Frontier

SPIRITUS

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

Spiritus Technologies, PBC

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

Los Alamos, NM; Bay Area, CA; Wyoming

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

Charles Cadieu

Brief company or organization description <20 words

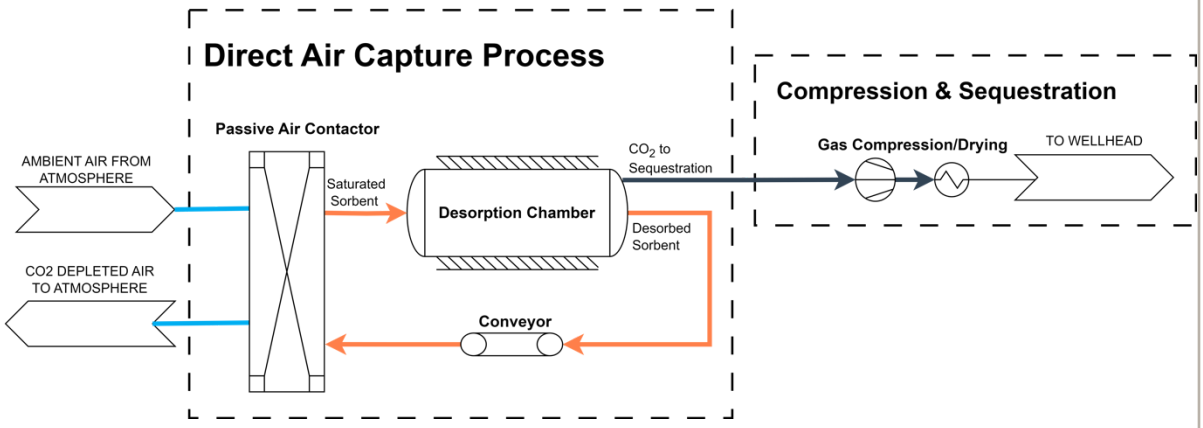
Spiritus is a public benefit corporation with a mission to accelerate the sustainable stewardship of our climate using DAC+S.

1. Public summary of proposed project 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. Aim for 1000-1500 words.

Spiritus has developed a novel direct-air-capture (DAC) solid sorbent material and is developing the accompanying processes for megaton scale CO_2 capture and sequestration. The solid sorbent is exceedingly low in cost yet has fast kinetics for adsorption and desorption. Our DAC process has been tailored to the unique properties and performance of the solid sorbent and is energy efficient, requires minimal capex investment, and can run effectively on a variety of renewable energy sources. The resulting levelized cost of capture (LCOC) is projected to be <$75/t$CO_2$ and is <$150/t$CO_2$ for the first-of-a-kind project.

We refer to Spiritus' DAC approach as a Spiritus "Carbon Orchard", which addresses a priority innovation area for new lower-cost DAC approaches and non-TVSA desorption processes. Every Orchard uses passive air contacting (no fans), a low temperature desorption process, and a modular design that allows rapid scale-up. The solid sorbent, called "Fruit", adsorbs CO_2 from the ambient air through passive contacting and is conveyed to a centralized, fully-contained and novel non-TVSA desorption system. Once desorbed, the Fruit are circulated back to the contactors, referred to as "Trees", for additional passive air contacting, repeating the cycle. The modular design of a "Grove" allows scaling from 2,000 tpy to 2,000,000 tpy, and raw material supply chains for the sorbent are already in existence to reach these scales. The low temperature thermal requirements of our desorption process allow for utilization of renewable energy sources, and future plants can be constructed anywhere there is renewable energy and a sequestration option.



Spiritus' "Carbon Orchard": Sorbent is loaded into a Passive Air Contactor and conveyed to a Desorption Chamber. Desorbed CO_2 is piped for compression and geological sequestration. Desorbed sorbent is returned to Passive Air Contractors using Conveyors to repeat the cycle.

Our flagship DAC facility, called "Orchard 1", is located in Wyoming, USA and will be scaled to 2 MtpyCO_2 of DAC+S (sequestration) to provide long term carbon storage. The CO_2 will be stored in a deep saline aquifer with stratigraphic trapping as the primary early-term trapping mechanism, followed by residual and solution trapping as formation brine re-invades the CO_2-occupied pore space, and eventual precipitation. The low end of durability for this process is 1000s of years and the upper bound is undefined. For Orchard 1, the land lease is in place, the geo-formation/pore-space

has been identified, key financial stakeholders are engaged, and the first carbon removal is being offered for delivery in 2026.

Achieving DAC at <$75/t$CO_2$ LCOC requires a Rubik's Cube solution: all key parameters need to be optimized concurrently. Our sorbent and process optimize all major drivers of cost: energy input, sorbent cost and durability, adsorption/desorption kinetics, and facility capex. In summary, there are two primary innovations that drive Spiritus' low-cost DAC approach: a novel sorbent technology and a non-TVSA desorption process. We complement this innovation with a CDR solution that delivers high-quality CDR to the market: MRV, attractive LCA, a viable risk-mitigated project, community engagement, environmental justice, quick time to market, and a scalable approach to achieve $GtCO_2$/yr removal.

Spiritus is led by co-founders Charles Cadieu, PhD (repeat deep tech founder with multiple exits in diverse industries) and Matt Lee, PhD (bio-inspired materials expert with successes across national security and energy, with 10+ years at Los Alamos National Lab) and complemented by a founding team, expert partners, and service providers spanning engineering, procurement, and construction, MRV, community engagement, audit, environmental law, corporate law, and project financing.

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.

We are offering carbon removal of tons for purchase from the first phase of Orchard 1 in Wyoming. The first phase will be a >2,000 tpy facility with co-located geological sequestration, online in 2026. For this project, the land lease is in place, the geo-formation/pore-space has been identified, key financial stakeholders are engaged, and the monitoring well is scheduled to be drilled. As the first phase of the project is de-risked and demonstrates capability, we will scale Orchard 1 to a capacity of 2 Mtpy to meet off-take agreements from the voluntary market.

Current cost projections from the first phase of Orchard 1 place the LCOC at $149/t (excluding sequestration costs). The LCOC is approximately 2/3 opex and 1/3 capex.

To achieve the $100/t target marginal improvements on our sorbent and process are required and economies of scale need to be recognized to achieve reductions in the cost of sequestration. In the second phase of Orchard 1 we expect to reach an LCOC of <$100/t and sequestration costs ~$25/t at a scale of ~500,000 tpy. In the final phase of Orchard 1 LCOC is expected to be <$75/t and sequestration costs <$20/t, thus achieving the $100/t goal.

To achieve the 0.5Gt/y target, we need to build additional Orchards with the modular approach, scale sorbent manufacturing, and develop multiple geological sequestration projects. The modular design of the Orchard allows rapid reproduction of the process. The sorbent manufacturing approach is scalable using inputs currently produced on global scale sufficient to achieve the 0.5Gt/y target. Further development of sequestration sites will enable sufficient pore space for 0.5Gt/y sequestration rate.

DAC+S is considered a high-quality form of CDR because of the ease of verification of the quantity of carbon removed. We go beyond this base capability of the approach to provide real-time monitoring and verification of capture and sequestration using sensors, algorithms and compute to enable provable CDR, in contrast to more conventional approaches that estimate removals. This provides increased transparency and assurance to our CDR customers that their resources are achieving their

goals.

In summary, the goals for the first phase of Orchard 1 are to demonstrate end-to-end DAC+S using our novel process and profitable DAC+S given voluntary market purchases. Achieving this goal will enable financial resources to support scale-up of Orchard 1 and other projects and enable us to attract investment of Orchard project development, sorbent manufacturing capability, and sequestration site development. If successful, this project would demonstrate a clear path to achieving Frontier's goals of $100/t and 0.5Gt targets.

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.

As in any novel technology and scale up over orders of magnitude, there are key risks. These risks include:

- **Process scale-up.** Scale-up and real-world performance of the DAC process are the greatest areas of uncertainty. *Mitigation: realistic timelines for technology maturation up the TRL ladder with increasing scale of demonstrations / pilots before full deployment.*
- **Sorbent performance.** Multi-year sorbent durability under adsorption/desorption conditions. *Mitigation: accelerated aging studies are ongoing plus real-world testing.*
- **Sorbent manufacturing scale-up.** We need to validate our manufacturing solution at the scales necessary to achieve megaton DAC capability. *Mitigation: corresponding scale-up of sorbent manufacturing capability with associated MRL maturation.*
- **Geological sequestration.** Risks include saline aquifer composition, plume migration, induced seismicity and timeline risk on permitting. *Mitigation: validate saline aquifer composition, extensive modeling of plume migration and risk of induced seismicity to meet permitting requirements. Appropriate timelines from well permitting have been included in our delivery timeline. Furthermore, we have identified a second project site that could serve as a backup or additional CDR opportunity.*
- **Renewable energy access.** In the short-term, we may need to use non-renewable power sources while getting access to adequate supply of renewable power sources, which would increase the carbon intensity of the process in the short-term. *Mitigation: seek PPA agreements and develop on-site renewable capability.*
- **Access to capital.** As we scale, project financing is an area of uncertainty. *Mitigation: secure long-term off-take agreements to reduce financial risk to stakeholders.*

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)*	714 tons
Delivery window *(at what point should Frontier consider your contract complete? Should match 2f)*	2026-2027

Levelized Price ($/ton CO_2)* *(This is the price per ton of your offer to us for the tonnage described above)*	$700/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).*