

EDAC Labs

Carbon dioxide removal prepurchase application Summer 2023

General Application

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

Public section

The content in this section (answers to questions 1(a) - (d)) will be made public on the [Frontier GitHub repository](#) after the conclusion of the 2023 summer purchase cycle. Include as much detail as possible but omit sensitive proprietary information.

Company or organization name

EDAC Labs, Inc.

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

Baltimore, MD

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

Brian Toll

Brief company or organization description <20 words

EDAC Labs electrochemically transforms salt into acid and base to drive carbon removal processes.

1. Public summary of proposed project¹ to Frontier

- a. **Description of the CDR approach:** Describe how the proposed technology removes CO₂ from the atmosphere, including how the carbon is stored for > 1,000 years. Tell us why your system is best-in-class, and how you're differentiated from any other organization working on a similar approach. If your project addresses any of the priority innovation areas identified in the RFP, tell us how. Please include figures and system schematics and be specific, but concise. Aim for 1000-1500 words.

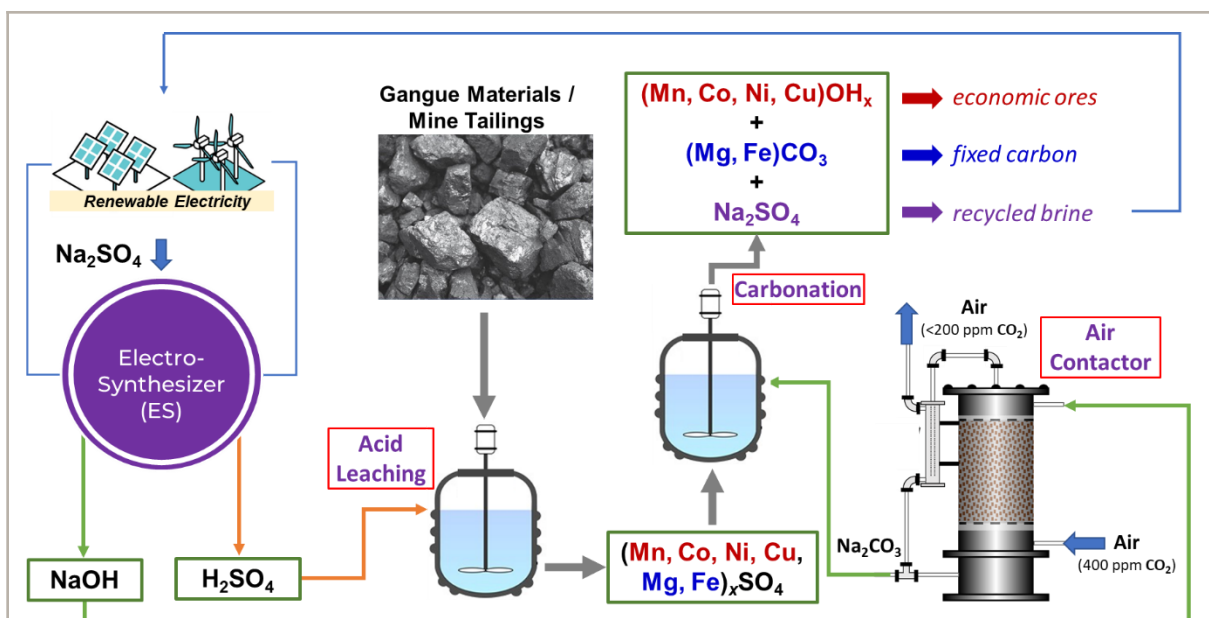
¹ We use "project" throughout this template, but note that term is not intended to denote a single facility. The "project" being proposed to Frontier could include multiple facilities/locations or potentially all the CDR activities of your company.

EDAC Labs, Inc has exclusively licensed a novel electrochemical salt splitting process from Johns Hopkins University that we call “electrosynthesizer.” This energy-efficient synthesis of acid and base uses only electricity and brine as inputs, operates at ambient temperature and pressure, and is directly relevant to Frontier’s area of focus on cross cutting technologies. This system has the potential to supply acid and base for direct air capture, ocean alkalinity enhancement, direct ocean capture, and other decarbonization activities where acid and/or base prove essential, and it is EDAC Labs’ intention to become a supplier of electrosynthesizer technology to various CDR developers.

Another exciting application is to leverage the electrosynthesized acid and base to develop carbon-negative gangue mineral processing with critical metal (e.g., Ni, Co, Cu, etc.) extraction. In one scenario, we might process ground virgin materials from an ultramafic mine or quarry. In another scenario, which is the scenario we are proposing for this project, we re-process ultramafic mine tailings. The re-processing of mine tailings extracts economic value from recovered metals while simultaneously permanently sequestering carbon in the form of solid carbonates (e.g., magnesium and iron carbonate). The bench-scale development for this project is supported by the ARPA-E MINER Program through a \$2M grant to Johns Hopkins University. The goal of this application is to help fund a field demonstration of a system that captures 1 ton of CO₂ per day.

The mechanism of integrating carbon capture and sequestration into mining is straightforward (see diagram below). Specifically, sodium sulfate salt is separated into high-concentration sulfuric acid and sodium hydroxide. High-concentration sulfuric acid is used for leaching gangue materials from magnesium and iron-containing ultramafic ores such as olivine, brucite and serpentine, which often contain nickel, manganese, and other critical minerals (albeit at low concentrations, typically <1 wt.%). The sodium hydroxide solution is delivered to an air contactor to capture CO₂ to create sodium carbonate (“soda ash”), which is then added slowly to the leachate to raise the pH and carbonate anions in the solution. This allows for sequential precipitation of different metal carbonates/hydroxides, producing enriched ores of the critical metals that can be sold to metal refineries. Additionally, carbon dioxide is permanently sequestered as magnesium and/or iron carbonate. Sodium sulfate remaining in the solution is then recycled and fed back to the electrosynthesizer, which also avoids the discharge of sulfate salts from the processing.

Compared to other DAC approaches, our innovation produces solid carbonates as permanently fixed carbon instead of CO₂ gas, and thus saves the costs needed for further sequestration of gaseous carbon. Our technology also addresses some environmental issues associated with mine tailing, creatively turning an environmental hazard into a useful feedstock for carbon capture and sequestration.



Our energy-efficient electrosynthesizer is the foundational technology that provides acid and base for systems that capture and release CO₂ gas (for other CDR technologies), for the proposed carbon negative mining as described above, for ocean alkalinity enhancement, or for direct ocean capture. While we have seen innovations in salt splitting electrochemistry from several firms in all these specific applications, we believe that our system is differentiated from others because it can achieve higher concentrations of acid (e.g., >3M or H₂SO₄) and base, and it can operate at higher energy efficiency (>60%) and higher energy density, where higher energy density means smaller machines, less membrane area, and lower capex per ton of CO₂ sequestered.

Mining companies are strongly motivated to reduce their carbon footprints (for example, the [Tailing Technologies Open Call](#) from BHP and Rio Tinto). Based on our preliminary TEA of what this system looks like at scale, we expect to offset a significant amount of our NOAK cost per ton through the sale of extracted critical minerals. Additionally, since our systems will be located on existing mining property, we expect very low “indirect” cost adders in the system (for example, we are not constructing and operating a new class VI well, our “carbonated tailings” end up in the same place they were already being stored such that we are not buying land or transporting materials).

Energy will be the primary driver of operating cost, and the electrosynthesizer represents about 80% of total energy consumption. Like all DAC projects, at scale a renewable power source will need to be constructed. Thus, another important consideration with respect to our process is the ability to easily start and stop the electrosynthesizer, and the ability to store acid and base in simple plastic tubs. These features enable time shifting, which is when we match the high-energy acid-base generation process to peak renewable resources. We would still run the low-energy air capture and back-end processes 24 hours a day to maximize system capacity.

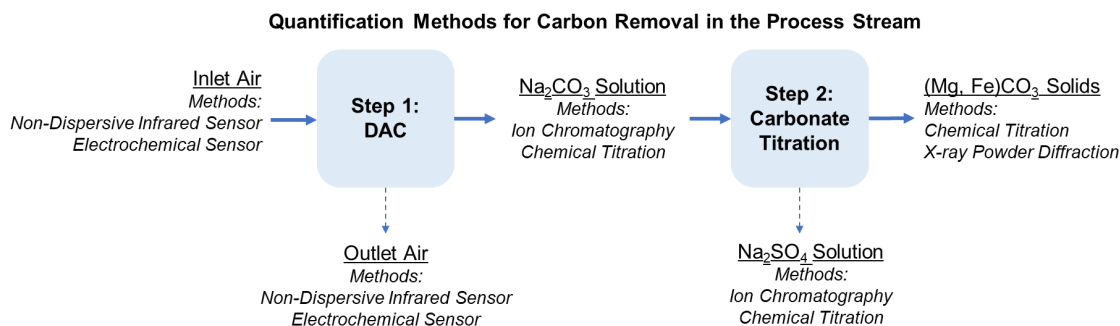
In summary, the EDAC Labs electrosynthesizer is a breakthrough solution in the energy-efficient synthesis of acid and base. When applied to the processing of mine tailings, we provide both carbon sequestration and carbon utilization.

- b. **Project objectives:** What are you trying to build? Discuss location(s) and scale. What is the current cost breakdown, and what needs to happen for your CDR solution to approach Frontier's \$100/t and 0.5Gt targets? What is your approach to quantifying the carbon removed? Please include figures and system schematics and be specific, but concise. Aim for 1000-1500 words.

For this project, EDAC Labs will partner with a mining operation that creates mine tailings from the specified rock types. We will provide infrastructure to support 1 ton/day CO₂ capture in the form of magnesium and iron carbonates that will be stored on the mine site. We will run this system for 1 year and assign these tons to the Frontier pre-purchase. The timing of this project aligns well with EDAC Labs' efforts to bring this technology out of the laboratory and into the real world.

In terms of market size, we reference a recent paper² from Dr. Laura Lammers: "Of the billions of tons of tailings and waste rock produced, around 420 Mt consist of basic or ultramafic rocks that have the potential to sequester ~175 Mt of CO₂ annually.... Nickel mining will need to increase by more than 5 times by 2040 in order to meet global renewable energy goals, and tailings production will increase at least in proportion to critical element production as ore grades decrease." Additionally, we previously mentioned the potential for mining virgin ultramafic rocks as another potential market that combines critical mineral extraction with carbon sequestration. According to the USGS³, the United States alone contains 6,000 square miles of accessible ultramafic rocks. EDAC Labs has not performed LCA analysis on this process in virgin mines, but we would expect a favorable analysis when processing and storage occur on the original land (no transportation).

For this project, the two-step approach for carbon removal includes direct air capture and carbonate titration, both of which employ measurable techniques for quantifying the amount of carbon removed.



Step 1: Direct Air Capture. In the first step, the direct air capture unit will extract CO₂ from the air and convert it into soda ash in aqueous solution. This is achieved by passing air through aqueous NaOH solution for multi-phase chemical reaction. We will measure the CO₂ concentration difference between the inlet air and outlet air and detect the post-capture solution's pH and carbonate concentration.

Step 2: Carbonate Titration. In the second step, carbonate titration will precipitate the carbonate in forms of magnesium carbonate and iron carbonate as final carbon fixation. This process involves reacting the captured CO₂ with Fe- and Mg-bearing precursors to produce Fe- and Mg-bearing carbonates. This process is a liquid-phase reaction with solid precipitates. We will measure the chemical composition of the solid carbonates and monitor the carbonate concentration in the

² Laura N. Lammers, Yanghua Duan, Luis Anaya, Ayumi Koishi, Romario Lopez, Roxanna Delima, David Jassby, and David L. Sedlak. "Electrolytic Sulfuric Acid Production with Carbon Mineralization for Permanent Carbon Dioxide Removal." ACS Sustainable Chemistry & Engineering 2023 11 (12), 4800-4812

³ <https://pubs.er.usgs.gov/publication/ds414> and <https://www.earth.columbia.edu/articles/view/2393#:~:text=Courtesy%20U.S.%20Geological%20Survey,at%20or%20near%20the%20surface.>

post-reaction solution. For example, the quantity of carbon sequestration can be quantified using techniques like X-ray powder diffraction (PXRD), which can estimate the abundance of hydrated magnesium carbonates in the tailings with a precision of approximately 5% relative for mineral species present in amounts greater than 10 wt.%.

- c. **Risks:** What are the biggest risks and how will you mitigate those? Include technical, project execution, measurement, reporting and verification (MRV), ecosystem, financial, and any other risks. Aim for 500-1000 words.

Technical Risks: Scaling the electrosynthesizer and air contactors. The electrosynthesizer with our novel design is different from the commercially available products such as chlor-alkali electrolyzer or membrane electrolyzer for hydrogen. The air contactor for direct air capture with electrosynthesized alkaline solution also has the scale-up challenge for its size and energy consumption. Mitigations: The ARPA-E program provides substantial resources for cell engineering. EDAC Labs has also engaged engineering consultants to identify best practices for scaling up. BAC is a world expert on cooling towers, which are slightly modified for use as air contactors, and has expressed confidence in their ability to deliver state of the art air capture equipment.

Project Risks: Identification of a site for operation. Mitigations: We have started the process of identifying mines in the US and Canada that could host a demonstration process. We plan to approach these potential partners with the results of an integrated test scheduled for this fall.

MRV Risks: The long-term measurement and verification of fixed CO₂ as mineralized carbonate. Mitigations: We have conducted the detailed and quantified measurement of CO₂ in our operation and closed the CO₂ mass balance in all steps. We have developed quantified methods to monitor the mineralized carbonate's stability. We plan to work with third parties to validate the CDR methodology and monitor the long-term CDR.

Ecosystem Risks: Products may change the local ecosystem of the mining site. Mitigations: We have evaluated the original environmental impact report as well as research literatures of the potential mining locations for our projects and found no regulatory limitation or direct hazard to the ecosystem with silica (byproduct), siderite and magnesite (CDR products). We plan to work with third parties to conduct a comprehensive environmental impact assessment. Our initial view is that this system is environmentally favorable because we are recycling sulfuric acid and we are removing toxins from existing mine tailings that otherwise might have leached into ground water over time.

- d. **Proposed offer to Frontier:** Please list proposed CDR volume, delivery timeline and price below. If you are selected for a Frontier prepurchase, this table will form the basis of contract discussions.

Proposed CDR over the project lifetime (tons) <i>(should be net volume after taking into account the uncertainty discount proposed in 5c)</i>	318 tons
Delivery window <i>(at what point should Frontier consider your contract complete? Should match 2f)</i>	By end of 2025

Levelized Price (\$/ton CO₂)* <i>(This is the price per ton of your offer to us for the tonnage described above)</i>	\$1,573
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** 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 and reflect reductions from co-product revenue if applicable).*

