Removr

Carbon dioxide removal prepurchase application

Summer 2024

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 2024 summer purchase cycle. Include as much detail as possible but omit sensitive and proprietary information.

Company or organization name

Removr

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

Lysaker, Norway

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

Alex Bell

Brief company or organization description <20 words

Removr is an innovator of efficient, sustainable carbon removal technology focused on industrial-scale DAC deployment without the use of water, fossil fuels, chemicals, critical minerals, external heat or material handling.

1. Public summary of proposed project[1] to Frontier

a. **Description of the CDR approach:** Describe how the proposed technology removes CO_2 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. 1000-1500 words

[1] We use "project" throughout this template, but the 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.

DAC is proving to be one of the only negative emissions technologies that has the potential to effectively and verifiably remove CO_2 from the atmosphere at scale, and deliver the promise of a Net Zero world for future generations.

Removr aims to scale up DAC this decade with a safe, sustainable approach that is positioned to potentially deliver the lowest lifecycle unit costs among known DAC solutions. To do this, we focus only on developing industrial-scale DAC facilities that deploys carbon removal technology based on an existing, well-established solid sorbent material, zeolites, that is positioned to reduce execution risks and accelerate deployment. Our capture technology is agnostic towards carbon storage methods, but for the purposes of this application, we intend to permanently sequester CO_2 captured and removed from our DAC process by in-situ geological carbon mineralization in Iceland's basaltic subsurface formations via our CO_2 storage partner, Carbfix.

Removr's process is a solid sorbent temperature swing. The technology we deploy runs on renewable electricity and uses zeolites as a sorbent.

Removr's zeolites-based solution operates on a temperature swing process (-40º C to 220º C) at atmospheric pressure, requiring only renewable electricity as a power input. The technology requires no pressure equipment, which in turn mitigates process risk and reduces long-term capex.

In addition, Removr's DAC facilities have the potential to address other non-CO_2-related sustainability challenges. Removr is designing its scale DAC plants to operate as a 'virtual battery' to assist in addressing other non-CO_2 sustainability challenges. Removr's DAC plants represent a large, flexible load that can operate with fast frequency demand response to assist in balancing power grids that are fast becoming increasingly renewables-based. In addition, Removr's has the potential to be a net positive producer of water given the uniqueness of the company's technology approach. We believe these capabilities are additive to Frontier's areas of focus for the 2024 cycle.

We believe Removr's zeolite-based technology holds unique, differentiated advantages for DAC:

- extremely stable material (high cyclic stability), 15 years efficacy in adsorbing CO_2 at atmospheric concentrations
- uniquely safe when compared to other sorbents: zeolites are a non-hazardous, non-toxic inert microporous mineral that occurs naturally and is also produced synthetically
- already produced in large amounts by established leading western companies
- not based on any critical materials
- totally water-free process
- approximately 10x cheaper per kg CO_2 captured than leading amine or MOF-based technologies

Overcoming zeolites' hydrophilicity is a key technical challenging to unlock zeolites' significant potential as a DAC sorbent material. Removr has developed a solution that requires no additional energy to remove the water from the air before it hits the zeolite adsorption stage, utilizing silica gel to dehydrate the incoming humid ambient air as it enters the DAC facility. Removr has designed a static bed solution where ambient airflow is pushed through silica gel packed into the beds, where water in the gas phase is removed from the airflow without the use of additional energy, rotating equipment or material handling. This novel process is currently being patented by Removr.

An industrial-scale DAC plant is equivalent to a large factory, where design, engineering, construction and operational principals have much more in common with industrial practice than high iteration, digital technology product logic. The Removr team is deeply experienced in successfully developing and operating large, capital-intensive industrial projects, thus we believe the company is well positioned to execute its scaling strategy towards targeted megaton DAC levels.

The production of all major materials across the economy occurs in large process plants, thus driving Removr's sole focus on deploying DAC at large, industrial-scale levels to strive towards minimizing levelized unit production costs. Building large saves on material amounts and costs (and embedded emissions) and drives energy efficiencies. For economies of scale, the minimum cost of a product is dictated by the cost and weight of the raw materials. Industrial scale-up focused on large size components provides several advantages over scaling on quantity alone. Larger components have a lower theoretical minimum cost per unit produced and utilizing existing off-the-shelf equipment enables immediate economies of scale capture. Digital twin models (dynamic simulators) and other advanced digital design tools such as computational fluid dynamic (CFD) and steady-state simulations accelerate testing and learning curves previously only available through physically building many smaller iterations.

How is the carbon stored for >1,000 years?

Removr is focusing this application on CDRs produced from the company's initial commercial DAC plants in Iceland, where the project team includes Carbfix, the world's leading permanent carbon sequestration company, as our CO_2 storage provider. The Carbfix process involves injecting water-dissolved CO_2 into Iceland's unique basaltic subsurface formations that effectively converts the CO_2 mixture into stone underground in under two years through technology that imitates and accelerates natural processes, providing a permanent and safe carbon storage solution. All the injected CO_2 can be expected to remain sequestered for thousands of years, as rapid subsurface reactions between the water-dissolved CO_2 and suitable rocks (such as basalt) turn the CO_2 into solid carbonate minerals that are stable over geological timescales.

How does our technology address areas of focus for Frontier in 2024?

- **"Projects that leverage existing industrial assets or processes to scale carbon removal quickly and at lower costs."**
  - Removr deliberately focuses on using and repurposing existing industrial materials and components to de-risk and accelerate DAC deployment. Our team leverages decades of experience and networking in the realm of industrial refrigeration, heat exchangers, ducting, and EPC management to position the company to scale up CDR as quickly and cost-effectively as possible.
  - Co-location of Removr's DAC facilities with industrial facilities that produce waste heat or waste cold could enable meaningful savings on capex and opex given potential energy efficiencies of integrating such waste streams into Removr's process that requires temperature ranges of –40º C to 220º C.

- **"Projects that provide local environmental and economic co-benefits that build community and policy support." (DAC area of focus)**
  - Removr's technology allows it to be a uniquely safe employer and benign neighbor. First, from an occupational health and safety point of view, the Removr plant is completely safe, as it operates at atmospheric pressure and uses no toxic materials such as amines or heated potassium. Furthermore, zeolites do not require any movement or handling once secured into the static bed design due to the material's durability and stability, unlike other DAC sorption processes might require. This translates to less operator exposure and less vehicle transporting of harmful substances on local roads. Water use, water access and aquifer pollution are a major challenge in many communities, whereas Removr's technology for CO_2 removal from ambient air requires no use of water.
  - Removr's DAC facilities do not use water for CO_2 removal and actually have the potential to become a net positive producer of water given the uniqueness of the technology process. By optimizing operations, water can potentially be drawn out of Removr's system utilizing excess refrigeration system capacity during both periods of select environmental conditions and in certain locations. At a 1 MTPA capacity, Removr estimates it could produce approximately 250,000 TPA of water for usage in the local community under optimal conditions.

- **"Projects able to use and/or procure energy efficiently and effectively"**
  - Beyond capturing CO_2, Removr is positioning its assets to solve other sustainability challenges. Our DAC facilities represent a large, flexible power load that has the potential to operate as an effective virtual battery with AI-driven fast frequency demand response operations. During grid stress events, Removr's plants will be designed for fast operational shutdown to deliver the curtailed power back to the

network to help balance supply and demand. This is designed to lower both volatility of power prices and lower the overall electricity price to the benefit of residents of the local community. Grids that are becoming more renewables-based show difficulties in matching increasingly variable supply with variable demand, with large flexible demand response representing an important solution along with battery storage.

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 cost and scale criteria?[2] What is your approach to quantifying the carbon removed? Please include figures and system schematics and be specific, but concise. 1000-1500 words

Removr intends to build and operate its first large-scale DAC plant using its zeolite-based solid sorbent technology and 100% clean electricity in the Nordic region. The facility, called Project Polar, is designed for 50,000 tons per annum (TPA) of capacity and located in Hellisheiði, Iceland. Removr intends to start operations of Polar in 2026, with ramp up to full capacity by 2028.

This project will be Removr's inaugural scaled commercial project following improvements of key technical process have been validated at smaller scale (H_2O removal and CO_2 purity processes). Removr has delineated a full value chain solution for Polar, including constructing and operating the DAC plant, and securing 100% clean, geothermal power-supply from our partner, ON Power, and underground storage of CO_2 from Carbfix.

The first objective of Polar is to document and demonstrate that the technical principles of Removr's DAC solution is suited for full commercialization, and apply learnings from potential systems and dynamic effects of building a first large DAC plant to future commercial projects. Secondly, the Polar scale-up step will enable Removr to gain experience and learn to improve our design and construction of the NOAK plant. This is a necessary scaling step to reach the megaton scale.

Location: This project will be built on-site at ON Power's Hellisheiði Geothermal Power Plant in Iceland. Removr has executed agreements with ON Power and Carbfix for the land lease, power supply and CO_2 storage. These are the same partners used by Climeworks who also build and operate their DAC plants within the same geothermal park. Currently, Iceland is one of few global locations that has a fully operational value chain for CO_2 geological storage and available clean power.

Removr is evaluating locations for future larger DAC projects in the US, Canada, Middle East and other global sites. Removr is able to design DAC plants suitable for operation in all parts of the world, however plant efficiency and cost will depend on specific the inlet conditions. Regions with cold and low humidity environmental conditions likely represent the most efficient and cost-effective locations for Removr's technical approach.

Scale: 50,000 TPA

Removr's strategy is based on building large-scale DAC facilities to maximize capex and opex efficiencies per ton of CO_2 captured and stored considering economies of scale and required land use. Removr' DAC process uses proven technology and known processes. Removr is highly focused on developing an effective supply chain for all required equipment and components and has already established collaborative relationships with key suppliers to position for readiness for megaton-scaled DAC facilities by 2030. For the Polar project, Removr is optimizing its design for current dimension

[2] We're looking for approaches that can reach climate-relevant scale (about 0.5 Gt CDR/year at $100/ton). We will consider approaches that don't quite meet this bar if they perform well against our other criteria, can enable the removal of hundreds of millions of tons, are otherwise compelling enough to be part of the global portfolio of climate solutions.

limits for off-the-shelf components for the first scaling step.

Building even large-scale capacity facilities will require more available land and a deeper, more mature market for CDR offtake. Removr's ambition is to build multiple megaton plants, each of which will incorporate learning and improvement steps from previous facilities. This strategy may also include evaluating new technologies (e.g. adsorbents) to further improve our processes, and increase removal capacity and/or efficiencies.

What is your approach to quantifying the carbon removed?

CO_2 captured within Removr's DAC facilities will be measured by calibrated instruments both at the outlet of the DAC plant and at the injection hub delivered by Carbfix. There is effectively no transportation of CO_2 required for the Polar project, as the injection hub is located directly adjacent to the Polar plant with short steel pipes connecting the facilities. The detailed LCA for the entire process including storage will be used to calculate how much CO_2 will be required for injection to remove a net ton of CO_2. The process is verified by DNV and Puro. Removr acknowledges that correct and verified measurements are an important part of the process as this is directly linked to CDR credits sold.

Current cost breakdown for 50,000 TPA, ref. TEA:

Capex: 1,389 $/ton

Fixed Opex: 36 $/t

Variable Opex:

- Levelized energy costs: 151 $/ton
- Water use (for Carbfix CO_2 storage process): 16 $/ton
- CO_2 storage: 20 $/ton
- MRV and quantification costs: 6 $/ton

Total: 1,618 $ /ton

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. 500-1000 words

- **Technical concept** not ready for next scaling step. If the technical concept is not ready or fully verified in previous steps, the Polar project may not meet the required acceptance criteria/ objectives without significant cost and schedule delays. This could be related to new or unforeseen concepts which must be verified before project implementation in the next phase. Mitigation steps to reduce these risks include testing and optimization of two technical processes identified in our Genesis pilot project currently underway, including learning and documenting CO_2 adsorption processes and verifying the dehydration process in a controlled environment. Removr will also utilize its dynamic simulator developed to document the process function and verify the simulator with actual test data. In addition, Removr will utilize standard mitigation processes such as design review, risk review and internal design verification. For each scaling step, Removr will implement learning points from previous projects. For instance, the second phase of the Polar project will include learnings and improvements from both the Genesis project and Polar first phase.

- **Development Schedule.** The overall progress plan is developed from firsthand experience-based estimates as limited real reference class data exists for similar DAC projects. There is a risk that the plan is too optimistic, fails to capture key tasks, faces challenges during equipment delivery and/or commissioning, or other factors that could delay the project. Prior to FID, a detailed schedule will be developed to increase accuracy of the development timeline. Removr utilizes standard energy industry project forecasting and management practices, and known principles and equipment within its technical process. We consider the Removr technology approach as a generally low-complexity solution given the use of all known materials (zeolites), equipment and components. This low-level process complexity is an important mitigation factor to reduce the likelihood of unforeseen issues occurring during project execution. The Removr team has several decades of experience of executing large capital-intensive project from the oil and gas and other heavy industries. Learning from execution of first phase of Polar will be important input when developing a realistic schedule for Polar second phase.

- **Constructability and issues during construction and commissioning.** There is a risk that construction of the project (ductwork, component assembly and commissioning, and other factors) is more challenging than first anticipated. This could lead to schedule delays and cost overruns. Processes may also be working differently compared to results shown in the dynamic simulator (e.g. if leaking occurs) leading to time-consuming fault-finding processes. Risk mitigation is a specific consideration of contracts (EPC/EPCM) and responsibility for the different contractors such that scope and related risk is clear. This includes early consideration of how to determine if the failure is related to process versus construction issues, such as leakages in joints versus equipment. Ensuring components are tested at the manufacturer (FAT) prior to installation is another mitigation step to consider. This risk is partially mitigated by the generally low complexity of the Removr DAC concept. Furthermore, Removr is undertaking a constructability workshop with EPC contractor Stantec in June, 2024 to further mitigate risk related to this topic.

- **CAPEX estimation.** There is a risk that the cost estimates for engineering, procuring, construction and commissioning are too low. Current capex estimates are at Class 4 at minimum according to AACE International. Cost estimates will be further developed with supplier input, line-by-line verification by external parties, e.g. owner's engineer as part of FEED engineering and prior to FID.

- **Supply chain, power and infrastructure.** There is a risk that the local supply chain and infrastructure has insufficient capacity to deliver services for Removr's facilities. Site selection for Polar is based on several factors including supply chain, power/grid connection and required infrastructure. The carbon removal sector in Iceland is fairly established already with scaled DAC plants already operating in the same region as Polar. During FEED and detail engineering, supply chain will be extensively involved and execution of LLI procurement will likely be required following FID (prior to detailed engineering).

  Removr is currently working diligently to establish and secure its long-term supply chain to ensure execution of its scaled DAC facilities. The Removr team has visited key suppliers in Iceland to clarify and agree on the project scope, and the company has aligned with local EPC contractors, Owners Engineer and architect for assistance in permitting processes and storage capacity. For instance, the company has executed several LOIs and collaboration agreements with sorbent material and equipment suppliers to design, develop and source scaled equipment required for Removr's larger concept plants.

  For the Polar facilities in Iceland, Removr has executed Heads of Terms and LOI agreements for CO_2 storage with Carbfix and 100% clean geothermal power and land leases with ON Power. The Geothermal park in Hellisheiði Iceland is a unique location with an established supply chain and minimum permitting risk for DAC.

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)	5000 tons proposed for prepurchase.

(should be net volume after taking into account the uncertainty discount proposed in 5c)	Project lifetime volume is 1,230,000 tons
Delivery window *(at what point should Frontier consider your contract complete? Should match 2f)*	Deliveries start in Q4 2026 and can last up to 5 years for prepurchase
Levelized cost (\$/ton CO_2) *(This is the cost per ton for the project tonnage described above, and should match 6d)*	\$1,618/ton CO_2
Levelized price (\$/ton CO_2)[3] *(This is the price per ton of your offer to us for the tonnage described above)*	\$943/ton CO_2

[3] 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).