycle life of the capture solvent.

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 | Demonstrate complete integration and operation of a 1 kg/day system | This system will be critical in matching flow rates through the contactor, mass exchanger, and electrochemical swing cell. It will serve as the design basis for the larger 100 kg/day and 1 t/day systems. | Q3 2022 | $CO_2$ removal will be quantified through direct measurement of the $CO_2$ output with select in-line monitoring of critical streams. |

| | | | | |
|---|---|---|---|---|
| **2** | Finalize electrochemical reactor architecture for 100 kg/day system | Proper sizing of the modular, basic repeat unit is critical for manufacturing and deployment. The focus of this build will be to systematically increase the total capture capability, while finalizing the proper design of the reactor. | Q2 2023 | $CO_2$ removal will be quantified through direct measurement of the $CO_2$ output with select in-line monitoring of critical streams. Design efforts will focus on optimizing the output of a single unit. |
| **3** | ASPEN Simulation of the entire 1 t/day DAC process cycle, including robust accounting of heat, mass and energy balances | The system design will guide the equipment sizing, allowing for complete OEM & vendor engagement to ensure on-time delivery of the system. | Q4 2023 | Technical documentation can be provided showing the complete system design, including PFDs, P&IDs, and equipment list. |

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** | ~0.06t/yr | 0.365t/yr | Added capacity through scaling of the system. |
| **2** | 0.365t/yr | 36.5t/yr | Added capacity through scaling of the system. |
| **3** | 36.5t/yr | 36.5t/yr | No added capacity. Milestone focuses on finalizing plant design. |

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 | \$1200/t$CO_2$ | \$1200/t$CO_2$ | Preliminary estimates are based on a 1 t/day system, so no cost change is captured at this time. |
| 2 | \$1200/t$CO_2$ | \$1200/t$CO_2$ | Preliminary estimates are based on a 1 t/day system, so no cost change is captured at this time. |
| 3 | \$1200/t$CO_2$ | \$1200/t$CO_2$ | Preliminary estimates are based on a 1 t/day system, so no cost change is captured at this time. |

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?

U.S. President Joe Biden - to create a formal U.S. Carbon Cap and Trade system, with complete standards for measurement and verification, to rapidly accelerate the adoption of natural and engineered carbon abatement and removal solutions.

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

Stripe has created an ecosystem that can amplify the reach of our project to connect with passionate, talented problem solvers. Stripe can further help the team grow by introducing motivated professionals and industry leaders with expertise in plant design and electrochemical reactors, as well as business building.

## 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.

| |
|---|
| Negative emissions technologies (NETs) have the potential to positively impact all life on the planet and thus the external stakeholders are all encompassing. The immediate stakeholders are:<br>• CarbonBuilt, SeaChange (another Stripe recipient) and other industrial companies in need of atmospheric $CO_2$ supply<br>• EPCs and OEMs who will be contracted to assist in the delivery of the plant<br>• Energy and water utilities<br>• Materials suppliers<br>• Local communities near the deployment site |

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.*

| |
|---|
| These efforts are in their nascency and we are open to feedback on how to best ensure equitable, responsible deployment of the system. We anticipate engaging external stakeholders both directly and through external consultants, where applicable. UCLA's Institute for Carbon Management (x/44 is a spinout company of the Institute) is also building a community engagement competence that will be supportive of our efforts. |

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?

| |
|---|
| Not applicable at this stage of engagement. |

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 anticipate that the processes for (a) and (b) will grow to maturity as we begin implementing the project described in this application. |

## 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?

This project will be fulfilled in Los Angeles, CA or Birmingham, AL. Therefore, the team will engage with the data made available by CalEnviroScreen 4.0, or similar, which quantifies the negative impacts of pollution and the populations that most bear these burdens, to understand the vulnerabilities and historical injustices in the areas surrounding the site. It will be critical that the project is net carbon negative to not cause further harm. Additional considerations to noise pollution and traffic for construction will be made, with the team working with local authorities and community leaders to find a harmonious solution.

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

The group will tackle concerns head on and with transparency. The perceived most important step will be ensuring the safe handling and disposal of all hazardous materials to prevent any contamination of local land or water supply. The site will produce hydrogen so proper handling, including engineering controls and monitoring, is needed to mitigate the risk of leakage and ignition. The DAC system design minimizes material inputs, and only relies on water and clean electricity. Further, considerations will be taken to minimize energy consumption and plant footprint to further reduce the impacts on the local community.

## 9. Legal and Regulatory Compliance (Criteria #7)

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

Not applicable at the current stage of development. We anticipate working with the Southern California Air Quality District (SCAD) and other regulatory commissions to ensure safe, responsible deployment of the technology.

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 project will require permitting for construction and operation of the facility, including permits for handling and storage of hazardous materials. While these permits have not yet been secured, due to the current stage of development, we anticipate having all necessary permits secured between Q4 2022 and Q2 2023 for successful delivery of the project.

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?

| |
|---|
| To the best of the team's knowledge, no. No engagement has been undertaken to date. |

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.

| |
|---|
| There are two possible locations where the demonstration plant will be built, and the design is still being finalized. Together, these create uncertainty as to what local ordinance will regulate the permitting process, and what exact quantities of materials will be required. |

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)

| |
|---|
| The project has not pursued nor received any tax credits from a government compliance program to date. As of the time of writing, there are no immediate plans to pursue this during the proposed delivery window for Stripe's purchase. |

## 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**<br>*metric tonnes $CO_2$* | 318 $tCO_2$ |
| **Delivery window**<br>*at what point should Stripe consider your contract complete?* | June 2024 to May 2025 |
| **Price** (\$/metric tonne $CO_2$)<br>***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.* | \$1200/$tCO_2$ |

# 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 | N/A |
| 2022 | 0.00016 |
| 2023 | 0.00016 |

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 | N/A |
| 2022 | To be finalized - active area of development |
| 2023 | To be finalized - active area of development |

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

1. What sorbent or solvent are you using?

| |
|---|
| System is looking at high capacity solvents, including the industrially-relevant amine family. |

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

| |
|---|
| 0.18 to 0.72g$CO_2$/gSolvent (0.25 to 1.0 mol $CO_2$ per mol solvent) |

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

| |
|---|
| Solvent can be completely unloaded (of $CO_2$) at sufficient pH, so 0.18 to 0.72g$CO_2$/gSolvent |

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)

| |
|---|
| Amines, a candidate solvent, are readily available due to their use in industry, including traditional scrubbing and carbon capture and storage, with a global production estimated at 2.46MT in 2023. The material is currently sourced through small vendors for laboratory use. The team is also working with international chemical companies to ensure environmentally and socially responsible sources of amines (or alternative solvent) to minimize externalities. |

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

| |
|---|
| The solvent is continuously cycled through an *in-situ* acid and base generation process that controls a pH swing. The $CO_2$ is desorbed upon acidification and the solvent is regenerated upon alkalization. Currently, the process requires ~7.5 MWh/t$CO_2$ (gross), with ~2.2 MWh/t$CO_2$ being generated in hydrogen co-production, for a net energy of ~5.3 MWh/t$CO_2$. In time, with scale-up and design improvements, the energy requirement is anticipated to rapidly fall to ~3.2 MWh/t$CO_2$ (gross) and ~2.0 MWh/t$CO_2$ (net), respectively, in subsequent iterations. |

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 system is entirely powered by renewable electrons. If sited in Los Angeles, the project will use the Green Power plan from Los Angeles Department Water and Power (LADWP), with a carbon intensity of 0.014 t$CO_2$e/MWh. The cost of electricity is assumed at $69/MWh and is believed to be constant for the project. |

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)*

| |
|---|
| Besides electrons, the only continuous input is water, estimated at \$1.62/$m^3$. This can be sourced directly from the utility. |

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

| |
|---|
| For this project, we will need 820L of water per tonne of $CO_2$ removed. Future generations will only require half of this amount, at 410L of water per tonne of $CO_2$ removed. |

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

| |
|---|
| System is continuously cycled, with the cycle time being finalized in design. |

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

| |
|---|
| Amines are most susceptible to degradation at elevated temperature; e.g., during thermal cycling, which this process eliminates. Degradation related to possible oxidation is under investigation, but is believed to be minimal at the DAC operating temperature. Alternative solvents are also being investigated. |

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

| |
|---|
| Conservatively, we estimate >6000 hours or >2000 cycles |

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 solvent is a hazardous material and will be disposed of in accordance with local regulations at end-of-life. Proper disposal can occur via physical or chemical methods. In addition, we are also looking at methods for solvent rejuvenation/circularity at its end-of-life. |

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.

x/44's direct air capture technology is uniquely suited to pair locally with industrial processes to provide atmospheric $CO_2$ supply. Importantly, the electrochemistry allows for flexible operation such that the extent of the pH swing can be tuned to produce fractionally (or fully) enriched $CO_2$ streams (e.g., ranging from 5-to-99 vol.% $CO_2$), and allows the process to cycle up-and-down in its capacity while following renewable energy generation. Further, the combination of the modular design and lack of continuous inputs beyond the readily-available requirements of electricity and water, ensures complete geographic freedom in siting that cannot be satisfied by today's leading DAC technologies.

Importantly, x/44's cost projection of (net) ~\$65/t$CO_2$ is 30-80% lower than today's leaders, with Carbon Engineering projecting \$94-232/t$CO_2$ and Climeworks projecting \$100-\$300/t$CO_2$.

# Application Supplement: $CO_2$ Utilization

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

## Feedstock (Criteria #6 and #8)

1. How do you source your $CO_2$, and from whom?

> CarbonBuilt currently sources its $CO_2$ from industrial emitters (e.g., bioenergy, bioethanol) removing what would otherwise be atmospheric $CO_2$ accumulations while producing low-carbon construction products. Importantly, this $CO_2$ utilization occurs without a need for $CO_2$ capture, concentration, purification, or treatment at ambient pressure and low temperature. To our knowledge, CarbonBuilt is the only $CO_2$ utilization technology, globally, that is able to utilize dilute $CO_2$ directly in this manner in its mineralization process.
>
> x/44's fractionally enriched $CO_2$ stream will directly provide atmospheric $CO_2$ to CarbonBuilt to demonstrate direct coupling with DAC.

2. What are alternate uses for this $CO_2$ stream?

> Currently, there exist no alternate uses for the industrial $CO_2$ (waste) streams that form a feedstock/input to the CarbonBuilt process. For this reason, CarbonBuilt's technology enables direct and unambiguous removal of $CO_2$ by beneficially utilizing $CO_2$ borne in dilute, hard-to-concentrate $CO_2$ emissions that are emitted by hard-to-abate industrial sectors.
>
> Partnering with x/44 offers CarbonBuilt geographic flexibility, greatly enhancing economics and project logistics - while ensuring direct atmospheric removal of $CO_2$. In addition, however, x/44's fractionally enriched $CO_2$ streams can also be coupled with emerging mineralization technologies, such as SeaChange Inc., or with other users including green houses.

3. Do you have a pathway towards sourcing atmospheric $CO_2$ so as to achieve carbon removal? *(e.g. Future coupling of process to direct air capture)*

> CarbonBuilt (and SeaChange) are working intensively with their partners to develop transformative, modular systems for fractional (>5vol% $CO_2$) DAC that will seamlessly integrate with their $CO_2$ utilization (removal) systems. For the case of CarbonBuilt, at commercial-scale, x/44's technology will allow CarbonBuilt to readily utilize atmospherically sourced $CO_2$ and "cut-the-cord" to classical point-source $CO_2$ emitters. DAC integration will greatly improve the locational and logistical flexibility of CarbonBuilt's solutions, further enhancing the economics and the scaling potential of the technology.

## Utilization Methods (Criteria #4 and #5)

4. How does your solution use and store $CO_2$? What is the gross $CO_2$ utilization rate? *(E.g. $CO_2$ is mineralized in Material at a rate of X $tCO_2$ (gross) / t storage material).*

| |
|---|
| CarbonBuilt's Reversa™ process reacts dilute, gas-phase $CO_2$ with portlandite ($Ca(OH)_2$) via an acid-base reaction to produce limestone ($CaCO_3$), a cementation agent, in an energy efficient manner, with no requirement for capture, concentration, purification or treatment. The limestone formed binds sand and stone similarly to OPC in traditional concrete. CarbonBuilt's products are functionally, and performance equivalent to traditional concrete with a $CO_2$ footprint that is up to 105% lower than traditional concrete. On account of the downhill thermodynamics of carbonation, the process is rapid and able to achieve $CO_2$ mineralization rates ranging between 1.5-5% (by mass of concrete). |

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?

| |
|---|
| Concrete products produced using CarbonBuilt's Reversa™ technology will be used in exactly the same ways that conventional concrete products are used. As noted in our answer to question 2(c) in the main application, $CO_2$ mineralized in these products as calcium carbonate will remain stabilized for tens of thousands to millions of years, as evidenced by the geologic record and humanity's use of lime mortar materials. |

6. How do you ensure that the carbon benefits you are claiming through a $CO_2$ utilization process are not double counted? *(E.g. If sourcing $CO_2$ 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?)*

| |
|---|
| In the absence of a rigorous (e.g., blockchain-based) process for tracking carbon benefits from cradle-to-grave, benefits (economic, regulatory and/or marketing) will need to be properly accounted for so that they are not double-counted across the value chain of suppliers, partners and customers. We recognize that norms and policies to prevent double-counting, across the entire spectrum of utilization opportunities, are still being established. Broadly speaking, we are committed to being an active participant in the cross-stakeholder dialogue that is occurring in this regard, and to making full use of industry-specific best practices. More specifically, we commit to establishing a verifiable methodology (including, for example, contractual arrangements with our Partner, and between our Partner and their customers) to prevent double-counting of benefits for the specific project proposed herein. For clarity, our economic analysis for the project does not include any product price premium that could be derived from marketing the carbon benefits to an end customer nor any "tipping fee" charged to the $CO_2$ provider. |