[RedoxNRG] Carbon Removal Purchase Application

General Application

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

Company or organization name

RedoxNRG OÜ

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

Kesk 2, Narva-Jõesuu, 29021, Estonia

Name of person filling out this application

Nadezda Kongi, Vladislav Ivanistsev

Email address of person filling out this application

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Brief company or organization description

Electrochemical carbon dioxide removal and conversion to value-added products

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.

The RedoxNRG team has developed an advanced carbon capture system that pulls carbon

dioxide directly from the air and provides it as a feedstock for high-value products. Our experiments showed that we capture CO_2 at a very competitive energy expenditure compared with other direct air carbon (DAC) capture technologies. The RedoxNRG electrocapture agent materials (TALx) with optimized micro- and macroporosity, as well as with balanced redox activity and conductivity, can be exceptionally energy-efficient for reversible DAC. According to our theoretical modeling results, our materials can perform at a Faradaic efficiency of up to 100%, a capacity of 10–15 mmol g^{-1}, an energy cost of 20–40 kJ mol^{-1}, and an operating cost of 12–24 US$ per ton of CO_2 captured. Thus, applying RedoxNRG electrocapture to DAC will be a confident step towards energy-efficient CO_2 capture needed to reach a safe level of CO_2 in the atmosphere. Driven by renewable power, the electrochemically-mediated RedoxNRG system is controlled precisely to reduce energy losses. Since our technology is based on inexpensive materials developed in our laboratory [N. Kongi et al. patent WO2020035607], the resulting device is modular and easily scalable to meet capacity criteria of 0.5 Gt CO_2/yr by 2040. In this proposal RedoxNRG offers to permanently sequester electrocaptured CO_2 into carbon negative calcium carbonate ($CaCO_3$), produced from oil shale waste containing mainly CaO.

Since the 1960s, Estonia has been the largest oil shale producer and consumer in the World. Inevitably, Estonia has one of the highest CO_2 emissions per capita in the World. Of the 13–15 million tonnes (Mt) of oil shale mined annually in Estonia, about 93% is consumed by power plants to generate electricity, with a production of approximately ~5–6 million tons of waste ash annually. Only 2% of the ash is recycled for construction materials, agricultural and road construction purposes. It is estimated that Estonian power plants have produced ~800 Mt of ash to date. Recent developments by Tallinn University of Technology involving oil shale ash–water suspension carbonation demonstrated that oil shale ashes are able to bind up to 290 kg CO_2 per ton of ash [Uibu et al.]. A simplified approach for CO_2 binding by alkaline oil shale ash (or its leaching wastewaters) in the form of a precipitated calcium carbonate (PCC)-type material can be found HERE. Established protocol allows successful conversion of oil shale ash via a carbonation route into high purity ~99% calcium carbonate ($CaCO_3$) at room temperature and atmospheric pressure using water for the dissolution of Ca-containing compounds (info about recent developments in Estonia).

The aim of the RedoxNRG is to contribute to the circular economy by providing electrocaptured CO_2 for producing widely used raw materials with negative CO_2 emission.

CO_2 electrocaptured by the RedoxNRG DAC system can be directly diverted into a reactor, where it is converted into $CaCO_3$ (Fig. 1). Carbon negative precipitated $CaCO_3$, can be converted into value-added materials that can be utilized in various applications such as road base or construction materials, plastic, sealants and adhesives, paints and coatings, food and pharmaceuticals, paper, cement, construction materials, etc. (Chang et al. Front Energy Res. 2017) and may thereby partially compensate for the overall cost of electrochemical DAC.

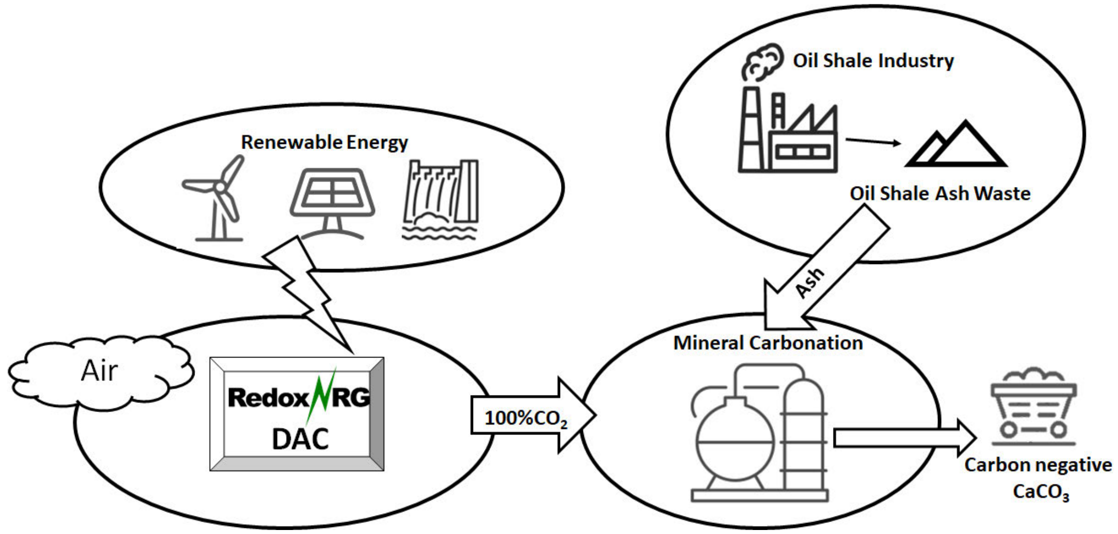

Figure 1. RedoxNRG contributes to the circular economy producing carbon negative material.

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.)*

RedoxNRG OÜ offers the companies a technical solution capable of reducing their CO_2 footprint. Estonian companies who operate in the oil shale industry (The enterprises of the shale industry are Eesti Energia AS, Viru Keemia Grupp AS, Kiviõli Keemiatööstuse OÜ (Alexela Group AS) and Kunda Nordic Tsement AS) are very interested in collaborative projects to explore and find new ways to use oil shale ash. Using electrocaptured CO_2 we will turn their hazardous oil shale ash waste into valuable carbon negative products. To date there is no established market player to support DAC CO_2 for the oil shale industry. The RedoxNRG solution will be beneficial in many ways for all stakeholders, securing its position as a reliable electrocaptured CO_2 supplier.

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

The project is high risk as we target the reversible and energy-efficient direct air CO_2 capture, which is an ultimate goal of many research and industrial fields. We will be opening new opportunities for CO_2 capture, storage, and utilization.

Major risks are:

-CO_2 capture process flow optimizations might not be implemented in the time allocated for the project. Even though the identified optimizations might not be implemented in the

allocated time, they will be noted, and they will be useful for further research or practical applications. -Another risk is that the DAC system will be susceptible to the parasitic effects of oxygen, and competing reactions with hydrogen and oxygen can be detrimental to the electrode surface activity. -Risk associated with mineral carbonation partners, who can refuse purchasing DAC CO_2, due to higher price compared, for example, versus CO_2 captured from flue gas.

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

https://patents.google.com/patent/WO2020035607A1/en

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

a. Please fill out the table below.

	Timeline for Offer to Stripe
Project duration *Over what duration will you be actively running your DAC plant, spreading olivine, growing and sinking kelp, etc. to deliver on your offer to Stripe? E.g. Jun 2021 - Jun 2022. The end of this duration determines when Stripe will consider renewing our contract with you based on performance.*	01.01.2024-31.12.2024
When does carbon removal occur? *We recognize that some solutions deliver carbon removal during the project duration (e.g. DAC + injection), while others deliver carbon removal gradually after the project duration (e.g. spreading olivine for long-term mineralization). Over what timeframe will carbon removal occur?* *E.g. Jun 2021 - Jun 2022 OR 500 years.*	01.01.2024-31.12.2024

Distribution of that carbon removal over time *For the time frame described above, please detail how you anticipate your carbon removal capacity will be distributed. E.g. "50% in year one, 25% each year thereafter" or "Evenly distributed over the whole time frame". We're asking here specifically about the physical carbon removal process here, NOT the "Project duration". Indicate any uncertainties, eg "We anticipate a steady decline in annualized carbon removal from year one into the out-years, but this depends on unknowns re our mineralization kinetics".*	Evenly distributed over the whole time frame
Durability *Over what duration you can assure durable carbon storage for this offer (e.g, these rocks, this kelp, this injection site)? E.g. 1000 years.*	Calcium Carbonate: >1000 years

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

Durability of $CaCO_3$ is >1000 years under ambient conditions.

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.)*

Calcium carbonate is a well known chemical compound which is stable under normal storage and handling conditions. According to MSDS $CaCO_3$ ignites on contact with fluorine; incompatible with acids, alum, ammonium salts, and mercury + hydrogen. $CaCO_3$ is expected to cause no oxygen depletion in aquatic systems. It has a low potential to affect aquatic organisms. $CaCO_3$ is non-combustible but may decompose upon heating (above 840°C) to produce CO_2. Overall, the produced $CaCO_3$ is known to be environmentally safe and stable over geological time frames (millions of years).

d. What durability risks does your project face? Are there physical risks (e.g. leakage, decomposition and decay, damage, etc.)? Are there socioeconomic risks (e.g. mismanagement of storage, decision to consume or combust derived products, etc.)?

What fundamental uncertainties exist about the underlying technological or biological process?

When heated above 840°C, $CaCO_3$ decomposes, releasing carbon dioxide gas and CaO. When stored improperly $CaCO_3$ is expected to react with CO_2 saturated water and produce water soluble $Ca(HCO_3)_2$.

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.)*

Our technological processes are well-optimized and enable us to measure the amount of CO_2 captured and utilized for the production of $CaCO_3$. The well-established process of $CaCO_3$ production takes place in an isolated environment where we can directly measure the CO_2 input and utilization rate. In terms of durability, we will be carefully selecting and assessing our customers to make sure that the final product meets the durability requirements and the risk of CO_2 release will be avoided throughout the lifetime of the end-product.

3. Gross Capacity (Criteria #2)

a. Please fill out the table below. **All tonnage should be described in metric tonnes here and throughout the application.**

	Offer to Stripe (metric tonnes CO_2) over the timeline detailed in the table in 2(a)
Gross carbon removal Do not subtract for embodied/lifecycle emissions or permanence, we will ask you to subtract this later	360 tonnes of CO_2
If applicable, additional avoided emissions e.g. for carbon mineralization in concrete production, removal would be the CO_2 utilized in concrete production and avoided emissions would be the emissions reductions associated with traditional concrete	ca. 0.8 tonnes of CO_2 per all CO_2 captured during the project -In synthesis of redox capture materials we utilize a green and facile mechanosynthetic approach developed in our laboratory. This method employs low-cost commercially available materials, is time and energy-efficient, results in no solvent/toxic waste and does not require a complex

production	post-synthetic treatment. ca. 72 tonnes of CO_2 per all CO_2 captured during the project -The key reactions in $CaCO_3$ production addressed in this project are exothermic. Extra heat produced can be used as a source of heating energy, which will further decrease a carbon footprint and reduce emissions if the same heating energy would be obtained from fossil fuels (e.g. methane).

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)*

RedoxNRG system will extract 360 tonnes of CO_2 directly from the air. The CO_2 capacity will be calculated precisely based on the redox-flow battery stack configuration, where the specific capacity of the CO_2 capture agent TALx material will be taken into account. 100% of the electrocaptured CO_2 will be consumed by the mineral carbonation process. Planned gross removal: 360 tCO_2 for 01.01.2024-31.12.2024 project duration. In order to calculate additional avoided emissions we used a model proposed by https://platform.impact-forecast.com/ software, when we compare two synthetic routes for preparation of our electrocapture agent materials: our method - liquid-assisted grinding/compression; conventional method - solvothermal synthesis. Calculation of additional avoided emissions by produced heat in mineral carbonation can be found HERE.

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).

Capture capacity: Our lab-scale prototype is not in constant operation yet, CO_2 capture agents are in the

research and development phase, and gross removal of a single-cell prototype <1kg CO_2/year.

Amount of TALx catalyst used in a current single-cell configuration (Fig. 2) is 20 mg, so ideally it would bind 13 mg of CO_2 per cycle. Single-cell cyclic voltammetry measurements have indicated the catalyst stability during 30 000 s (ca. 30 capture/release cycles).

Sequestration capacity:

In order to sequester 360 tonnes of CO_2 offered to Stripe we need ca. 1000 tonnes of oil shale ash. Current available amount is ca. 800 000 000 tonnes of raw material.

Once all the oil shale waste ash is recycled, we will concentrate on electrochemical reduction of CO_2 to formic acid for emerging fuel cell technologies.

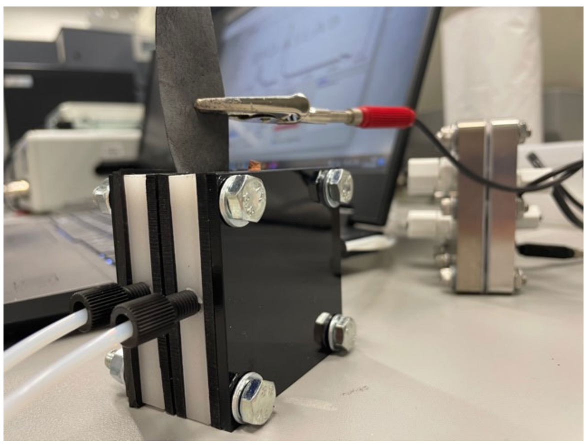

Figure 2. Single-cell electrocapture test setup in RedoxNRG electrochemistry lab.

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.)*

Material capacity:

Considering we modify TALx by substituting every hydrogen atom in the cycle with oxygen, we obtain 12 adsorption sites per 1 TALx molecule. This would mean that we can adsorb 12 moles of CO_2 per 1 mol of our adsorbent agent. Which in turn means that we can adsorb 12 moles of CO_2 per 813 g of TALx, yielding an upper limit of 15 mmol/g of capacity. 15 mmol of CO_2 equals 660 mg of CO_2, hence the proposed upper limit is 0.66 g of CO_2 per 1 g of catalyst.

Unit capacity: To consider the required size of the proposed system, let's assume an average wind speed of 3.5 m s^{-1} for Estonia [https://www.ilmateenistus.ee/kliima/kliimanormid/tuul/]. Now assuming 1 m^2 inlet of air, each second we can process air of 3.5 m^3, which contains 3.5×0.77=2.695 g of CO_2. Recalculating this per day yields 232 kg/day per 1m^2 of inlet, so to achieve the goal of 1 tonnes/day we require about 4.3 m^2 air inlet (or 4 units with 1m^2 inlets).

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.

• *Up to 5 links* -www.redoxnrg.com -Report on preliminary tests validating our redox-active capture agent material can be found HERE -Green catalyst production method related paper submitted (file available upon request). -Example of existing technology for CO_2 mineralization HERE

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	360 tCO_2
Gross project emissions	3.7 tCO_2
Emissions / removal ratio	0.01
Net carbon removal	356.3 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 last year for a* *simple example, or [CarbonCure's] for a more complex example).* If you've had a third-party LCA performed, please link to it.

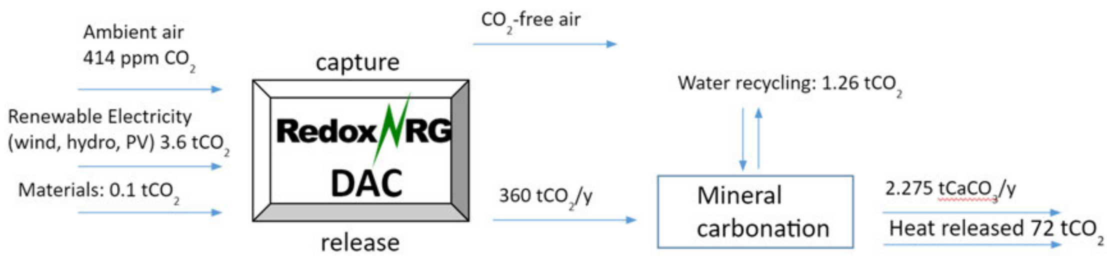

Figure 3. Process flow diagram for RedoxNRG carbon removal solution (all reported values are corresponding to 360 tCO_2 captured).

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?

This process flow diagram (Fig. 3) is presented for the overall process of DAC and mineral carbonation. However, in LCA we would like to focus only on DAC. Selection of precise mineral carbonation procedures will be done by our partners. Variation in parameters in the mineral carbonation part may occur.

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.

1) Renewable electricity for DAC (wind, PV, hydro): 0.00998 kg CO_2 per MJ or 9.98 kg CO_2 per 1 GJ. Assuming that we utilize ca. 1 GJ per 1 tCO_2:

   360 tCO_2×9.98 eq = 3592 kg CO_2 or 3.6 tCO_2

2) Materials (chemicals, electrode materials): 0.3 kg CO_2 eq per t of CO_2

   0.3 kg×360 tCO_2/1 t = 108 kg = 0.1 tCO_2

3) Heat: 0.1 tonnes of CO_2 per 1 ton of $CaCO_3$ produced = will save 72 tonnes of CO_2
4) Water (industrial reverse osmosis water Europe) = 0.00858 kg CO_2 per 1 kg H_2O

   3.5 kg×360 tCO_2/1 t = 1.264 tCO_2

We plan to perform a more precise LCA on the full process, once the partnership with the mineral carbonation company is established and exact mineral carbonation process details will be available.

e. If you can't provide sufficient detail above in 4(d), please point us to a third-party independent verification, or tell us what an independent verifier would measure about your process to validate the numbers you've provided. (We may request such an audit be performed.)

We can make corresponding project details available upon request.

5. Learning Curve and Costs (Backward-looking) (Criteria #2 and #3)

We are interested in understanding the learning curve of different carbon removal technologies (i.e. the relationship between accumulated experience producing or deploying a technology, and technology costs). To this end, we are curious to know how much additional deployment Stripe's procurement of your solution would result in. (There are no right or wrong answers here. If your project is selected we may ask for more information related to this topic so we can better evaluate your progress.)

a. Please define and explain your unit of deployment. (*E.g.* # of plants, # of modules) *(50 words)*

CO_2 electrocapture agent materials are in the process of optimization. By the end of 2022 several working prototypes (20×20 cm^2 per module) will be ready to be scaled from 20 *up to* 100 units with 25 modules each. The corresponding units will be merged into 4 efficient plants.

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

Year	Units deployed (#)	Unit cost ($/unit)	Unit gross capacity (tCO_2/unit)	Notes
2021	1	$23160	<1 $kgCO_2$/Year	First prototype is based on the model carbon nanotubes-supported materials. In the new device nanocarbon support is not needed.
2020	1	$15000	<0.1 $kgCO_2$/Year	Bench-scale laboratory single-cell setup for preliminary testing of the concept.

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.)*

So far costs are stable, since we employ small-scale setup. Our future costs are expected to decrease due to optimized scaling of synthesis and measurement cycle optimizations.

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

# of units	Unit gross capacity (tCO_2/unit)
4 plants	~90 tCO_2/unit

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

We ask these questions to get a better understanding of your growth trajectory and inflection points, there are no right or wrong answers. If we select you for purchase, we'll expect to work with you to understand your milestones and their verification in more depth.

a. What is your cost per ton CO_2 today?

~$1700 /$tCO_2$

b. Help us understand, in broad strokes, what's included vs excluded in the cost in 6(a) above. We don't need a breakdown of each, but rather an understanding of what's "in" versus "out." Consider describing your CAPEX/OPEX blend, assumptions around energy costs, etc.

~$1700 /$tCO_2$ includes material development, stack assembly, tools, energy and consumables. Excluded: facilities-related costs, personnel costs.

c. List and describe **up to three** key upcoming milestones, with the latest no further than Q2 2023, that you'll need to achieve in order to scale up the capacity of your approach.

Milestone #	Milestone description	Why is this milestone important to your ability to scale? (200 words)	Target for achievement (eg Q4 2021)	How could we verify that you've achieved this milestone?
1	POC device trial tests	First working prototype based on TALx capture agent materials will be up and running. This will help us to establish necessary protocols for POC device cycling operations. We will be able to perform TALx material durability tests and capture capacity and kinetics validations.	Q3 2022	Experimental evidence will be provided in the form of data-in-brief. Patent application filed.
2	DAC prototype auditing	We will have more accurate data on the amount of spent materials and energy expenditure in the scaled-up unit to have a better picture of DAC cost which is necessary for negotiation with our potential partners from the mineral carbonation site.	Q4 2022	Experimental evidence will be provided in the form of a research paper.
3	Planning and performing field tests of stacked and scaled-up units with our mineral carbonation partners.	This will strengthen the trust in our technology from other stakeholders and interested industrial parties.	Q2 2023	We will provide a letter of intent from at least one of our mineral carbonation partners, who will install our DAC device at their facility.

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	<1 kg CO_2/year	>1 kg CO_2/year	First working prototype based on TALx materials will run for a longer time periods and will electrocapture higher amount of CO_2 when compared to present situation, where prototype is not running continuously.
2	>1 kg CO_2/year	~1 tCO_2/year	The 1st phase of pilot scaling-up for large scale operation.
3	~1 tCO_2/year	~100 tCO_2/year	The 2nd phase of pilot scaling-up for large scale operation and ultimate goal achievement.

d. How do these milestones impact your costs, if at all?

Milestone #	Anticipated cost/ton prior to achieving milestone (ranges are acceptable)	Anticipated cost/ton after achieving milestone (ranges are acceptable)	If those numbers are different, why? (100 words)
1	>$1700/$tCO_2$	~$1000/$tCO_2$	Going away from carbon nanomaterials will contribute to cost reduction.
2	~$1000/$tCO_2$	~$500/$tCO_2$	Successful scale up improves overall per $ performance
3	~$500/$tCO_2$	~$100/$tCO_2$	Growing confidence in our process reliability for the stakeholders has a key role

			in reaching the proposed target cost.

e. If you could ask one person in the world to do one thing to most enable your project to achieve its ultimate potential, who would you ask and what would you ask them to do?

Elon Musk as a top CEO influencer. It would be enough if he would just say that he believes in our technology and its successful appliance both on Earth and Outer Space.

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

Provide valuable contacts in the emerging and competitive field of DAC applications, which will pave the roads for further collaborations.

7. Public Engagement and Environmental Justice (Criteria #7)

In alignment with Criteria 7, Stripe requires projects to consider and address potential social, political, and ecosystem risks associated with their deployments. Projects with effective public engagement tend to do the following:

- Identify key stakeholders in the area they'll be deploying
- Have some mechanism to engage and gather opinions from those stakeholders and take those opinions seriously, iterating the project as necessary.

The following questions are for us to help us gain an understanding of your public engagement strategy. There are no right or wrong answers, and we recognize that, for early projects, this work may not yet exist or may be quite nascent.

a. Who are your external stakeholders, where are they, and how did you identify them?

Estonian research community (Universities, Academy of Science, Estonian Research Council), key oil shale industrial players (see above), political forces and members of the public sector. It is essential for our project that society continues to value the clean nature and shares the interest of the reduction of the emission of the greenhouse gases.

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

Our team includes members of the Estonian Research community. We have strong contacts with the oil shale industry and provide consulting to them. Successful engagement with

politicians and the public will be backed by sound dissemination and PR events to emphasize the importance of CO_2 recapture from the air and reducing the greenhouse effect.

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?

We learned that the interest in making the world more sustainable is very high among our policy makers. Current oil shale industrial players are looking for opportunities for CO_2 capture at affordable rates. The awareness of potential benefits of DAC technologies is still poor among most of the external stakeholders.

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 plan to raise further public awareness of the CO_2 topic importance by open science events, hand-on tutorials and presentations in public schools and universities. RedoxNRG already has social media channels (FB, Instagram, Youtube, LinkedIn) which are actively promoting.

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

We would like to address the affordability of DAC technology, so that every country can participate in reducing the carbon footprint.

11. Legal and Regulatory Compliance (Criteria #7)

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

Our system is in compliance with the rules defined by the Estonian Ministry of Environment.

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

Recently, oil shale ash was excluded from the list of hazardous industrial waste list, therefore, we do not need special permission to handle and process it if needed in the research phase of the project.

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

N/A

d. Does the project from which you are offering carbon removal receive credits from any government compliance programs? If so, which one(s)? (50 words)

To date, none.

12. Offer to Stripe

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

	Offer to Stripe
Net carbon removal (metric tonnes CO_2)	356.3 tCO_2
Delivery window (at what point should Stripe consider your contract complete?)	01.01.2024-31.12.2024
Price ($/metric tonne CO_2) ***Note on currencies:*** *while we welcome applicants from anywhere in the world, our purchases will be executed exclusively in USD ($). If your prices are typically denominated in another currency, please convert that to USD and let us know here.*	$500/$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	2.0×10^{-6} km^2
2022	4.0×10^{-6} km^2
2023	4.0×10^{-5} km^2

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

Year	Contactor Footprint (m^3)
2021	0.3 m^3 (>1kg CO_2/year)
2022	12 m^3 (~1t CO_2/year)
2023	4 plants × 12 m^3 (90t CO_2/year per plant)

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

1. What sorbent or solvent are you using?

TALx materials, which are a conductive redox-active metal-organic framework-based solid composites.

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

0.66 g of CO_2 per 1 g of catalyst (theoretical estimation per cycle)

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

0.66 g of CO_2 per 1 g of catalyst (theoretical estimation assuming 100% reversibility, currently 90% reversibility is achieved)

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)

TALx materials are synthesized in our laboratory from affordable commercially available precursors. With the scaling of our solution, we hope to increase our sorbent materials development and production facility.

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

Electrochemical cycling by potential switch, <1 GJ per tonne of CO_2.

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)

Renewable energy source, but still bound to the local electricity grid. Preferable PV, wind turbines. Costs according to the market situation. The ultimate goal is to run exclusively on the renewable energy source, which is solely dedicated to the DAC system and is not grid dependent.

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)*

DAC requires no additional water for cycling.

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

Not applicable

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

Currently cycling max 30 cycles per day (each cycle 15 min)

Projected cycling protocol: 90 cycles per day

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

TALx based materials may be sensitive to long-term cycling and environmental conditions. Research and development will be concentrated to decrease the sensitivity of our electrode materials to hydrogen and oxygen, which can be detrimental to the electrode surface activity and electrocapture capacity.

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

Our aim is to optimize the durability of the electrode materials to be stable during continuous operation for at least 180 days. We will develop an additional electrochemical activation procedure, which will be performed in order to strip the impurities accumulated on the electrocapture agent surface and extend its end-of-life.

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.

Spent TALx capture materials can be further recycled. After optimized carbonization in inert atmosphere (heat treatment in tube furnace at 800-900 ℃, 2h, nitrogen flow) it will form electrocatalytic transitional metal-nitrogen-carbon composite material, which can further be used as a cathode catalyst in polymer electrolyte membrane fuel cells or in water splitting electrolysers. Spent sorbent is not hazardous and does not require special disposal.

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.

Company	Type	Power Consumption (kWh/tCO_2)	Regeneration conditions	Issues	Capture cost
Carbon Engineering	Using hydroxides and temperature swing	1750–2000	850°C	0.5t emitted for each 1t of CO_2 captured,	$232/t (current
Climeworks	Using solid sorbents with a temperature and moisture swing	1750–2000	100°C	Requires access to steam/waste heat	$750/t (current)
Global Thermostat	Using solid sorbents with a temperature and moisture swing	1500–1750	75-85°C	Requires access to steam/waste heat	~$200/t (current)
Verdox	Electrochemical dissociation	~600	Room temp	Immature production capability, requires specialised electrodes	~$100/t (projected)
Mission Zero Technologies	Electrochemical separation	400–600	Room temp	Requires access to renewable energy	~$100/t (projected)
RedoxNRG	Electrochemical capture/release using potential swing	~300	Room temp	Requires access to renewable energy	~$100/t (projected)

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?

Pure CO_2 will be fed directly from the RedoxNRG DAC device.

2. What are alternate uses for this CO_2 stream?

Direct utilization in CO_2 electrolyser to reduce CO_2 to value-added products, such as formic acid. RedoxNRG has experience in CO_2 electroreduction to formate (corresponding article is in press).

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)*

RedoxNRG solution is DAC in nature

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).*

CO_2 from the RedoxNRG DAC system is directly supplied to the carbonation plant, where process efficiency reaches 100%.

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?

Durability of $CaCO_3$ is >1000 years under ambient conditions.

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?)*

RedoxNRG is responsible for the whole system (DAC and utilization), which makes it easier to follow the usage and also provide evidence for the auditors if needed to prove that the carbon benefits are not double counted.