Clairity Technology

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

Clairity Technology Inc.

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

Culver City, CA

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

Glen Meyerowitz

Brief company or organization description <20 words

Clairity Technology develops systems for direct air capture and storage of atmospheric CO2 that are durable and verifiable.

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. Please include figures and system schematics and be specific, but concise. 1000-1500 words

Clairity's Best-in-Class Approach to CDR and Differentiation

Clairity's best-in-class approach to CDR is "simplicity by design," which is enabled by our sorbent and key process decisions. Clairity's alkali carbonate sorbent, which is the backbone of our technology, will enable low-cost DAC and be a critical piece of gigaton scale CDR.

[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.

Alkali carbonates are low-cost, abundant, and environmentally safe, enable low-energy regeneration and generate co-benefits such as water generation. Our integration of alkali carbonates into a simple, highly efficient DAC process provides numerous advantages over other approaches in the field. Clairity is a world leader in alkali carbonates as DAC sorbents with characterization and testing expertise, extensive lab operations, data across thousands of tests, and advanced modeling capabilities.

Alkali carbonates are produced at the scale of tens of millions of tons per year and therefore we are not subject to supply chain constraints which are common for other DAC approaches that rely on amine and MOF sorbents. Alkali carbonates can support megaton scale DAC today with no need for new manufacturing facilities or supply chains, enabling critical and rapid scalability without ballooning costs and timelines.

Our sorbent can be regenerated at low temperatures, unlike calcium oxide sorbents that require regeneration at >800°C. Additionally, the enthalpy of desorption is lower than calcium oxide sorbents and similar to many amine and MOF sorbents. Alkali carbonates are safe to manufacture and use – sodium bicarbonate is baking soda! By comparison, amines and amine-functionalized MOFs may be volatile or in aerosol form, presenting environmental risks and hazards, and may react to form carcinogens.

Clairity's process does not use vacuum or pressure to enable regeneration of our sorbent, further reducing cost and complexity. No steam is used for regeneration of our sorbent, meaning we do not need boilers and heat recovery systems for efficient operation. Unlike amines that may degrade at elevated temperatures in the presence of oxygen, alkali carbonates are stable which enables a simpler and lower cost regeneration system.

Alkali carbonate sorbents enable geographic differentiation when compared to other sorbents as they operate best in arid environments such as the Southwestern United States and the Middle East. Calcium oxide and amine sorbents perform better in humid environments. This geographic distinction can help to create a risk-adjusted portfolio by expanding the coverable land area. Deployments of DAC in arid climates present multiple advantages to humid climates, primarily due to high solar resource availability in arid regions. DAC projects in these regions will have greater access to lower cost clean power. Arid regions also have significantly less arable land than non-arid regions, mitigating concerns about land use. Nevada, the site of Clairity's first DAC facility, and Arizona have the second and third lowest amount of cropland as a percent of total land area of any US states, at 0.8% and 1.6% respectively [Economic Research Services, US Department of Agriculture, 2017].

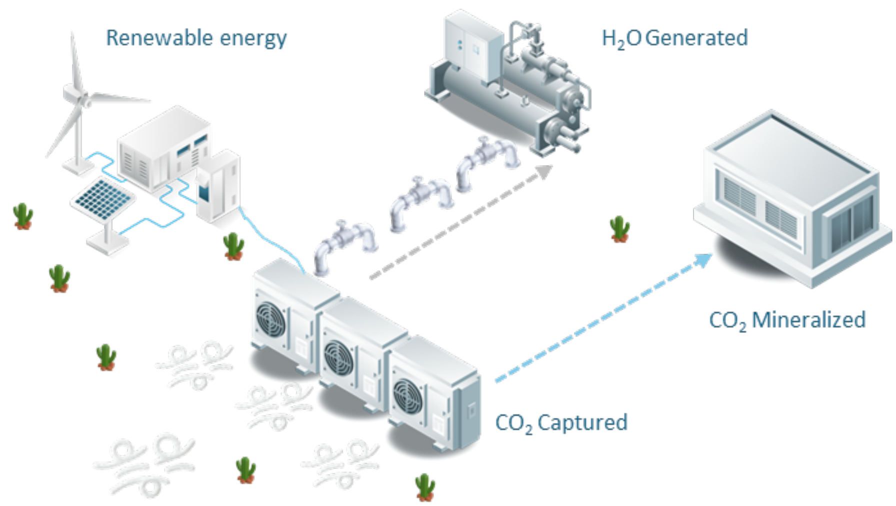
When utilized with our groundbreaking processes, the unique properties of alkali carbonate sorbents will provide advantages in critical areas that will enable this technology to rapidly scale in a cost-effective manner.

CDR Approach

Clairity Technology develops novel integrated direct air capture and storage technology to accelerate the deployment and reduce the cost of durable carbon dioxide removal. Clairity uses a solid sorbent approach, where an alkali carbonate sorbent is coated onto a ceramic honeycomb substrate. Air is actively blown over the sorbent to saturate it with CO2. A chemisorption process occurs where CO2 and H2O are adsorbed and the carbonate is converted to a bicarbonate. Once the sorbent is sufficiently saturated with CO2, the sorbent material is transported from an adsorption station to a desorption station, where it is heated and undergoes a low-temperature regeneration to release and collect the CO2, converting the bicarbonate back to carbonate. The H2O that was adsorbed is also regenerated and can be condensed.

Clairity has developed our own ex-situ mineralization pathway that can use a range of magnesium or calcium containing feedstocks to react with and durably sequester CO2 for >1,000 years. Clairity is excited to integrate alkaline industrial waste reclamation with our technology. We have engaged with providers of raw material feedstocks that can be used to durably sequester the CO2. Clairity is bringing additionality to the value chain of fly ash by using this industrial byproduct, which is typically landfilled, as a carbonation feedstock. The United States generates approximately 50 million tons of new fly ash annually, with even more disposed of in existing ash ponds, making valorization of this waste a win for multiple stakeholders.

The following figure shows the Clairity Process powered by clean renewable energy sources, where air flows across our DAC system and CO2 and H2O are extracted. High-purity CO2 is fed into a mineralization process where it is durably sequestered for >1,000 years. At the same time, the desorbed H2O is condensed, and potable water is generated which can be provided to water-stressed communities.



Clairity is not limited to ex-situ mineralization pathways, and the CO2 that we remove can be processed to generate high-purity CO2 (>99.5%) to enable a wide range of sequestration pathways, such as geologic injection. We are in conversation with multiple operators of future Class VI wells.

Frontier RFP Priority Innovation Areas Addressed by Clairity

(1) Clairity is integrated with existing industry by performing carbonation of fly ash, which would otherwise be disposed of as a waste material in landfills.

Fly ash is produced as a byproduct of burning coal. In 2022, about 38% of all fly ash produced in the US was disposed of in landfills as a waste product. This represents tens of millions of tons of feedstock material which could otherwise be used to sequester over a megaton of CO2 each year! Clairity's process works with landfilled fly ash, using our carbonation process to sequester CO2 removed from the atmosphere via DAC. This enables waste reclamation paired with durable credit generation.

(2) Clairity's approach provides environmental and economic co-benefits to local communities.

Project Juniper will be Clairity's first commercial DAC facility, and it will be carbon negative and water positive. Our approach to direct air capture is one of the few that will generate water as a co-benefit for local communities. Most DAC processes consume water, which will become an increasing strain on communities as DAC scales to megaton and gigaton levels. Our technology can be deployed in arid regions that experience water scarcity. The ability of our technology to provide water to local communities is a significant environmental and economic co-benefit to build community and policy support. We are already seeing support develop for our project in Southern Nevada through engagements with the Southern Nevada Water Authority.

(3) Project Juniper enables additional revenue sources outside of carbon credits.

Clairity has developed a process that enables the carbonation of raw material feedstock to durably store CO2 for >1,000 years. The output product from this ex-situ mineralization process can be valorized and sold to construction companies for use as a replacement for Portland cement, aggregate, or other monetizable product. We expect there to be a large opportunity for revenue from mineralization to offset nearly the entire price of CO_2 storage.

(4) Clairity's multiple DAC innovations enable increased scalability and reduced cost of carbon removal and durable storage for delivery of verified CDR credits in 2025.

(4.1) Clairity has developed an ex-situ mineralization process that uses feedstock material rich in calcium and magnesium to sequester CO_2. The use of an ex-situ mineralization system means we do not need to liquify or create supercritical CO_2, both of which are extremely energy intensive. Our process is feedstock agnostic and can utilize a variety of inputs such as olivine, brucite, gypsum or fly ash which are available in massive quantities globally.

(4.2) There are no inherent supply chain limitations for the Clairity Process, compared with many other direct air capture sorbent approaches such as amines and MOFs. Our approach to DAC is uniquely scalable and offers significant cost reductions compared with alternatives. We use alkali carbonates coated onto ceramic honeycomb substrates for the process sorbent. Alkali carbonates are produced in massive quantities, millions of metric tons per year. Similarly, ceramic honeycomb substrates are produced in massive quantities. This makes us very competitive with existing players. Our sorbent capacities and energy use are already as low or lower than incumbent sorbents based on publicly available data, allowing faster iteration down the cost curve.

(4.3) Project Juniper is modular, and its adsorption and desorption parameters can be varied independently in response to external variables such as energy cost and clean power availability. For instance, instead of curtailing excess solar power, Project Juniper can tune cycle durations, flow rates, temperatures, and other variables to use excess clean power capacity. We are also in conversation with multiple developers of novel nuclear systems to provide clean, firm nuclear energy and associated waste heat as a firm power source for Project Juniper.

Sources

https://www.ers.usda.gov/data-products/major-land-uses.aspx

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

Current Project and Future Deployments

Project Juniper is the first end-to-end direct air capture and carbon storage project that will co-generate potable water for water-stressed communities, all operated by a single supplier. This will also be the first direct air capture facility in Nevada. With a nameplate capacity of 2,500 tons of CO_2 removal per year and over 1,000 liters of water generation per day, Project Juniper is carbon negative and water positive. Project Juniper will demonstrate the energy efficiency of the Clairity Process and its ability to scale quickly at a low-cost while being powered entirely by renewables.

Project Juniper will be located in Southern Nevada. We are working with NV Energy, the local grid operator, to source clean power for this project. NV Energy has a history of providing clean power to customers and bringing new power online for new demand. We are working with developers of small modular nuclear reactors (SMRs) to integrate electricity and waste heat into our systems.

Project Juniper Phase 1 will be online in 2024, with direct air capture and storage activities able to be

[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.

verified by third parties. Project Juniper Phase 2 will come online in 2025 and involve the buildout and commissioning of additional modules. The success of Project Juniper will be Clairity's first step towards deployment of >100 $MtCO_2$ per year capacity by 2050. The following figure shows a rendering of Clairity's megaton scale deployment, operational by 2030.

Our approach and technology are perfectly suited for arid climates, including geographies in the US, Africa, Asia, Australia, and the Middle East. Combined, these regions of the world have gigaton scale sequestration capacity via subsurface injection and ex-situ mineralization pathways. These regions also have the highest solar irradiance in the world, making them the perfect regions to deploy the >100 TW of new solar + battery storage required for these future projects. These regions have inexpensive land and power, making them the ideal locations for achieving gigaton scale CDR.

Bringing Down Costs

Clairity is laser focused on reducing the levelized cost of CDR while increasing scale.

Our current cost for CDR is $710 / tCO_2. The main drivers of future expected costs are capital expense, driven by sorbent price and process complexity, and operational expense, driven by energy intensity and limited access to clean power. Upkeep and maintenance related to sorbent degradation are also expected to drive levelized cost of DAC.

Clairity's TEA supplement includes a detailed breakdown of our current costs. Clairity is continually finding ways to lower costs and increase revenue, we encourage interested parties, potential collaborators, and investors to reach out for the most current cost breakdowns and revenue projections.

We are actively bringing down the cost of DAC by (1) using sorbent materials that are low-cost; (2) designing processes that can be implemented with low-cost hardware, thereby reducing the capital cost; (3) implementing energy efficient processes; (4) project siting in parts of the country with low costs of energy, land, construction, and other siting costs; and (5) producing co-benefits and additional revenue sources from the project beyond carbon credits.

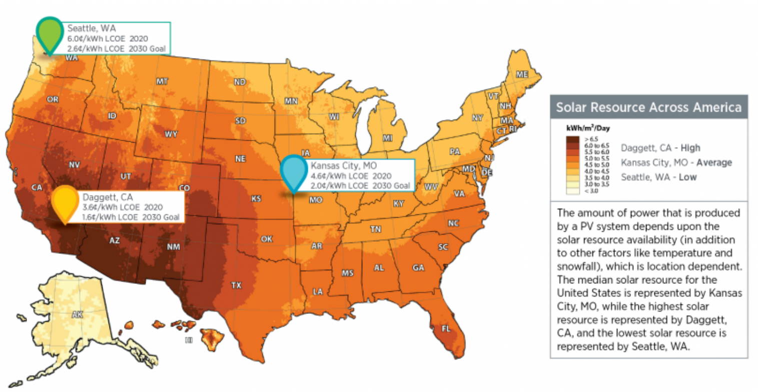
(1) Our process uses alkali carbonate sorbents loaded onto ceramic honeycomb substrates. These materials are all low-cost and produced in high-volume today. Our sorbent is stable with a lifespan of >3 years in our operating conditions.

(2) Our DAC process is simple and does not require a high degree of site customization to achieve project goals. We can incorporate many commercial-off-the-shelf (COTS) components, including HVAC hardware, standard resistive heaters, fans, and other components to operate our process.

Without the need for vacuum chambers, the capital cost and complexity for regeneration chambers are dramatically reduced.

(3) Our DAC approach is energy efficient and fully electric. We expect our first pilot to enable an energy efficiency of better than 2 MWh / tCO2 removed. Desorption is performed at low temperatures, with no vacuum or steam required. Low temperatures enable the use of renewable energy for all phases of the process.

(4) Nevada, Arizona, and California are some of the best locations to deploy new solar in the US, with high solar resource availability. Our technology performs better in arid climates, unlike amine or calcium looping systems that require humidity to efficiently adsorb CO2. This enables us to take advantage of lower energy costs and a rapidly expanding renewables grid. US DOE has set a goal of $20 / MWh of utility-scale PV for the median solar resource in the US by 2030. They expect the cost in high solar resource locations, such as Nevada, to be 20% lower, enabling a price as low as $16 / MWh.



(5) Beyond removing CO2, our project generates potable water from the air. Additionally, we perform ex-situ mineralization and create a material aggregate that can be sold to construction companies. These additional revenue streams can offset the price of future projects.

Actively driving down costs at every stage and maximizing all potential revenue streams will enable a levelized cost of removal of <$100 / tCO2 at scale.

Increasing Scale

We are not subject to the same supply chain constraints as other direct air capture approaches. Clairity uses an alkali carbonate sorbent that is loaded onto a ceramic honeycomb substrate. Both carbonates and ceramics are abundant, low-cost, environmentally friendly, and very stable. Clairity has a partnership with one of the largest ceramics manufacturers in the world to provide the substrates for our systems. Our sorbent manufacturer currently produces enough material to bring online 14 Mt / yr of additional CO2 removal capacity, and they are one of over a dozen bulk manufacturers of this sorbent globally. An alkali carbonate-based DAC approach has the capacity to scale to >0.5 Gt / yr of cumulative CDR capacity by 2050.

Our system relies on a relatively simple process at ambient pressure so we can use existing HVAC technology which is produced at massive scale today. Furthermore, all-electric heating in our regeneration process operates with standard oven technology that has been operating for decades with low cost and high reliability. Not only are these low-risk technologies already inexpensive and reliable, but they are highly scalable in the future.

Project Juniper Co-Benefits

Project Juniper has multiple co-benefits that differentiate this as a unique CDR project, help to increase community adoption, and serve as secondary revenue streams.

Project Juniper will be water positive. Our system works as sorbent desiccant system too, which can perform atmospheric water harvesting (AWH) to enable energy efficient generation of >1,000 liters per day of potable water. Our project will be sited in Southern Nevada, and we are in active conversation with the Southern Nevada Water Authority so water generated by our system can benefit water-stressed communities in the region.

Additionally, Project Juniper will enable industrial alkaline waste reclamation. We are sourcing industrial alkaline waste that is rich in calcium and magnesium to carbonate and durably sequester CO2. Our process works with feedstock that otherwise would have been sent to landfills.

Net-Zero Nevada: From Pledge to Action, published by the Kleinman Center for Energy Policy and members of the Clean Energy Conversions Lab at UPenn, explores the scalable opportunity for carbonated materials in Nevada. Reclaimed carbonated waste can be used as synthetic aggregates, mitigating the total emissions from the mining of aggregates. The supply of alkaline industrial wastes in Nevada represents a vast opportunity for both CO2 storage and utilization for construction projects in the state, enabling significant synergies for the state economy. According to the Net-Zero Nevada report, the annual consumption of construction aggregates in Nevada exceeds 30 Mt as recently as 2017, and the carbonation of alkaline industrial kiln dusts from providers in Nevada would represent less than half a percent of the current market for aggregates in the state, indicating that these carbonated wastes could 'almost certainly be used on existing projects within the state'. This represents a promising near-term opportunity for CO2 storage and utilization using Clairity's approach.

Quantifying CDR

Direct air capture and carbon storage (DACCS) is a highly quantifiable process with relatively low uncertainty compared with other CDR pathways. Our DAC process will generate a low-pressure CO2 fluid that can be sequestered via a range of methods. Project Juniper will incorporate a closed, engineered system where a mineral feedstock is exposed to gaseous CO2 to durably sequester the CO2. A calibrated flowmeter is used to inject CO2 into the reactor, where CO2 sensors monitor for mineralization and leakage from the reactor. Coulometric titration on the starting feedstock and mineralized product will be performed to ensure the sensors yield accurate measurements during the project reporting period. Leakages, uncertainties, and risks of reversal are accounted for in our estimates of carbon removal efficiencies to determine net CDR credits based on gross CDR performed.

There are existing ICROA endorsed standards and methodologies that Clairity will use to quantify the carbon removed and to issue verified credits to buyers. Clairity will be compliant with existing methodologies to ensure adequate monitoring and modeling to provide high-quality credits that have >1,000 years of durability.

References

https://www.energy.gov/eere/solar/solar-energy-technologies-office-updated-2030-goals-utility-scale-photovoltaics

https://kleinmanenergy.upenn.edu/research/publications/net-zero-nevada-from-pledge-to-action/

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

Project Juniper is a first-of-a-kind direct air capture and storage project which will result in expected (and unexpected) challenges. Our team has performed extensive lab scale, bench scale, and small pilot scale testing across a wide range of conditions and environments to mitigate risks associated with this project. The main uncertainties we expect are:

(1) Capacity factor of our system in the field.

(2) Carbon removal efficiency for a mid-sized direct air capture pilot system.

(3) Access to and cost of clean power.

(4) Access to low-cost project financing.

We have performed extensive testing across a range of environmental conditions, varying temperatures, humidities, CO2 concentrations, and more, to quantify the impact of varying conditions on the performance of our sorbent. This data has been validated across a range of scales, from lab to small pilot. Once validated, our team developed an advanced model that incorporates each of these parameters to model the system performance in real-time. Using six years of climate data from the NOAA US Local Climatological Data service, we have been able to calculate what the capacity factor of our system would have been in previous years. However, future environmental conditions may vary from previous years and result in a change in performance from the expected baseline.

Clairity estimates a carbon removal efficiency of 85% is achievable for Project Juniper. We have developed high-fidelity life cycle assessments (LCAs) based on process and design for each aspect of Project Juniper. Sensitivity analyses of these LCAs have been performed per ISO 14044. These LCAs enable us to estimate the net CDR credits that can be issued based on gross CDR performed. For example, we expect that Project Juniper will have a lifespan of 10 years for the purposes of our LCA, however, the actual lifespan of the project may be shorter as our technology advances and matures. Additionally, we expect that the shipping method for material feedstock for mineralization to have a significant impact on carbon removal efficiency. The 2023 UK Government GHG Conversion Factors gives the emissions factor for an average bulk carrier to be 3.53 gCO2e / tonne*km and for an average cargo carrier to be 13.21 gCO2e / tonne*km. Transporting small volumes of materials for a FOAK project may inherently have higher emissions factors than larger, bulk volume transports for future projects.

Access to and cost of clean power will be a challenge for any DAC project. We are actively working with NV Energy, the local grid operator in Southern Nevada, to ensure that Project Juniper will have access to an abundance of low-cost clean power. NV Energy has a history of working with major clients, such as Google and the Las Vegas Raiders, to provide clean power to meet sustainability goals. Clairity expects to engage with grid operators and project developers to bring online new power and use power purchase agreements (PPAs) to drive down the cost of power of the lifespan of future projects. We expect the scale of future projects to drive our ability to negotiate the best pricing for these projects. High availability of clean power also enables us to improve the capacity factor of our system, thus further driving down the cost of CDR credits for buyers.

The cost of capital will have a significant impact on the cost of CDR from Project Juniper. Prepurchases of CDR credits from buyers like Frontier will be catalytic in decreasing the price of credits from this project while accelerating the timeline to deployment. Contracts for CDR offtakes will make Project Juniper bankable, allowing us to bring on low-cost capital, such as debt or equity financing, which will be beneficial for the price of CDR credits from Project Juniper.

These challenges we face are, of course, not unique to Clairity. Climeworks published a blogpost on May 15, 2024, that shared many of their challenges related to deploying DAC technology in the field, highlighting issues similar to those our team has identified related to capacity factor and carbon removal efficiency. We will continue to work hard to overcome obstacles on our mission to accelerate the deployment and reduce the cost of durable carbon dioxide removal.

https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2023

https://climeworks.com/news/the-reality-of-deploying-direct-air-capture-in-the-field

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) *(should be net volume after taking into account the uncertainty discount proposed in 5c)*	700 tons CO2
Delivery window *(at what point should Frontier consider your contract complete? Should match 2f)*	Q1 2026
Levelized cost ($/ton CO_2) *(This is the cost per ton for the project tonnage described above, and should match 6d)*	$710 / ton CO2
Levelized price ($/ton CO_2)[3] *(This is the price per ton of your offer to us for the tonnage described above)*	$710 / ton CO2

[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).