Frontier

Deep Sky - Carbyon

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

Carbyon

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

The Netherlands

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

h.deneve@carbyon.com

Brief company or organization description <20 words

Carbyon is a Dutch company producing DAC machines

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.

The technology of Carbyon targets to lower the Total Cost of Ownership of the air capturing process to $100/ton. This is achieved by drastically increasing the reactor density which lowers the CAPEX cost of the system.

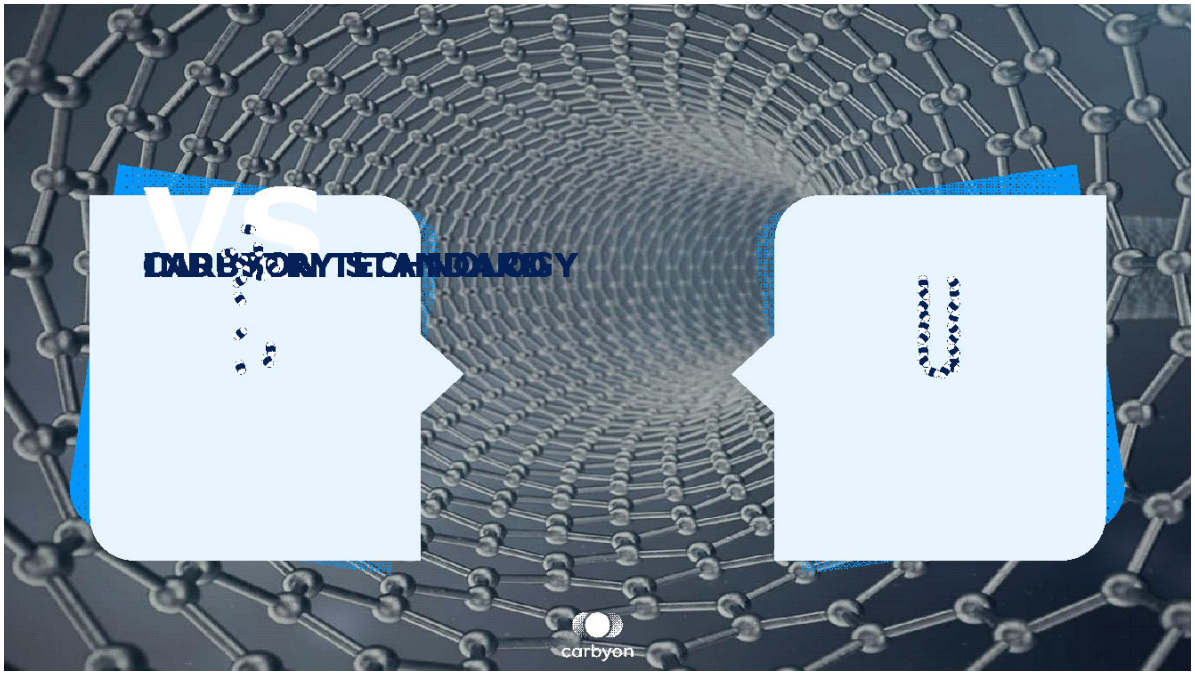
Carbyon has demonstrated reactor densities of 200 ton CO2 per m3 per year which is 10 times higher than with conventional DAC technology. At such high densities the CAPEX cost per ton of CO2 can be as low as $50 per ton.

The high reactor density of the Carbyon technology is achieved using a fast swing process whereby the sorbent material can be re-used every few minutes instead of every few hours. The sorbent material can be saturated to 40g CO_2 per kg of sorbent within just 30 seconds. Subsequently it takes only 10 to 20s to heat the sorbent material and harvest the CO_2. In this way the yield of the sorbent material becomes very high, leading to a high reactor density and therefore a very low CAPEX cost. In particular when used in combination with intermittent renewable energy sources like wind and solar the low CAPEX costs significantly lowers the Total Cost of Ownership compared to conventional DAC technology

The energy consumption of the process is comparable to the energy consumption of existing DAC technologies although the fast swing process does offer future options to lower the energy consumptions to levels below 2500 kWh/ton.

DAC is particularly suited for Carbon Dioxide Removal as it delivers the CO2 as a concentrated gas. This facilitates the long term storage in empty oil and gas fields or other forms of geological storage.

The fast swing nature of the Carbyon sorbent is a result of using single atom layers of K2CO3, coated on the walls of an activated carbon carrier offering 3000 m2 of surface area per gram of pristine material.



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.

Carbyon will build two test system of 100 ton per year each on its own premises in Eindhoven, The Netherlands.

We will quantify the amount of CO2 by measuring the CO2 gas stream that is produced by the DAC machine.

The CO2 will be delivered to the Dutch system for underground storage of CO2 – re-using empty oil and gas fields under the North Sea.

These test systems are the first step in a process that should lead to mass manufacturing of DAC systems from 2031 onwards. With current proven high reactor densities the sales price of a mass-produced 100 ton per year system would be around 40.000 Euro. For a system producing 100 ton per year during 25 years, the CAPEX cost would therefore be 16 Euro per ton of CO2. Taking into account an intermittency factor of 50% for wind this would become 32 Euro per ton of CO2. With the intermittency of solar (25%) this would amount to 64 Euro per ton of CO2

The CAPEX costs of the first test systems are expected to be substantially larger than the costs of the mass manufactured systems.

The other main cost of DAC is the energy consumption. Carbyon has developed an all-electric system. Current energy costs are around 5000 kWh per ton of CO2 and we expect that this energy consumption can be lowered to 2500 kWh per ton by 2025. When operated in regions with abundant wind or solar conditions where the cost of renewable electricity is around 1,5 Eurocent per kWh the cost of the power consumption would then be around 37,5 Euro per ton of CO2.

The costs of underground storage in empty oil and gas fields is estimated at 50 Euro per ton of CO2.

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 DAC technology of Carbyon is TRL-4 and was only demonstrated on a small scale so far. This means there remain significant risks regarding the upscaling of the technology.

The Dutch system for storage of CO2 in empty oil and gas fields is beind build but experience serious delay. Yet it is expected to become operational in 2025.

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)*	360 ton
Delivery window *(at what point should Frontier consider your contract complete? Should match 2f)*	2025-2026
Levelized Price ($/ton CO_2)* *(This is the price per ton of your offer to us for the tonnage described above)*	1000 Euro per ton**

** 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).*

**Actual costs for this project are a lot higher because these two systems of 100 ton each will be the first prototypes that we will test. For obvious reasons we cannot claim the full cost but we consider this submission rather as a support for the ongoing developments

[redacted]

[redacted]

- [redacted]

[redacted]

- [redacted]