Noble Thermodynamics

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

Noble Thermodynamic Systems, Inc.

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

California, USA

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

Mazin Tabsh

Brief company or organization description <20 words

Noble Thermodynamics is developing a CDR approach to remove CO2 from waste biomass while generating bioenergy with zero air pollution.

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

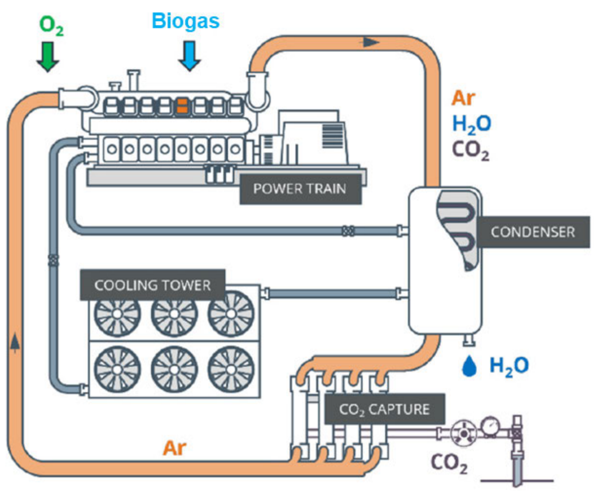
a. **Description of the CDR approach:** Describe how the proposed technology removes CO_2 from the atmosphere, including how the carbon is stored for > 1,000 years. Tell us why your system is best-in-class, and how you're differentiated from any other organization working on a similar approach. If

[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.

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.

Our carbon dioxide removal (CDR) approach centers around the utilization of sustainable waste biomass-derived biogas to generate bioenergy while simultaneously removing 100% of the carbon dioxide and eliminating air pollution, including nitrogen oxides (NOx) and particulate matter. The carbon dioxide is then transported to a partner carbon storage facility for permanent geological sequestration.

At the heart of our CDR approach is the innovative Argon Power Cycle (APC) technology. This advanced bioenergy generation system achieves ultra-high efficiencies while integrating carbon removal and eliminating air pollution. The APC system employs a closed loop thermodynamic cycle where naturally generated biogas is burned with oxygen in an argon-rich environment. The resulting exhaust, consisting of CO2, water, and the argon working fluid, is directed through a condenser to reclaim the water. Through a CO2 capture process, the CO2 is recovered, while the argon is recirculated within the system. The CO2 is then geologically stored, completing the CDR process. The inclusion of argon as the working fluid in the cycle enhances the system's efficiency and prevents the formation of harmful nitrogen oxides.



The APC system offers several notable advantages. Firstly, it has the capability to remove 100% of the carbon dioxide emissions produced from the combustion of biogas through a highly efficient carbon management system. Additionally, the APC exhibits superior performance in terms of fuel to electricity conversion ratio compared to existing leading bioenergy generation technologies. It achieves a remarkable 10 percentage points higher efficiency, resulting in greater energy generation from the same amount of biomass.

Moreover, our technology is suitable to be deployed at distributed sites where biogas is a by-product, at a scale as small as 20 tons per day of biogas generation. This characteristic sets us apart from other solutions as it allows for economic viability and operational efficiency in distributed biogas facilities. Wastewater treatment plants and landfill sites, for instance, can now benefit from bioenergy generation and carbon dioxide removal, which would otherwise be challenging due to their limited scale and lack of economies of scale.

By enabling bioenergy generation and carbon dioxide removal at small-scale distributed facilities, our technology expands the reach and impact of carbon dioxide removal efforts. It provides a viable solution for facilities that may have previously been excluded from participating in carbon removal projects due to their size or location. This decentralized approach enhances the overall effectiveness of carbon dioxide removal strategies and contributes to a more sustainable and resilient energy landscape.

In addition to addressing carbon dioxide emissions on a global scale, we recognize the pressing issue of air pollution, which has localized impacts on nearby communities. The APC sets itself apart from other power generation technologies by producing bioenergy without any air pollutants, making it an environmentally friendly solution. The elimination of nitrogen oxides (NOx) and particulate matter presents a significant co-benefit of our CDR project, immediately improving local air quality.

By developing this integrated system with the APC as its core, our CDR approach enables the conversion of carbon-neutral biogas facilities, such as wastewater treatment plants or landfill sites, into commercially viable carbon dioxide removal projects. These sites not only remove carbon dioxide from the atmosphere but also extract more useful energy from the same volume of biomass while completely eliminating local air pollution.

To maximize the carbon removal potential of our system, surplus energy generated through our CDR approach, beyond the project's needs, can be utilized in various ways to amplify its decarbonization impact. It can contribute to avoiding carbon dioxide emissions by powering Direct Air Capture (DAC) projects or charging electric vehicles with zero-emission energy. The dispatchable bioenergy derived from our CDR approach ensures consistent power supply throughout the day, eliminating the need for energy storage.

By leveraging the capabilities of the APC and its associated benefits, our CDR approach provides a comprehensive and sustainable solution for carbon dioxide removal, bioenergy generation, and air pollution reduction.

To complete our CDR pathway, we plan to collaborate with established and developing carbon storage hubs in North America, focusing initially on the deployment market in this region. These partnerships will allow us to leverage the stringent regulatory and permitting requirements enforced by regulatory agencies such as the Environmental Protection Agency (EPA) in the United States, ensuring the safe and reliable storage of the removed carbon dioxide.

When considering the entire value chain of our CDR approach, which includes natural biogas formation, bioenergy generation, carbon dioxide transport, and carbon dioxide storage, the only segments that generate carbon dioxide emissions are the transport and storage phases. However, we anticipate that the volume of emissions associated with these activities is minimal, relative to the total carbon dioxide removed through our approach. This demonstrates the overall efficiency and effectiveness of our CDR system in minimizing carbon dioxide emissions across the life cycle of the CDR process, with the majority of emissions being removed rather than released into the atmosphere.

By prioritizing secure carbon storage and working in compliance with rigorous regulatory standards, we are dedicated to ensuring the responsible management of removed carbon dioxide. This commitment ensures that our CDR approach not only effectively removes carbon dioxide from the environment but also maintains the highest standards of safety and environmental protection throughout the entire value chain.

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.

Project Objectives:

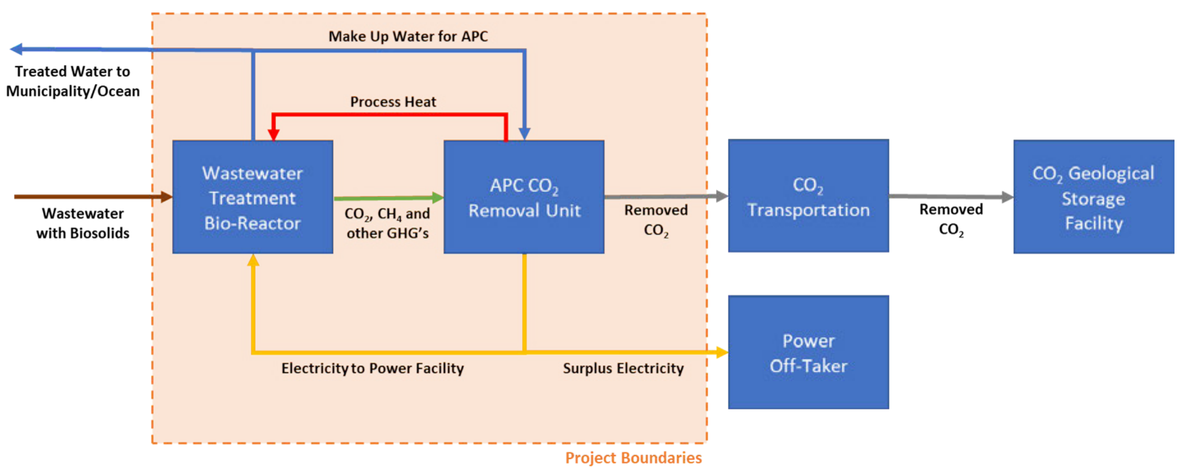
The primary objective of our first-of-a-kind BECSS project is to prove the technical and commercial viability of deploying the Argon Power Cycle (APC) technology at a municipal waste facility, generating bioenergy while removing carbon dioxide from the atmosphere. Simultaneously, we seek to improve the energy generation efficiency and eliminate air pollution at the project site with the deployment of the APC.

To achieve this objective, we aim to break the cycle of carbon dioxide capture and release that occurs during traditional biogas disposal processes. Rather than releasing carbon dioxide into the atmosphere through biogas flaring or combustion with conventional power generation technologies, we intend to transform the existing "carbon neutral" wastewater treatment facility into a "carbon negative" facility. This transformation will be accomplished by utilizing the APC technology, which removes 100% of the carbon dioxide generated in the biomass digestion process. The carbon dioxide will then be transported by truck to a local carbon storage hub to be geologically sequestered. The durability and safety of the carbon storage will be ensured by the carbon storage hub through compliance with the stringent licensing and monitoring requirements established by the Environmental Protection Agency (EPA) for Class VI carbon dioxide injection wells.

In addition to the direct removal of carbon dioxide, our project offers two significant co-benefits. Firstly, the APC technology's ultra-high efficiency allows for the generation of a substantially higher amount of electricity from the same biomass volume compared to alternative combustion solutions. This surplus electricity will be utilized to electrify vehicles and heavy machinery on-site and at nearby industrial facilities. By utilizing this surplus power, we can avoid additional carbon dioxide emissions and contribute to further decarbonization efforts. This aspect of the project enhances its carbon reduction potential.

Secondly, the APC technology eliminates local air pollution, including harmful substances such as nitrogen oxides (NOx) and particulate matter, which is especially crucial for the communities located near facilities that handle biomass. By eliminating air pollution, we address environmental justice concerns that may arise and work towards improving the air quality and overall well-being of the local community.

Below is a preliminary project schematic illustrating the integration of the key component of the proposed CDR project.



Project Location and Scale:

Our team has conducted an initial site selection screening process and has identified a suitable wastewater management facility in the California Bay Area for the deployment of our proposed project. This project will remove over 300 tons of carbon dioxide per day from this facility - carbon dioxide that would otherwise continue to be released into the atmosphere at the facility.

Furthermore, we have identified two suitable carbon storage hubs for the project in the Bay Area. These locations have been chosen due to their proximity to the proposed project site and their potential for carbon storage. Both sites have submitted applications to the EPA for Class VI carbon dioxide injection well licenses and are awaiting approval. Once approved, these sites will serve as the permanent storage locations for the captured carbon dioxide.

In the project configuration at the proposed site, bioenergy that is surplus to the project site needs will be generated through the deployment of the APC system. This surplus electricity, which is carbon-free, will be sold to a nearby industrial site. The electricity will be utilized to power electric vehicles and heavy machinery, contributing to further reductions in air pollution and benefiting the local community.

To ensure the successful implementation of the project, we have set a target to have firm agreements in place with the project site host facility, carbon storage partner(s), and power off-taker(s) by the end of Q4, 2023. These agreements will solidify the partnerships necessary for the project's execution and pave the way for its successful operation.

CDR Quantification:

Our approach to quantifying the carbon dioxide removed is based on comprehensive monitoring and measurement throughout the project, ensuring accuracy and verifiability. We have established two key measurement and verification points within the value chain to track the carbon dioxide that is removed.

The first measurement point occurs at the outlet of the APC system, immediately after biogas combustion. At this point, the carbon dioxide will be accurately measured and accounted for. This measurement will take place prior to loading the carbon dioxide onto trucks for transport to the carbon storage facility.

As the carbon dioxide is transferred from the trucks and injected into the geological formation for long-term storage at the carbon storage facility, a second measurement and verification process takes place. This step is crucial to ensure accurate accounting of the carbon dioxide that is stored (completing the carbon removal process). It also provides confirmation that the carbon dioxide is properly accounted for and there has been no loss of volume in transit. The infrequent likelihood of leakage once the carbon dioxide is injected into the reservoir, as supported by scientific research (Alcalde et al., https://www.nature.com/articles/s41467-018-04423-1), adds to the confidence that the volume of carbon dioxide measured at the carbon dioxide injection site accurately reflects the volume that is permanently stored, and thus confirms the success of the project's carbon removal efforts.

In addition to monitoring the carbon dioxide volumes, the project will implement rigorous data collection and analysis procedures. These procedures will account for the surplus electricity generated by the APC system and its utilization in avoiding additional carbon dioxide emissions. By carefully tracking the electricity utilization and its associated carbon dioxide avoidance, we will provide a comprehensive assessment of the carbon dioxide removal impact through our CDR solution.

Through this approach, which includes comprehensive monitoring, accurate measurement, and rigorous data analysis, we will be able to quantify the carbon dioxide removed from the atmosphere with precision and provide verifiable data on the effectiveness of our CDR solution.

Achieving Frontier's $100/ton and 0.5Gt Targets

Our current techno-economic models indicate that our CDR approach is well-positioned to achieve costs significantly below Frontier's target of $100 per ton of carbon dioxide removed. As we consider transportation economies of scale and manufacturing efficiencies at the NOAK (Nth of a Kind) scale, the cost projections become even more favorable. However, one crucial factor that impacts our trajectory is the development of carbon storage infrastructure.

Since geological storage is an integral part of our CDR approach, the continued expansion of carbon storage infrastructure plays a vital role in maintaining low costs. As more carbon storage facilities are established, the availability and cost of carbon storage are expected to decrease. Additionally, the increased availability of carbon storage facilities will contribute to reducing carbon dioxide transport costs, as transportation distances are likely to decrease with the development of more storage sites.

In terms of scalability, data from the International Energy Agency (IEA) and the International Renewable Energy Agency (IRENA) indicate that the global bioenergy generation potential ranges from 10,000 to 14,000 terawatt-hours (TWh) per year. This corresponds to a carbon dioxide abatement potential of 8 to 12 gigatons (Gt) per year. By capturing just 5% of this global bioenergy market potential through widespread deployment of the APC technology, we can achieve Frontier's target of 0.5 Gt/year of carbon dioxide removal.

These estimates demonstrate the significant potential of our CDR approach in terms of cost-effectiveness and scalability. By leveraging CCS infrastructure development and tapping into the vast bioenergy market, we can achieve substantial carbon dioxide removal while meeting ambitious targets set by organizations like Frontier.

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.

The project execution and ecosystem areas present the biggest risks to the success of our CDR project.

From a project execution perspective, deploying a new technology at a public municipal facility, such as a wastewater management site, adds complexity due to risk tolerance and commercial alignment considerations. These facilities have strict operating regulations and lengthy approval processes, which can impact project costs and schedules. To manage these risks, we will apply a gated project management approach, identifying and addressing risks at each stage of development. Stakeholder engagement and buy-in will also be crucial for successful project execution.

On the technical side, retrofitting an existing facility with new technology poses inherent risks. The project will require specific adaptations to the site conditions and existing infrastructure. Since this project is the first of its kind, much of the facility design engineering will be new. However, unforeseen issues may arise during detailed engineering on the site, potentially leading to increased costs or schedule delays. Conducting a thorough review of the site early on will help identify major issues and allow for timely adjustments to manage associated risks.

In the project ecosystem, two significant risks are apparent: the development of carbon dioxide infrastructure and the offtake of surplus bioenergy generated by the project. An important consideration of our CDR project is the availability of carbon storage facilities located within an economically feasible distance from the project site. While there are several applications for Class VI carbon dioxide injection well licenses currently being processed by the EPA, the number of existing commercial carbon storage facilities is limited. Uncertainty remains regarding which sites will receive license approvals and secure positive internal investment decisions. To mitigate this risk, we are engaging with multiple developers of proposed carbon dioxide storage facilities that align with the project's criteria at an early stage to diversify our options.

Another risk within the project ecosystem relates to the offtake of surplus bioenergy generated by the project. Having established interconnections with the local electricity grid at the project site mitigates this risk significantly. Our preference is to partner with a power off-taker that maximizes the decarbonization benefits of our bioenergy, such as utilizing the surplus power for the electrification of vehicles or heavy equipment, or to power DAC facilities. To address this risk, we will continue actively exploring partnerships with power off-takers. As a secondary risk mitigation option, we may also consider selling the power directly to the local electricity grid.

In terms of measurement, reporting, and verification (MRV), we have little concern. The MRV protocols for carbon storage, which verify the total volume of carbon dioxide removed, are well-defined and monitored through EPA regulations and requirements for obtaining and holding Class VI injection well licenses. This ensures a high standard of MRV for our carbon dioxide storage project partner.

Managing and mitigating these risks will be crucial to the success of our CDR project. Through diligent planning, stakeholder engagement, early risk identification, and diversification of partnerships, we aim to address these challenges and achieve our objectives.

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)*	3,333 MtCO2
Delivery window *(at what point should Frontier consider your contract complete? Should match 2f)*	2026
Levelized Price (\$/ton CO_2)* *(This is the price per ton of your offer to us for the tonnage described above)*	$150/MtCO2

** 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).*