Frontier

Vaulted
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

Vaulted

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

Houston, Texas, USA

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

Julia Reichelstein

Brief company or organization description <20 words

Deep-well geologic slurry sequestration of organic waste for 10,000+ permanent carbon removal at scale

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. Aim for 1000-1500 words.

[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.

Vaulted geologically sequesters carbon-filled organic waste at scale. Our patented slurry sequestration technology allows us to geologically inject minimally processed organic wastes for permanent (10,000+ year) carbon removal.

Our approach is designed to be the lowest-cost, gigaton scale, permanent carbon removal. We sequester sludgy organic wastes (biosolids, manure, agricultural, food waste, paper sludge, etc) that today are sent to a landfill, dumped into an ocean/river, land applied, or otherwise left to decompose, releasing GHGs into the atmosphere. Vaulted's technical advantage is our suite of patented geologic slurry sequestration technologies. These technologies leverage geomechanics science to sequester solid-heavy slurries deep underground by dilating fissures in the rock such that solid particles can be emplaced between the rock facies, resulting in the permanent storage of carbon-bearing solids underground. This technology lets us sequester organic waste with minimal processing (and without plugging our wells). We inject 3,000+ feet under the earth's surface, where the organic waste is permanently trapped under a layer of impermeable rock - the same formations that have kept hydrocarbons underground for millions of years.

Our approach unlocks low-cost and scalable permanent CDR through efficiencies at each stage of the carbon removal process: capture, aggregate, process, and sequestration.

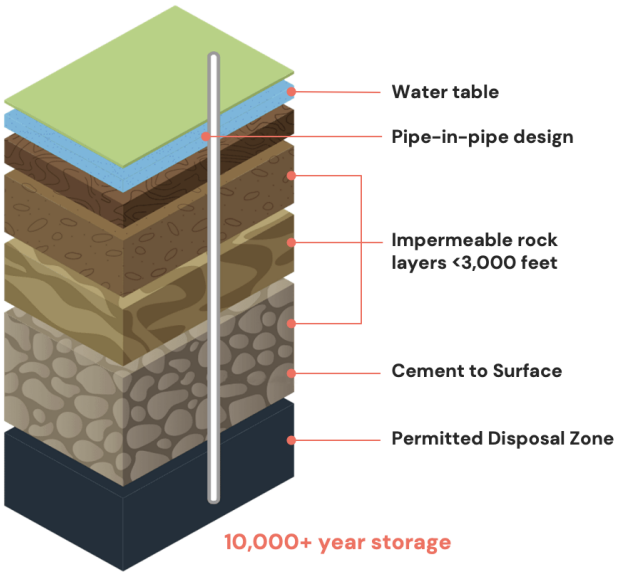
Capture: At the highest level, plants capture the carbon efficiently (and free to us) upstream through photosynthesis. The organic matter is then useful in the economy in some way (a human or animal eats it, it's processed for industry, etc), and eventually ends up as an organic waste.

Aggregate: We leverage the massive legacy investments made to capture and aggregate carbon: sewage systems, manure troughs, industrial biomass processing systems and our broader waste disposal systems that currently aggregate gigatons of organic waste every year. Our partnership model unlocks cheap carbon at scale: we will partner with waste water treatment plants, feedlots, CPG companies, paper mills, and landfills, taking the aggregated organic waste directly from them. Ideally we will co-locate wells at our partners' facilities to avoid transportation costs and emissions. Being a waste, we take ownership of the embedded carbon at low costs. Depending on the waste, we might get paid a tipping fee to take the waste, take it for free, or pay a small fee to take the waste. We won't compete for more in-demand dry fibrous wastes (forest residues, corn stover, etc) that are easier to combust but have increasing demand from our BECCs and BiCRS peers. This is helpful in reducing the overall long term costs of our feedstocks, while also increasing the total net feedstocks available for CDR. We will not have a tipping fee with tonnage for this RFP.

We take only waste biomass. Because our wastes are generally already aggregated, they have historically contributed to environmental pollution due to overapplication in local environments. We see this with nutrient runoff and pathogen build-up from over-application of biosolids and manure especially. By analyzing the specific composition of the waste at its aggregated location, we assess how much of the waste could be safely and sustainably absorbed by the surrounding environment. We then only take a % of waste that's above the sustainable application rate. This ensures that Vaulted does not contribute to undo nutrient depletion, nor induce leakage (e.g. sales of fossil fuel based fertilizer will not increase due to our activities). Building out these biomass sourcing assessment tools is a key piece of our ongoing sourcing and MRV work at Vaulted.

Process: Our slurry injection technology unlocks our ability to minimally process wastes. We do little - utilizing off-the-shelf equipment such as grinders, strainers, and mixers. We don't do complex, costly combustion processing, nor do we pyrolize or perform hydrothermal liquefaction. This makes our solution highly efficient, and, on average across wastes, are 90%+ negative.

Sequester: Our advantage is in our patented geologic slurry injection technologies, which allow us to identify, develop, and optimize subsurface resources for the sequestration of organic solids in minimally-processed slurries. We do this by injecting in such a way as to dilate fissures in the injection strata wide enough to admit solid particles carried by the slurry. At the end of the injection cycle, these solids are permanently vaulted by the closing of fissure walls. Our techniques derive from mature techniques first deployed commercially in the oilfield space over the past 30+ years. We own our own wells, with expertise in deep well operations that allows us to maximize our geologic capacity of each well. Our technologies and know-how cover all the critical domains for delivering successful sequestration - from site selection, feasibility studies, facility design, injection operations, to ongoing monitoring. For example, we hold patents on the use of real time data for slurry injection performance optimization, on novel techniques to project total safe storage capacity using injection data, as well as on using pressure data to characterize the extent of the subsurface waste storage domain. We have developed field



proven proprietary software which we use both for determining the feasibility of slurry injection in a particular location as well as analyzing injection data to ensure containment and to optimize disposal capacity.

The efficiencies delivered through our techniques across each stage of the process unlock a dramatically lower cost point. The core slurry injection technology also unlocks a flexibility to use a number of different (lower demand) organic waste sources, particularly sludgy and or contaminated wastes, which inturn unlocks the ability to achieve gigaton scale.

Vaulted address' Frontier's RFP for novel BiCRs approaches that maximize CDR efficiency while maximizing co-benefits. Our novel slurry injection technology allows a significantly lower processing cost and higher throughput for organic waste sequestration, unlocking a meaningful jump in overall removal efficiency compared to other BiCRs solutions. Beyond CDR, our approach has important environmental and human co-benefits. By taking organic waste that otherwise would have decomposed, we avoid significant methane emissions (which we don't credit for). We found each ton of waste we sequester avoids, on average, 5.8 tons of CO2e (using a 20 year GWP).

Beyond methane, our approach has significant local human and ecological co-benefits. The sludgy, aggregated, wastes we can take disproportionately harm the local communities where they are disposed of today. Absent Vaulted, the wastes disposed of threaten their nearby communities and environment through water, air, and soil contamination. This is from the local overapplication of the wastes to local land, as well as the pathogenic nature of the wastes we take. The Inspector General issued a report in 2018 finding 61+ known pathogens in biosolids, and stating land application had significant risk to human harm. From an environmental risk perspective, data collected for the EPA's 2000 National Water Quality Inventory identify agriculture (and primarily its wastes) as the leading contributor to water quality impairments in rivers and lakes and the fifth leading contributor to impairments in the nation's estuaries. Moreover, where we dispose of these wastes today is unjust. Decades of research out of the University of Michigan has shown that a high percentage of waste disposal sites are disproportionately located near low income communities and people of color in the United States (and similarly located globally). Thus, Vaulted's solution has an important role to play in helping to redress the historical environmental injustice in the US and globally.

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.

Vaulted is in the early days of building a geologic carbon sequestration platform that will permanently remove a megaton of carbon by 2028. We build, own, and operate deep well slurry injection wells near organic waste sources. We look for three things to come together for a site: 1) significant volumes (100,000+ tons annually) of organic waste (biosolids, manure, food & ag waste, etc), 2) a regulatory pathway for Class V well permitting, and 3) supportive geology for our slurry wells. Operating at scale we expect each well to be able to deliver 40,000-60,000+ tons of CDR annually, depending on waste type.

Vaulted is spinning off from Advantek Waste Management Services (Advantek), whose founders pioneered the use of deep well injection for solids wastes in the oil and gas industry. Their proprietary slurry injection technology has been proven over 20+ years to safely inject solids laden slurries, and has a perfect use case in permanent carbon removal. Between us, we have two built, permitted, and operational Class V wells. Advantek has been conducting a full scale pilot with the first of many waste partners, the city of Los Angeles. Situated in the Port of Los Angeles on Terminal Island, co-located with the wastewater treatment facility, Advantek's TIRE facility sequesters ~20% of the City of LA's post-anaerobic digestion biosolids. The site has a total capacity of 8.5M tons of waste. This pilot has proven the technological efficacy of the system operating at commercial scale with organic waste, while confirming that the platform needs carbon monetization to scale. The federal EPA issued the facility a "comfort" letter in 2018, confirming the technology is safe (does not leak, does not contaminate groundwater, does not not induce seismicity, etc). TIRE is our proofpoint facility for the technology working safely at scale, and we are not selling tonnage from TIRE at this time as we work on getting the facility certified with Puro and fully address additionality metrics, given the existing operations.

Our second well is our Great Plains facility in Hutchinson, Kansas. The facility hosts a network of 60 salt caverns, with a total capacity of 3.5M tons of waste across them. This well received its Class V permit for organic waste in 2022, and we are using it as our dedicated carbon removal well for our broad range of organic wastes. We are in the process of getting certified with Puro.Earth, after which we'll scale up operations at both existing well sites and prioritize getting new wells online. We are selling tonnage from only our Great Plains facility in this RFP, with waste coming from a mix of manure (45%), paper sludge (25%), and agricultural wastes (30%).

From a cost perspective, our approach is economical across each of the CDR steps (free capture, already aggregated by partners, minimal processing, at-cost high-efficiency sequestration). Today, we operate at <$300 per ton of CDR. We expect this to come down to <$100/ton by 2026, primarily

through achieving high utilization at each of our wells and co-locating new wells with waste sources (lowering capex and eliminating costs for transportation, as well as options for land and waste).

From a scalability perspective, there is no shortage of sludgy organic wastes. We conducted our own market analysis of global production of our key wastes, and estimated there are globally ~8.1 gigatons of waste produced annually across biosolids, manure, food waste, and paper sludge alone. If Vaulted took all that waste for CDR, we could deliver 2.4 gigatons tons of CDR annually. An independent academic paper from Professor Brian Snyder examined the CDR potential of all organic wastes globally. He "conduct[ed] a geospatial feasibility analysis of the continental U.S. and conclude[d] that adequate biomass, geological storage and wastewater is available to sequester 80 Mt CO2e yr−1. Estimates of potential biomass availability conclude that a mature industry might sequester on the order of 5 Gt CO2e yr−1, over 10% of contemporary CO2 emissions."

Vaulted's approach is inherently measurable - a closed loop system relying on direct sampling of waste, and real-time tracking of carbon. To quantify CDR, we first lab sample the organic waste to assess carbon content. We then subtract out all emissions associated with our removal activities. These include directly measuring emissions (generally fuel and electricity usage) from the aggregation, transportation, processing, and injection of the waste. We ensure we take only wastes (volume above the local sustainable application rate) to avoid leakage.

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.

1) Realized overall CDR market growth. We have a carbon removal technology that has the ability to scale rapidly. The market today for high quality, permanent, carbon removal is growing, but still nascent. Vaulted needs to be able to sell large (hundred thousand+ tons) of CDR offtake over the next few years. This is a massive scale-up of demand (a real market formation) that all suppliers collectively face the risk of not materializing. We face this risk in a somewhat unique way due to our commercial-scale operational plants ready for near-term scale. To meet our near term growth capacity, corporate buyers willing to pay >$100/ton must substantially increase on a tonnage basis.

2) R&D for handling new waste streams. We have demonstrated the efficacy of the technology at scale with biosolids in our LA well. Our Great Plains Facility will focus on new waste streams (manure, ag waste, paper sludge, etc), and with that will come R&D needs for proper processing and pre-treatment of those wastes. This will include methods to properly handle pathogens of the wastes, as well as managing more complex fiber structures to ensure we don't plug our wells.

3) Permitting risk - Our biggest bottleneck to growth is tied to permitting - how fast we can acquire permits for new well sites. Permitting timelines and risks vary across geographies - from country to country, and from state to state within the US. Acquiring a Class V permit could take months, up to a few years. We work with regulators and public officials to set standards for slurry injection well permits that provide assurance around safe operations (minimizing any risks for loss of containment, reversals, ground water impacts, or others) to try to speed up permitting timelines. In general, regulators have guided us to expect to permit under the Class V experimental classification until they would have enough instances to justify creating a standalone well class for this type of activity.

4) Nutrient removal - We geologically sequester a wide range of organic wastes that bear carbon, pathogens, as well as a broad array of other nutrients and minerals. This removal is both a positive for carbon and pathogens, but could pose a risk of nutrient depletion at scale. A key piece of Vaulted's work is to build out our waste assessment tool that will assess the boundaries of the waste we can take. This will include lab analysis of the waste itself for critical nutrients (NPK and others) combined with data inputs on availability of the local environment to absorb waste (acreage of cropland in surrounding area, type of crops grown, etc) to assess how much of the waste produced could be safely and sustainably absorbed. Vaulted will take volume from our waste partners only in excess of what the surrounding environment could absorb - ensuring what we are taking is truly waste, and is not causing nutrient depletion or fossil emission leakage outside of our system boundaries.

5) Methane risk - In theory, the geologic sequestration of organic waste presents some probability of methanogenesis in the subsurface pore space, but we do not believe there is a high likelihood of methane leakage. Firstly, we do not think subsurface methane formation is likely. We have seen that decomposition CO2 dissolves into formation brine in reservoir conditions, while methane is immobilized within the pore space if generated. This methane cannot migrate until there is sufficient aggregated methane to overcome the residual gas saturation (a criteria not achieved at TIRE based on our monitoring and confirmed by reservoir modeling). From Advantek's TIRE facility, de minimis amounts (<25 kg) of methane have been recovered after nearly 15 years of operation. Even if sufficient methane were generated downhole to overcome the trapping effect of the pore space, the methane is trapped by the same geologic formations that cause the containment of the injected waste within the formation - hundreds of feet of impermeable rock. We constantly monitor for methane presence at the wellhead and through our monitoring wells. Vaulted is also undertaking R&D around how to ensure methane generation can be arrested at scale (should that be necessary).

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)*	1,666.66
Delivery window *(at what point should Frontier consider your contract complete? Should match 2f)*	By end of 2023

Levelized Price ($/ton CO_2)* *(This is the price per ton of your offer to us for the tonnage described above)*	$300

** 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).*