Noya Inc.

Carbon Dioxide Removal Purchase Application

Fall 2022

General Application - Prepurchase

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

Company or organization name

Noya Inc.

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

San Francisco, CA, USA

Name(s) of primary point(s) of contact for this application

Daniel Cavero

Brief company or organization description

Direct air capture company removing CO_2 with a low-cost modular design and novel regeneration approach.

1. Project Overview[1]

a. Describe how the proposed technology removes CO_2 from the atmosphere, including as many details as possible. Discuss location(s) and scale. Please include figures and system schematics. Tell us why your system is best-in-class, and how you're differentiated from any other organization working on a similar technology.

Technology Description:

Noya's DAC technology is, broadly speaking, extremely simple. First, ambient air is moved by fans through our proprietary sorbent. The sorbent selectively reacts with CO_2 in the atmosphere and is temporarily captured. The sorbent saturates after 1 hour of capture.. At this time, a regeneration

[1] We use "project" throughout this template, but note that term is not intended to denote a single facility. The "project" being proposed to Frontier could include multiple facilities/locations or potentially all the CDR activities of your company.

chamber is closed around the sorbent, and the electro-thermal desorption process begins. Electrical current is passed directly through the monolithic framework of the sorbent, inducing joule heating and providing the heat required to both reverse the CO_2 capture reaction and regenerate the sorbent. The sorbent is heated to a regeneration temperature of 150°C within 5 minutes. The complete regeneration cycle takes about 60 minutes. The following schematic shows the two process steps.

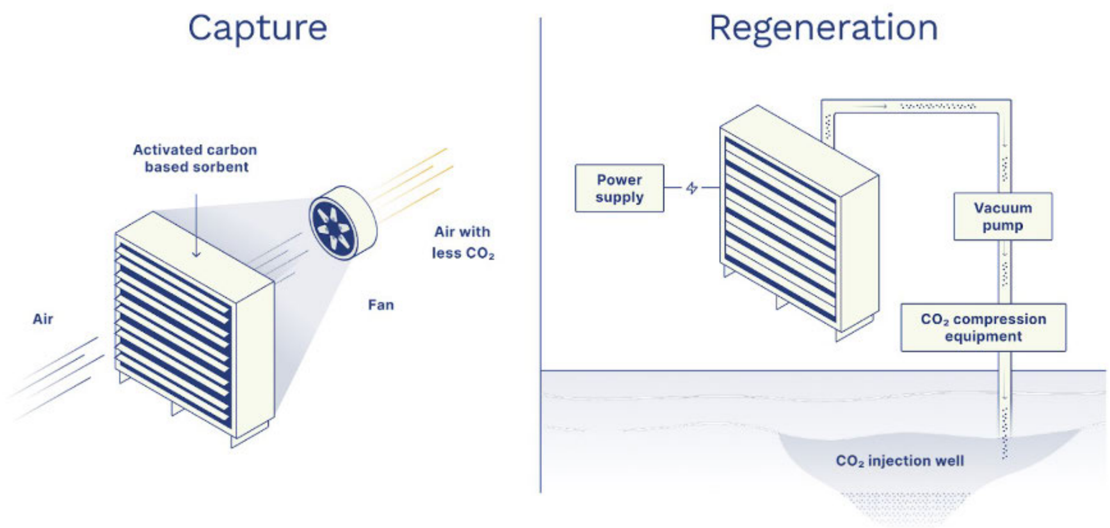


Figure 1: Noya's Direct Air Capture Process Overview

We use a carbonate <> bicarbonate reaction to capture CO_2. Our sorbent is proven to be extremely stable for CO_2 capture and is particularly effective as a chemisorption agent under ambient conditions. The compound exhibits high stability at much higher temperatures than are required for regeneration, making it a resilient and cyclable option for this application. Our sorbent is also a commonly used chemical in many industries, making it cost-effective and broadly available.

Noya's regeneration takes advantage of the electrical conductivity of activated carbon, the base of our sorbent material. Instead of heating up other pieces of equipment or fluids via electric power, we apply an electric potential to the sorbent itself. In turn, this heats up the sorbent directly by joule heating. The result is faster heating and cooling cycles. Due to the added mass and thermal energy losses, the heating/cooling cycle of the sorbent via direct heating can be about 7x longer than with joule heating. This is graphically depicted in- the figure below published in *Carbon.*

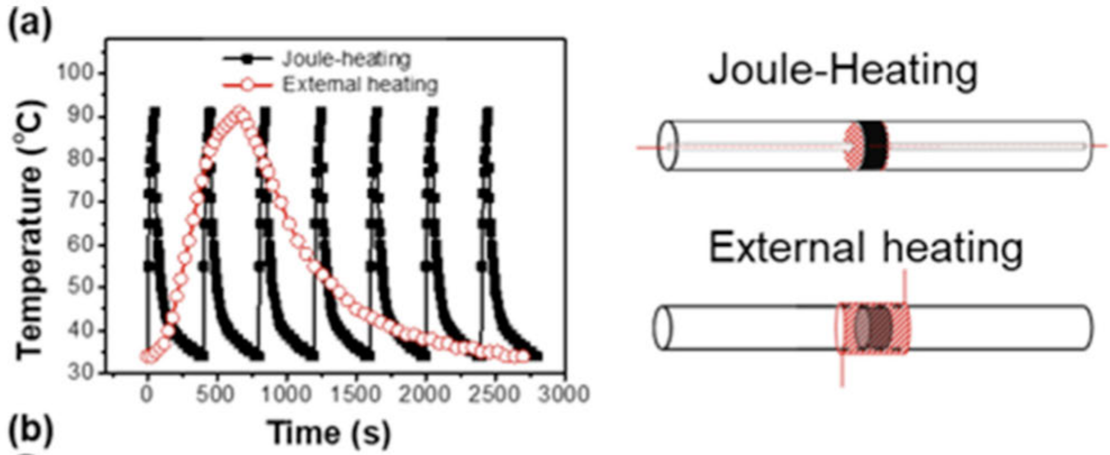


*Image from: Wang, K.; Zheng, Y..; Lin, W.; Yang, X.; Cao, Y.; Wang, H.; Peng, F.; Yu, H. Energy- efficient catalytic removal of formaldehyde enabled by precisely Joule-heated Ag/Co3O4@ mesoporous-carbon monoliths. Carbon. 2020, 167, 709-717.

Figure 2: A comparison of cycle times between Joule heating and external, direct heating

Location:

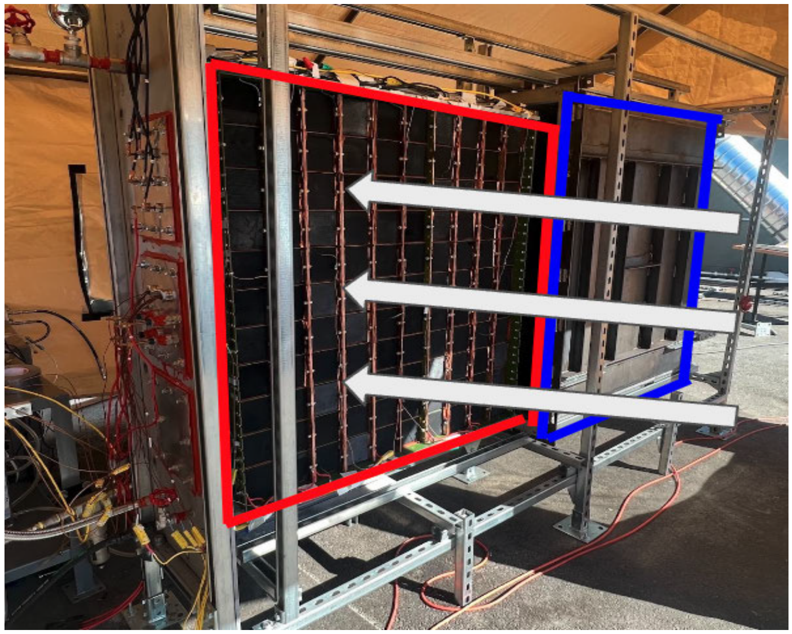
The proposed project location will be co-located with a sequestration site. The site has already been selected, a Heads of Terms document has been signed, and final terms are in the process of being finalized in a binding commercial agreement. The site will be ready to inject by Q3 2023. [More information in the Confidential Addendum]

Scale:

The proposed DAC system in this application will capture 1 ton of CO_2 per day. We have quickly iterated through different designs as we scaled up from bench-top to a 10kg/day pilot.

Below is an image of the 10kg/day pilot. The sorbent contactor is outlined by the red box. The white arrows represent the air passing through it during capture. The blue box outlines the regeneration chamber that moves to cover the contactor after capture is complete.

Figure 3: Noya's 10kg/day pilot system.



This device was constructed with off-the-shelf components, and it verified the scalability of the process from the lab scale, proved our joule heating method, and currently serves as an industrial testing vehicle for our technology.

The proposed DAC system will consist of "stacked" versions of the prototype shown above.

Why Noya's system is best-in-class:

Energy transfer for regeneration:

The single most costly process in DAC systems is regeneration. Other regeneration processes transfer energy to the sorbent by conduction within a heat exchanger, or convection by means of steam, air, or other gases. These have the inherent disadvantage of having to heat at least two other intermediary mediums before transferring the heat to the sorbent, not to mention the heat transfer resistances that are inherent to convective or conductive heating. Noya, on the other hand, uses electrical current based heating, also known as joule heating, to directly heat our sorbent without the need for any intermediary materials or heating steps.

During the use of heat exchangers for regeneration, electrical energy is used to heat a liquid by convection. The hot liquid then gets pumped through a heat exchanger and the heat is transferred inefficiently to the sorbent by conduction. The sorbent then releases the CO_2 to get extracted. This method of heating is much more complicated and costly than the system Noya is designing.

Steam energy transfer is even less straightforward. Electrical coils boil water to produce hot steam that transfers heat to the sorbent which causes the sorbent to release captured CO_2. After the sorbent releases the CO_2, it mixes with the steam. This steam has to be condensed out of the mixture so that the CO_2 is extractable. The heat of evaporation needed for this process accounts for 85% of the energy required to take room temperature water and convert it to 150ºC steam (a relatively high temperature in regeneration processes). Note this heat is lost during condensation. With Noya's technology, the added cost of a boiler and condenser is not needed. This saves capex investment into equipment and operational expenses to power the boiler and condenser.

Kiln or convection ovens offer some simplicity when compared to the other heating methods above. In this case air or other gases may be heated via electric heating and moved through the sorbent. Again in this case there is the need to heat up metals and air before the energy reaches the sorbent. The method Noya is using is much more efficient than a convection oven due to the direct electrical flow through the sorbent.

Noya's method of using joule heating allows our sorbent's conductive base to directly generate the heat from within the capture media to regenerate through the use of electrical power. This allows for a faster and leaner regeneration process with much less capex and operational expenses down the line.

Modularity:

Noya is pursuing ultra-fast scale-up, so we've designed our systems to be shipped easily and efficiently, by taking into account 40 foot shipping container dimensions. One shipping container can pack in 9 modules equating to a capture capacity of 1 ton of CO_2 per day.

Stability and scalability:

Other companies either use electro-thermal swing approaches or apply similar Joule heating methods to those employed by Noya, but fail to use cost-effective, scalable, stable materials with fully developed supply chains. As an example, Metal-Organic Frameworks (MOFs) have been proposed as direct air capture sorbent materials. These materials boast high adsorptive CO_2 uptake capacities, and certain studies indicate some potential for significant recyclability with specific MOFs. However, one particular concern which must be addressed for this class of materials lies in a current lack of scalability. A peer-reviewed article, published in *Applied Energy* in 2019 specifically states that "the novel sorbents" (MOFs in this case) "are not commercially available for bulk purchase" and as such "their cost [was] based on the cost of the ingredients."

The same article also outlines potential sorbent costs in the range of $7-100 per kilogram of sorbent. The proprietary sorbent used in Noya's pilot build (shown above) were priced at $3.24/kg of sorbent, and are available for bulk purchase today. As an additional chemical stability consideration, the vast majority of MOFs are held together by metal-oxo or metal-carboxylate bonds. These have been shown to be susceptible to acid or base-catalyzed hydrolysis under aqueous or humid conditions. This hydrolysis has the potential to destroy the framework material and render it useless as a DAC sorbent. In contrast, Noya's proprietary sorbent is chemically inert and stable under humid or aqueous conditions.

Finally, to the best of our knowledge, no MOF tested for DAC applications exhibits the low resistivity required for resistive-heat-based regeneration unless it was incorporated into a composite (e.g. polymer) material. This requires additional synthetic and fabrication steps after the initial synthesis and processing of the MOF. The proprietary sorbent material used in Noya's process possesses intrinsically low resistivity and can be heated by application of current before or after the addition of sorbent chemicals on a large scale.

b. What is the current technology readiness level (TRL)? Please include performance and stability data that you've already generated (including at what scale) to substantiate the status of your tech.

TRL - 5

High fidelity lab-scale testing			
Performance indicator	**Units**	**Value**	**Notes**
Joule heating cyclic lifetime with no measurable degradation	Cycles	168	Ongoing testing
Joule heating continuous (accelerated) lifetime	Hours	48	To accelerate our understanding of the lifetime of our sorbent, we are testing it continuously at the highest temperatures and power input conditions This is ongoing testing
Cyclic capacity of desorbed CO_2 per gram of sorbent	mmol/g	0 754	
Energy usage per cycle per gram of sorbent	J/g	192	

Pilot scale testing			
Performance indicator	**Units**	**Value**	**Notes**
Energy usage per cycle per gram of sorbent	J/g	54	Note this energy usage is much smaller than in the lab-scale case due to the decrease in thermal energy losses at the higher scale

c. What are the key performance parameters that differentiate your technology (e.g. energy intensity, reaction kinetics, cycle time, volume per X, quality of Y output)? What is your current measured value and what value are you assuming in your nth-of-a-kind (NOAK) TEA?

Key performance parameter	Current observed value (units)	Value assumed in NOAK TEA (units)	Why is it feasible to reach the NOAK value?
Sorbent Capture Capacity	0.754 mmol CO_2/g Sorbent	1.1 mmol CO_2/g Sorbent	This value has been exceeded in literature before with our planned sorbent base material. The current small-scale tests have been performed with an off the shelf version. We are working with contract manufacturers to tune the material to our specific needs. Source 1 Source 2
Regeneration Time	60 minutes	60 minutes	Same as currently observed value
Regeneration Energy Requirement	5.8 GJ/tonne CO_2	5.77 GJ/tonne CO_2	Decrease from the current observed value will mostly come from the scaleup of the small bench scale device where we are observing this

			value. Unaccounted heat losses are present in this device.

d. Who are the key people at your company who will be working on this? What experience do they have with relevant technology and project development? What skills do you not yet have on the team today that you are most urgently looking to recruit?

Noya currently has people in both operational roles and engineering roles that will be working to deploy this project.

Leadership

<u>CEO:</u> Josh Santos holds a B.S. in Chemical Engineering from MIT. He has proven experience scaling technology as part of the Model 3 Product team and in leading R&D teams as the first Program Manager of the electric vehicle team at Harley-Davidson.

<u>CTO:</u> Daniel Cavero holds a B.S. and M.S. in Mechanical Engineering from San Diego State University. Prior to co-founding Noya, he designed AI/Robotics products at Nod Labs and designed hyperloop fuselage components at rLoop.

Operations

<u>Technical Program Manager:</u> Amy Wilson holds a degree in chemical engineering and has years of experience in industrial manufacturing facilities, process engineering, and project management.

<u>Chief of Staff:</u> Spencer Anderson brings years of operational experience at hyper growth startups.

<u>Operations staff:</u> Banu Alkaya Aksoy has many years of experience in COO and CTO positions with relevant experience in the energy space.

Engineering

<u>Chemical Engineer:</u> Brandon Garcyzinski has years of project development and startup experience in the field along with relevant work in the catalysis field.

<u>Mechanical Engineers:</u> Nathaniel Gertzman, Aditi Dhadwaiwale, and Lizzie Tu are part of the mechanical team who combined have experience in modeling, CAD design, project development, and hands-on research and development work.

<u>Technician:</u> Gwen Gu has a degree in mechanical engineering with experience in building, troubleshooting, and maintenance of pilot systems.

<u>Controls Engineer:</u> Maarten Thomas-Bosum has a degree in physics, and has worked in industrial plant settings building PLC controls programs and electrical systems.

Research

<u>Principal Scientist:</u> Robinson Flaig holds a Ph.D. in chemistry and has worked extensively in carbon capture material development research.

We are actively recruiting an electrical engineer to help us with large-scale power system design for

scaling up. Noya is also looking to hire operators for the project local to the location of the build.

e. Are there other organizations you're partnering with on this project (or need to partner with in order to be successful)? If so, list who they are, what their role in the project is, and their level of commitment (e.g., confirmed project partner, discussing potential collaboration, yet to be approached, etc.).

Partner	Role in the Project	Level of Commitment
In confidential addendum	Sequestration partner	Signed Head of Terms document with commercial agreement in process

f. What is the total timeline of your proposal from start of development to end of CDR delivery? If you're building a facility that will be decommissioned, when will that happen?

The development will start in late 2022 with deployment in mid-2023. The CDR delivery in this proposal will start in 2024 and will complete in 2026.

g. When will CDR occur (start and end dates)? If CDR does not occur uniformly over that time period, describe the distribution of CDR over time. Please include the academic publications, field trial data, or other materials you use to substantiate this distribution.

CDR will occur uniformly from July 1, 2024 to December 31, 2026.

h. Please estimate your gross CDR capacity over the coming years (your total capacity, not just for this proposal).

Year	Estimated gross CDR capacity (tonnes)
2023	350
2024	4,550
2025	39,550
2026	39,550
2027	389,550
2028	389,550

2029	1,389,550
2030	2,389,550

i. List and describe at least three key milestones for this project (including prior to when CDR starts), that are needed to achieve the amount of CDR over the proposed timeline.

	Milestone description	**Target completion date** (eg Q4 2024)
1	Completion of design and basic testing of electronic components	Q1 2023
2	Completion of construction of direct air capture plant	Q2 2023
3	Commissioning of the plant and start of CDR	Q3 2023

j. What is your IP strategy? Please link to relevant patents, pending or granted, that are available publicly (if applicable).

We have filed provisional patents around the use of our sorbent with our electrothermal regeneration process. They have not been publicly published yet.

k. How are you going to finance this project?

The current plan is to fund this project with balance sheet capital raised through equity fundraising. If we are accepted into Frontier's portfolio, we will use the pre-purchase to support this project's financing needs.

l. Do you have other CDR buyers for this project? If so, please describe the anticipated purchase volume and level of commitment (e.g., contract signed, in active discussions, to be approached, etc.).

We have 3 CDR buyers, including Shopify, under contract for this project for approximately 260 tons, and we will fulfill these tons under contract first before delivering the tons offered to Frontier in this application. The pre-purchase we are applying for will help accelerate our progress towards installing this project.

m. What other revenue streams are you expecting from this project (if applicable)? Include the source of revenue and anticipated amount. Examples could include tax credits and co-products.

Not applicable.

n. Identify risks for this project and how you will mitigate them. Include technical, project execution, ecosystem, financial, and any other risks.

Risk	Mitigation Strategy
Delays in the shipping timelines for key parts	Many of the key parts have already been identified and the project timeline will allow us to lead time to order ahead.
Shorter-than-expected sorbent lifetime	We expect to be able to make improvements in sorbent formulation that will lower the frequency of sorbent replenishment needed.
The system can be exposed to unexpected poisons, resulting in less CO_2 captured	We are completing a detailed air analysis from our site location that will provide us more data to educate ourselves about poisons and make additional adjustments to our system where possible.
Weather conditions can impact construction timelines	We are building major components of the system in California and shipping to our partner facility abroad to minimize the impact of weather conditions causing delays.
Unforeseen project expenses increase the overall cost to install the project	We are currently speaking with different contracting agencies to ensure we understand timelines and costs to prevent significant project overruns.
Material structural failures can delay the project execution	Learnings from our first pilot will be applied when choosing the suppliers for this project.

2. Durability

a. Describe how your approach results in permanent CDR (> 1,000 years). Include citations to scientific/technical literature supporting your argument. What are the upper and lower bounds on your durability estimate?

In confidential addendum.

b. 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?

In confidential addendum.

3. Gross Removal & Life Cycle Analysis (LCA)

a. How much GROSS CDR will occur over this project's timeline? All tonnage should be described in **metric tonnes** of CO_2 here and throughout the application. Tell us how you calculated this value (i.e., show your work). If you have uncertainties in the amount of gross CDR, tell us where they come from.

Gross tonnes of CDR over project lifetime	8,750 Tonnes CO_2
Describe how you calculated that value	Project design for 350 tons per year for 25 years of operation.

b. How many tonnes of CO_2 have you captured and stored to date? If relevant to your technology (e.g., DAC), please list captured and stored tons separately.

Captured: 213 grams CO_2

Stored: None

c. If applicable, list any avoided emissions that result from your project. For carbon mineralization in concrete production, for example, removal would be the CO_2 utilized in concrete production and avoided emissions would be the emissions reductions associated with traditional concrete production. Do not include this number in your gross or net CDR calculations; it's just to help us understand potential co-benefits of your approach.

Not applicable

d. How many GROSS EMISSIONS will occur over the project lifetime? Divide that value by the gross CDR to get the emissions / removal ratio. Subtract it from the gross CDR to get the net CDR for this project.

Gross project emissions over the project timeline *(should correspond to the boundary conditions described below this table)*	608 metric tons of CO_2 emitted over 25 years of operation.
Emissions / removal ratio *(gross project emissions / gross CDR–must be less than one for net-negative CDR systems)*	0.069
Net CDR over the project timeline *(gross CDR - gross project emissions)*	8,142 metric tons CO_2 removed over 25 years of operation

e. Provide a process flow diagram (PFD) for your CDR solution, visualizing the project emissions numbers above. This diagram provides the basis for your life cycle analysis (LCA). Some notes:

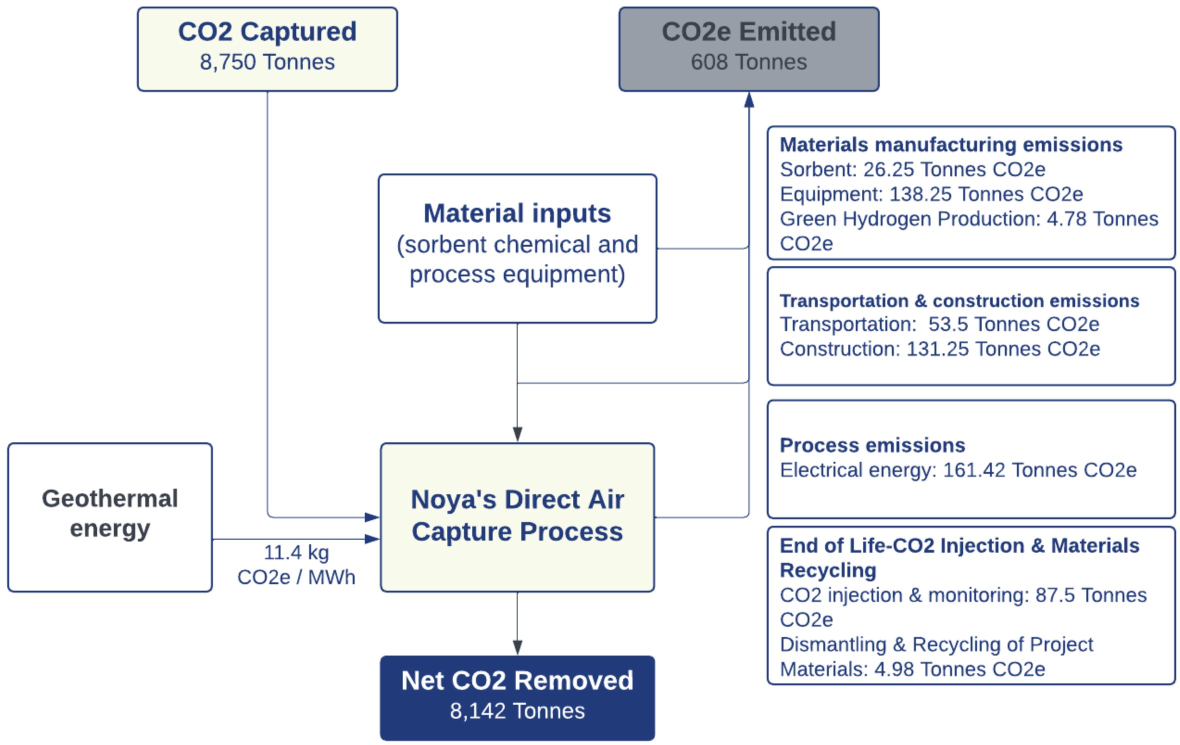


Figure 4 - Noya Process Life Cycle Analysis Summary

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

> We include sorbent, transportation, equipment, and construction emissions for the building of the project due to emissions involved in the production and erection of this project. Process emissions include electrical energy and CO_2 injection because these are the only emissions produced during the operation of the DAC system. We exclude CO_2 transportation costs and waste emissions during production because our DAC system is co-located with the permanent sequestration site. End of life emissions estimates assume that the recycling of the steel structure and the transportation of the equipment to a recycling facility are the main contributors.

g. Please justify all numbers used to assign emissions to each process step depicted in your diagram above. Are they solely modeled or have you measured them directly? Have they been independently measured? Your answers can include references to peer-reviewed publications, e.g. Climeworks' LCA paper.

Process Step	CO_2(eq) emissions over the project lifetime (metric tonnes)	Describe how you calculated that number. Include references where appropriate.
Geothermal Energy	161.42	566.4 MWh/yr energy (referenced in TEA) multiplied by 25 years operation, and 11.4kg CO_2e per MWh given by geothermal partner
Transportation and Construction Emissions	184.75	Transportation: Calculated by estimating the distance of raw materials to the manufacturing facility by sea and truck, and then the shipment of the materials to the project site. (https://www.lcacommons.gov/lca-collaboration/search/page=1&group=National_Renewable_Energy_Laboratory) Construction: Emissions were estimated for Noya's specific project based on an LCA paper published by Climeworks. (https://www.nature.com/articles/s41560-020-00771-9.epdf?sharing_token=MauoHxobZ3BVIaQnHIQutdRgN0jAjWeI9jnR3ZoTv0OEKeY9z0ZKZCHOJUdL6cEV9A-FuZA7TH7X4nBvetkQs0m2vrwRdM0JbjgOpOQwZ0nUnTZODiRY4BydPP_JmQbc2WmyNg5f1Obm7O3rbr_AjBPHYv5pB_BB5IAdDy_fcKU%3D)
Material Manufacturing Emissions	164.5	The material manufacturing emissions were estimated using the same database for raw materials as the estimated transportation costs.
End of Life CO2 Injection	87.5	Estimated based on data from sequestration partner per ton of CO_2 injected.
End of Life Recycling	4.98	Steel recycling: 9.4 metric tons steel-> 529kg CO_2e/ton of steel-> 4.97 tons of CO_2e (https://www.sciencedirect.com/science/article/pii/S0921344915301245 table 6 gross steel) Transportation to recycling plant: Project location to nearby recycling plant https://www.carboncare.org/en/co2-emissions-calculator.html -> 0.01489 tons CO_2e
Hydrogen Production	4.783	Green hydrogen production is used during the process at a rate of 1.25kg H_2 / 1.147 tons CO_2 captured by the system. Using geothermal energy from partner and the rate of 44kWh/kg H_2 (https://www.energy.gov/eere/fuelcells/doe-technical-targets-hydrogen-production-electrolysis)

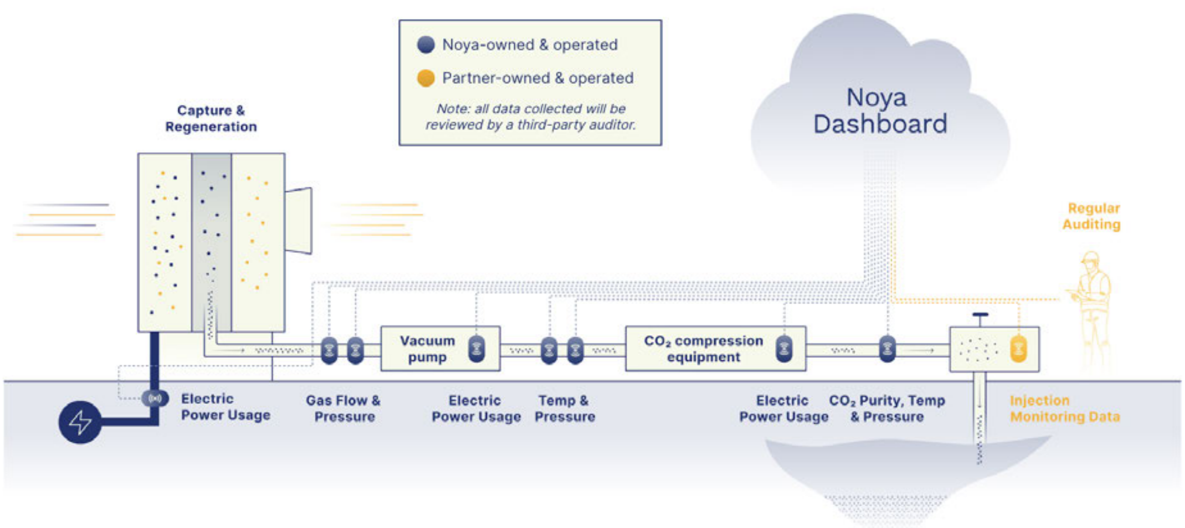
4. Measurement, Reporting, and Verification (MRV)

Section 3 above captures a project's lifecycle emissions, which is one of a number of MRV considerations. In this section, we are looking for additional details on your MRV approach, with a particular focus on the ongoing quantification of carbon removal outcomes and associated uncertainties.

a. Describe your ongoing approach to quantifying the CDR of your project, including methodology, what data is measured vs modeled, monitoring frequency, and key assumptions. If you plan to use an existing protocol, please link to it. Please see [Charm's bio-oil sequestration protocol]() for reference, though note we do not expect proposals to have a protocol at this depth at the prepurchase stage.

There are two pieces to our MRV approach - our approach to MRV on equipment and processes we control, and the MRV approach and processes our storage partner has put into place. This full approach is outlined in the image below. This image does not describe a complete design, as specifics are subject to change, but the broad strokes of our approach are all present.

Figure 5 - Noya's MRV Approach



On equipment we control, we will use a suite of sensors across the entire process that will track various product data streams. The data streams use two sensors to feed two calculations: CO_2 captured and CO_2 emitted. The CO_2 captured data stream relies on measurements taken from sensors that track gas flow rates, gas pressure, gas temperature, and CO_2 purity to calculate the amount of CO_2 our product is producing at every step along the way. The CO_2 emitted data stream uses measurements taken from current sensors and other electric power usage sensors to track total power consumption across the entire process, which we multiply by the emissions intensity of our power source to arrive at the total amount of CO_2 we emit with our process. With these separate data streams, we are able to track the real-time CO_2 capture and emissions performance with our system.

This data will integrate with data from our storage partner about everything that happens after we deliver the CO_2 to them for injection. Our sequestration partner uses two standards for post-injection MRV: ISO 14064-2 and the Verra Verified Carbon Standard (approval in-progress). They employ CO_2 gas detectors to monitor the environment at strategic locations around the well site, including the injection point and the surroundings, to ensure any surface leaks are measured. Additionally, leak detection systems monitor the injection site as well. The injection pipeline is monitored by pressure sensors in the pipe, and conductivity sensors are used to monitor unforeseen phase changes down-well. All of this data from our partner — leakage, energy for injection, and amount of CO_2 injected — is combined with our data to provide a reading of net CO_2 stored. This combination of data will be displayed in a dashboard for Frontier and our other buyers to review to understand where our data is coming from and validate the inputs and outputs we are measuring in real-time.

Besides all of the data we measure, we will partner with third-party auditors to audit our process, ensure our sensors and the data they produce line up with the reported numbers on our dashboard, and verify everything we're reporting is accurate. This auditing process will take place between 2-4 times per year.

b. How will you quantify the durability of the carbon sequestered by your project discussed in 2(b)? 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.)*

CO_2 leakage from the reservoir is very unlikely due to the mineralization process our storage partner uses. Outside of the main injection point, the CO_2 is monitored in the existing site by sampling the water from the geologic formation and by analyzing its geochemistry. Additionally, CO_2 surface flux measurements monitor a larger area above the storage reservoir as a redundant tool that ensures the detection of any potential leakage.

c. This tool diagrams components that we anticipate should be measured or modeled to quantify CDR and durability outcomes, along with high-level characterizations of the uncertainty type and magnitude for each element. We are asking the net CDR volume to be discounted in order to account for uncertainty and reflect the actual net CDR as accurately as possible. Please complete the table below. Some notes:

- In the first column, list the quantification components from the Quantification Tool relevant to your project (e.g., risk of secondary mineral formation for enhanced weathering, uncertainty in the mass of kelp grown, variability in air-sea gas exchange efficiency for ocean alkalinity enhancement, etc.).
- In the second column, please discuss the magnitude of this uncertainty related to your project and what percentage of the net CDR should be discounted to appropriately reflect these uncertainties. Your estimates should be based on field measurements, modeling, or scientific literature. The magnitude for some of these factors relies on your operational choices (i.e., methodology, deployment site), while others stem from broader field questions, and in some cases, may not be well constrained. <u>We are not looking for precise figures at this stage, but rather to understand how your project is thinking about these questions.</u>
- See this post for details on Frontier's MRV approach and a sample uncertainty discount calculation and this Supplier Measurement & Verification Q&A document for additional guidance.

Quantification component Include each component from the Quantification Tool relevant to your project	**Discuss the uncertainty impact related to your project** Estimate the impact of this component as a percentage of net CDR. Include assumptions and scientific references if possible.

Storage	<1% based on data from our sequestration partner outlined in confidential addendum geologic injection question 6.
Leakage	<1% based on data from our sequestration partner. More information outlined in confidential addendum question 4c from our sequestration partner.
Materials	<2% based on calculations of raw materials and construction costs with known data sets
Energy	<1% Geothermal energy emissions measured by partner at sequestration site
Secondary Impacts of Energy Demand	<1% Existing geothermal energy available for this project that would not take away energy from other users
Storage Monitoring and Maintenance	1% Sequestration partner is actively injecting CO_2 underground for permanent sequestration and actively monitors the wells to assure permanent sequestration of that CO_2 underground. More information on this outlined in confidential addendum geologic injection question 6 from our sequestration partner.

d. Based on your responses to 4(c), what percentage of the net CDR do you think should be discounted for each of these factors above and in aggregate to appropriately reflect these uncertainties?

5%

e. Will this project help advance quantification approaches or reduce uncertainty for this CDR pathway? If yes, describe what new tools, models or approaches you are developing, what new data will be generated, etc.?

Yes, it will. The main new tool we are developing will be our dashboard to report on our carbon removals that integrates a suite of sensor technology into one beautiful, easy-to-understand dashboard. This dashboard will track the new data we generate about how an activated carbon-based monolith performs in a direct air capture application.

f. Describe your intended plan and partners for verifying delivery and registering credits, if known. If a protocol doesn't yet exist for your technology, who will develop it? Will there be a third party auditor to verify delivery against that protocol or the protocol discussed in 4(a)?

Our sequestration partner's methodology has been validated in accordance with ISO 14064-2 and is the process of approval for a Verra protocol for delivering credits with their storage technology. We will develop a detailed protocol for everything within our boundary of control — everything from initial CO_2 capture to CO_2 delivery for storage — and use third-party auditors to verify everything within that boundary.

5. Cost

We are open to purchasing high-cost CDR today with the expectation the cost per tonne will rapidly decline over time. The questions below are meant to capture some of the key numbers and assumptions that you are entering into the separate techno-economic analysis (TEA) spreadsheet (see step 4 in Applicant Instructions). 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 work with you to understand your milestones and their verification in more depth.

a. What is the levelized price per net metric tonne of CO_2 removed for the project you're proposing Frontier purchase from? This does not need to exactly match the cost calculated for "This Project" in the TEA spreadsheet (e.g., it's expected to include a margin), but we will be using the data in that spreadsheet to consider your offer. Please specify whether the price per tonne below includes the uncertainty discount in the net removal volume proposed in response to question 4(d).

$1,500/ton. This does include the discount due to the uncertainty we mentioned above.

b. Please break out the components of this levelized price per metric tonne.

Component	Levelized price of net CDR for this project ($/tonne)
Capex	$950
Opex (excluding measurement)	$350
Quantification of net removal (field measurements, modeling, etc.)[2]	$200
Third party verification and registry fees (if applicable)	$0
Total	$1,500

c. Describe the parameters that have the greatest sensitivity to cost (e.g., manufacturing efficiencies, material cost, material lifetime, etc.). For each parameter you identify, tell us what the current value is, and what value you are assuming for your NOAK commercial-scale TEA. If this includes parameters you already identified in 1(c), please repeat them here (if applicable). Broadly, what would need to be true for your approach to achieve a cost of $100/tonne?

Parameter with high impact on cost	Current value (units)	Value assumed in NOAK TEA (units)	Why is it feasible to reach the NOAK value?
Sorbent Material Cost	$1,984.80/ton of raw materials	$164.84/ton of raw materials	These are the costs we have estimated for our future in-house material production including equipment CapEx

[2] This and the following line item is not included in the TEA spreadsheet because we want to consider MRV and registry costs separately from traditional capex and opex.

			and OpEx, raw materials, and labor.
Sorbent Lifetime	1 year	2 years	We have found scientific literature that suggests that activated carbon can last for more than 8,000 cycles when subjected to electric current (Li, B.; Dai, F.; Xiao, Q.; Yang L.; Shen J.; Zhang, C.; Cai, M. Nitrogen-doped activated carbon for a high energy hybrid supercapacitor. Energy Environ. Sci. 2016, 9, 102-106). For our process, 8,000 cycles are ~2 years of operation.

d. What aspects of your cost analysis are you least confident in?

> We are currently least confident in the costs of the raw materials, extrusion, and impregnation of our sorbent along with sorbent lifetime.

e. How do the CDR costs calculated in the TEA spreadsheet compare with your own models? If there are large differences, please describe why that might be (e.g., you're assuming different learning rates, different multipliers to get from Bare Erected Cost to Total Overnight Cost, favorable contract terms, etc.).

> The TEA calculated by this application is higher than Noya's internal TEA. The main differences are the contingency used in Frontier's TEA (higher than the numbers we use) and the EPC costs included in Frontier's TEA (higher than the numbers we use).

f. What is one thing that doesn't exist today that would make it easier for you to commercialize your technology? (e.g., improved sensing technologies, increased access to X, etc.)

> Increased access to permanent sequestration injection wells would open up many additional locations for our technology to be deployed.

6. Public Engagement

In alignment with Frontier's Safety & Legality criteria, Frontier requires projects to consider and address potential social, political, and ecosystem risks associated with their deployments. Projects with effective public engagement tend to:

- Identify key stakeholders in the area they'll be deploying
- Have mechanisms in place to engage and gather opinions from those stakeholders, take those opinions seriously, and develop active partnerships, iterating the project as necessary

The following questions help us gain an understanding of your public engagement strategy and how your project is working to follow best practices for responsible CDR project 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 relevant 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.

In confidential addendum.

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 and Arnestein's Ladder of Citizen Participation for a framework on community input.*

Not applicable.

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.

d. Going forward, do you have changes to your processes for (a) and (b) planned that you have not yet implemented? How do you envision your public engagement strategy at the megaton or gigaton scale?

Fundamentally, our community engagement strategy will involve identifying and partnering with local community groups, policy makers, worker's unions, local economic groups, and any other key location-specific groups. The intent of this partnership will be to identify the types of local benefits we can offer to the communities (beyond job creation) with our work and to ensure the needs/concerns of the community about our process are met and addressed.

7. Environmental Justice[3]

As a part of Frontier's Safety & Legality criteria, Frontier seeks projects that proactively integrate environmental and social justice considerations into their deployment strategy and decision-making on an ongoing basis.

a. What are the potential environmental justice considerations, if any, that you have identified associated with your project? Who are the key stakeholders? Consider supply chain impacts, worker compensation and safety, plant siting, distribution of impacts, restorative justice/activities, job creation in marginalized communities, etc.

[3] For helpful content regarding environmental justice and CDR, please see these resources: C180 and XPRIZE's Environmental Justice Reading Materials, AirMiners Environmental and Social Justice Resource Repository, and the Foundation for Climate Restoration's Resource Database

The main environmental justice concern we are working on with our first project is around ensuring that none of the utilities our process will consume (mainly electricity and water) are putting any of the needs of the nearby community at risk. We are working with our sequestration partner and their utility provider to ensure this is possible.

b. How do you intend to address any identified environmental justice concerns and / or take advantage of opportunities for positive impact?

We are being incredibly proactive about sharing worst-case project requirements with our partner to ensure all of the needs we have do not infringe on anything the community requires. Between now and project deployment, we will have weekly meetings with our partner to keep them up-to-date with our designs and needs, and we will solicit feedback on anything we may need to address with our process and project design work.

8. Legal and Regulatory Compliance

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

We have not received any legal opinions on the deployment of our process yet, but we are working towards achieving this during our early process design to ensure we are compliant in the locale we are building in.

b. What permits or other forms of formal permission do you require, if any, to engage in the research or deployment of your project? What else might be required in the future as you scale? 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 will work through all necessary permits with our local sequestration provider as we get deeper into the design process. We will require an environmental impact assessment and screening. We will also need a building permit and development permit issued by the local government. And, we'll need to ensure we abide by regulations concerning the shape and appearance of our structures so they blend into the natural landscape we will be deploying into.

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?

Yes, and we will outline more on the specific country in our Confidential Addendum. Our sequestration and power supply partners have worked with the government to create the guidelines and laws we will follow during project execution.

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.

We have clear legal and regulatory guidelines from our partners and the work they've done in supporting DAC project deployment at their facility.

e. Do you intend to receive any tax credits during the proposed delivery window for Frontier's purchase? If so, please explain how you will avoid double counting.

Not applicable.

9. Offer to Frontier

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

Proposed CDR over the project lifetime (tonnes) *(should be net volume after taking into account the uncertainty discount proposed in 4(c))*	700
Delivery window *(at what point should Frontier consider your contract complete? Should match 1(f))*	July 1, 2024 - December 31, 2026
Levelized Price (\$/metric tonne CO_2) *(This is the price per tonne of your offer to us for the tonnage described above)*	\$1,500

Frontier

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

1. What is the physical land footprint of this 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. Also, what is the estimated footprint if this approach was removing 100 million tons of CO_2 per year?

Land footprint of this project (km^2)	0.00016
Land footprint of this tech if scaled to 100 million tons of CO_2 removed per year (km^2)	40

Capture Materials and Processes

1. What material(s) is/are you using to remove CO_2?

> Solid, structured activated carbon sorbent with proprietary active chemical addition to facilitate carbon capture.

2. How do you source your material(s)? Discuss how this sourcing strategy might change as your solution scales. Note any externalities associated with the sourcing or manufacture of it (e.g., hazardous wastes, mining, etc.). You should have already included the associated carbon intensities in your LCA in Section 3.

> Solid sorbent materials are currently sourced from manufacturers that already make structured activated carbon monoliths. Proprietary chemicals are sourced from domestic suppliers with an existing supply of the chemicals. These proprietary chemicals require several manufacturing steps to arrive at the product we use, which include the process of extracting starting materials from mined minerals and hydrolysis steps. The most toxic by-product produced in the manufacturing of our proprietary chemical is chlorine gas, which is handled in compliant methods by the manufacturer. The sorbent and active chemical are combined with in-house processing. Wastes generated with in-house processing are minimal due to recycling and are able to be treated as non-hazardous waste. Sorbent manufacturing will be brought in-house in the future to give us more control over the manufacturing process, product, and emissions. Vertical integration will enable exploration of renewable sources of activated carbon. As the technology and manufacturing processes scale in the future, priority will be placed on using renewably sourced materials to continue to lower the carbon intensity of our process and supply chain.

Oxygen conversion catalyst is sourced from domestic or international catalyst suppliers. The use of this oxygen conversion catalyst will lead to a small amount of hazardous waste generation when the catalyst reaches end of life. However, it will be recycled to the fullest extent possible to retrieve precious metals.

3. How much energy is required for your process to remove 1 net tonne of CO_2 right now (in GJ/tonne)? Break that down into thermal and electrical energy, if applicable. What energy intensity are you assuming for your NOAK TEA?

The current total energy requirement for the process is 5.8 GJ/tonne of CO_2. This energy will be supplied solely with electricity.

4. What is your proposed source of energy for this project? What is its assumed carbon intensity? How will this change over the duration of your project? (You should have already included the associated carbon intensities in your LCA in Section 3).

Energy will be sourced from geothermal energy provided by our sequestration partner. The assumed carbon intensity is 11.4kg CO_2/MWh from this power source. Key criteria for future sites will be either access to existing renewable power (not necessarily geothermal) or the ability to install the power we will need.

5. Besides energy, what other resources do you require (if any, such as water)? 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 3).

Hydrogen is required to remove oxygen from the product stream. Green hydrogen will be acquired from a local supplier we have already identified. Water will be required to cool several process streams. This water will be obtained from our sequestration partner. The water losses mainly will be caused by evaporation, but any small waste water due to blowdowns or process upsets would be passed back to our partner for treatment.

6. Do you have experimental data describing how your system's CDR performance changes over time? If so, please include that data here and specify whether it's based on the number of cycles or calendar life.

Initial data suggests that the sorbent capture capacity currently degrades at an average rate of 0.1%/cycle at low (<100) cycles. Longer term cyclic data gathering will determine if this is a continuous decline or asymptotic. Data suggests the degradation declines in an asymptotic fashion, meaning degradation between cycles declines with increasing cycles. Sorbent replacement schedules will be determined based on necessary capture performance balanced with carbon dioxide removal cost per tonne. Further research will continue to increase cyclic capture stability of sorbent.

7. What happens to your capture medium at end-of-life? Please note if it is hazardous or requires some special disposal, and how you ensure end-of-life safety.

Capture medium currently is disposed of at end-of-life. This is a non-hazardous material and does not require special disposal. Oxygen conversion catalyst will require special recycle/disposal. The disposal will be handled by outside hazardous catalyst disposal contractors to ensure they are disposed of safely and disposal meets all local regulations. Recycling of capture medium will be a future research pathway to reduce carbon intensity of the process.

8. Several direct air technologies are currently being deployed around the world. Why does your DAC technology have a better chance to scale and reach low cost than the state of the art?

Our technology will rapidly scale and achieve low costs because of three factors: our electro-thermal regeneration process, usage of existing supply chains, and low necessary input energy. Our technology uses a simple electro-thermal swing regeneration process to capture and remove carbon dioxide from the atmosphere. This technology lowers both capital requirements for large scale processes and risks from unknowns of novel processes. It also reduces process cycle time because this technology heats up our sorbent from ambient temperatures to our regeneration temperature of 150°C in ~4 minutes. In addition to our regeneration process, our activated carbon sorbent and proprietary chemical additive are already manufactured on a global scale for separate uses. This allows us to leverage existing supply chains to quickly scale our technology. Finally, our process uses sorbent that requires low temperatures (150°C or less) to regenerate effectively. This means the process requires low amounts of energy inputs to capture and regenerate carbon dioxide, and the only energy input the process needs is electricity. Combining that low theoretical energy input with a highly efficient heating strategy — along with future heat integration opportunities — gives our process an exceptional opportunity to achieve scale and low costs.

Application Supplement: Geologic Injection

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

Feedstock and Use Case

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

Our sequestration partner will be injecting the captured CO_2 dissolved in water.

2. Do you facilitate enhanced oil recovery (EOR), either in this project or elsewhere in your operations? If so, please briefly describe.

No

Throughput and Monitoring

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

In confidential addendum.

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

Not Applicable

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

11 grams/second CO_2

Environmental Hazards

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

In confidential addendum.

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

In confidential addendum.