Frontier

Mantel Capture, Inc.

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

Mantel Capture, Inc.

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

Cambridge, MA

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

Danielle Colson

Brief company or organization description <20 words

Mantel is developing the first liquid phase materials that capture CO2 at high temperatures.

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.

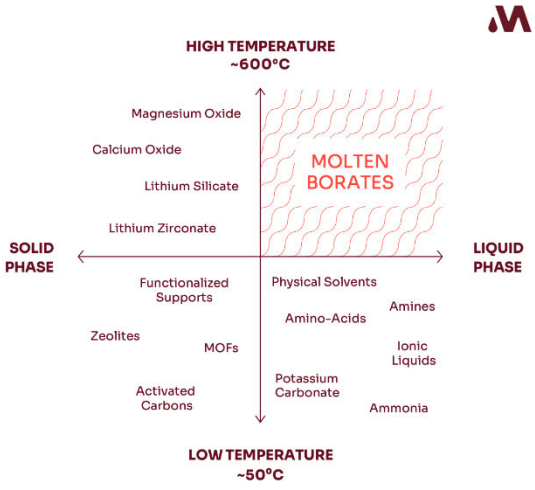
Mantel is developing the first molten-salt based carbon capture technology, a BiCRS (Biomass with Carbon Removal and Storage) solution that removes and abates CO2 emissions from industrial processes. Our molten borates are designed to operate at the high temperatures found inside boilers, kilns, and furnaces – enabling highly efficient carbon capture that has not been possible until now. Our technology can be applied across industry to reduce emissions and achieve net-negative emissions when paired with biogenic fuels. By solving for efficiency Mantel can reduce energy losses by more than 60%, and costs by half, unlocking carbon capture's role in reaching global net-zero emissions.

Most existing carbon capture systems operate at low temperatures. These materials and processes are limited by the efficiency penalty associated with low temperature operations. Our molten borates enable new process designs that locate the absorber and desorber inside a boiler, increasing thermal efficiency, and reducing the cost of carbon capture and storage by more than half. Additionally, Mantel's technology operates in the liquid phase, avoiding any challenges related to performance degradation.

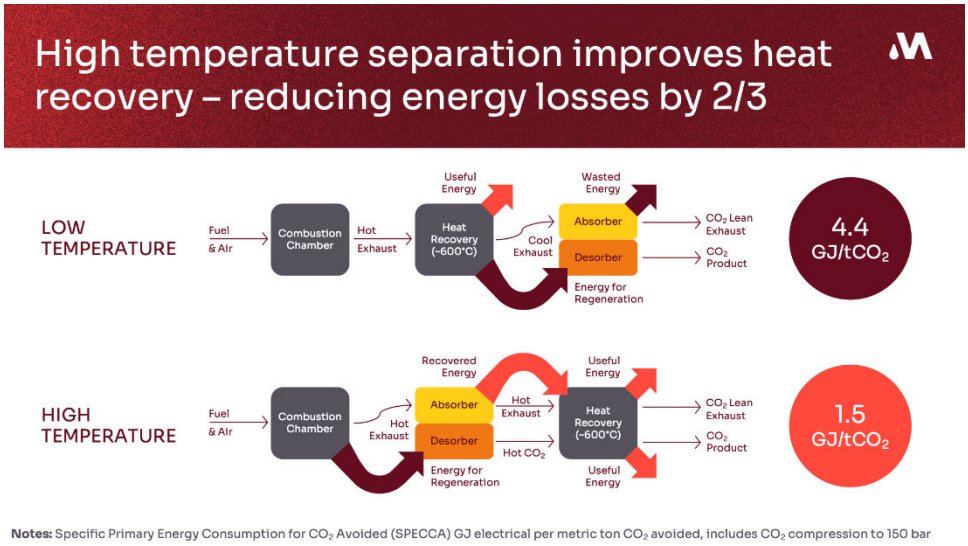
Mantel is using its patented molten borate technology to develop a retrofit system which captures CO2 from combustion of biogenic materials. The process burns a biogenic fuel and produces process heat and pure CO2. In this project, Mantel technology is being paired with municipal solid waste combustion. The fuel is 57% biogenic; the balance is anthropogenic. Without Mantel's project, the site would continue to release this carbon into the atmosphere.

Mantel has developed the first carbon capture material that operates at both high temperatures and the liquid phase.

We have developed and patented the first high temperature liquid phase carbon capture material

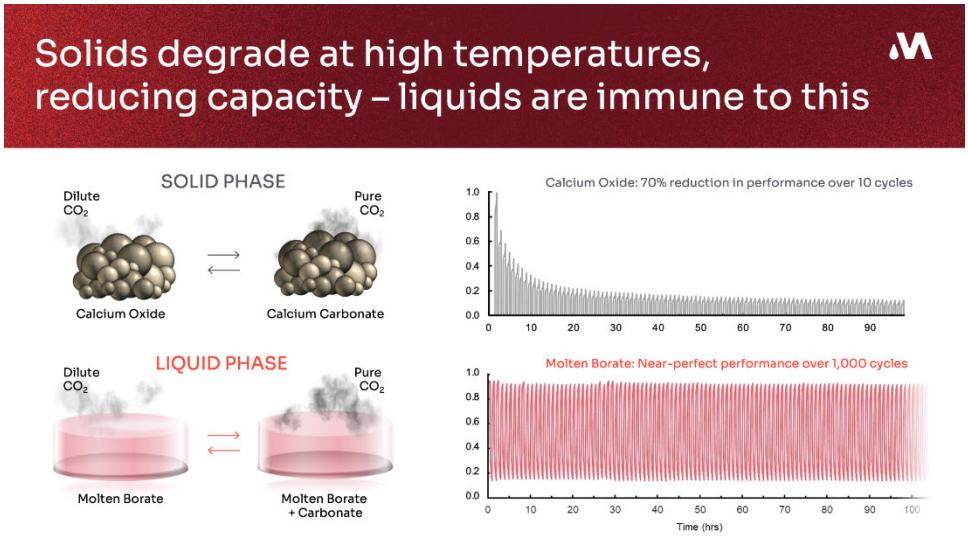


Most existing carbon capture systems operate at low temperatures, often at the back-end of the process. These materials and processes are limited by the efficiency penalty associated with these low temperature conditions. Mantel's molten borate technology enables new process designs that recover high-grade heat generated during absorption, thereby increasing thermal efficiency and lowering costs.



Notes: Specific Primary Energy Consumption for CO_2 Avoided (SPECCA) GJ electrical per metric ton CO_2 avoided, includes CO_2 compression to 150 bar

The concept of high-temperature carbon capture has been explored in the past but despite the efficiency advantages of operating at high temperatures numerous challenges have prevented deployment. These challenges are a result of using solid phase sorbents, in particular solid particles sinter at these conditions, rapidly losing their performance. Mantel's molten borates operate in the liquid phase, avoiding degradation challenges and demonstrating near-perfect cyclic performance for over 1,000 hours as shown in the chart below.



By combining the advantages of high-temperature operation and liquid phase chemistry Mantel is able to reduce the cost of carbon capture by 50% or more compared to the state-of-the-art amine technology.

The market: The emerging market for carbon removal has a wide variety of approaches. Example categories include but are not limited to Direct Air Capture (DAC), Direct Ocean Capture (DOC), Enhanced Weathering, Ocean Fertilization, Afforestation, Reforestation, Biochar, Biomass Pyrolysis/Gasification, in addition to Bioenergy with Carbon Capture and Storage (BECCS). Where BECCS is one of multiple promising approaches to Biomass Carbon Removal and Storage (BiRCS). Each approach has advantages and disadvantages associated with cost, scale, durability, and accountability. The market for carbon removal is expected to be large enough to support a range of

approaches, with the competitive advantage of each highly dependent on geographic location, policy support, and speed at which learning effects can reduce costs.

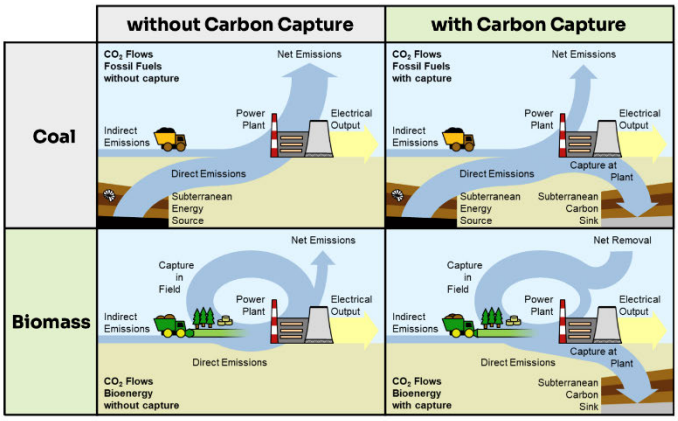
Carbon removal technologies have trade-offs between cost, scale, durability, accountability

Carbon Removal Technology	Direct Air Capture (DAC)	Bioenergy with Capture & Storage (BECCS)	Enhanced Weathering	Biochar & Soil Sequestration (SCS)	Ocean Fertilization	Afforestation & Reforestation
Cost	$200-$1,000/tCO$_2$	$100-$250/tCO$_2$	$50-$250/tCO$_2$	$0-$200/tCO$_2$	$20-$200/tCO$_2$	$0-$50/tCO$_2$
Scale	>20 GtCO$_2$/yr	2-20 GtCO$_2$/yr	1-10 GtCO$_2$/yr	2-5 GtCO$_2$/yr	0.01-1 GtCO$_2$/yr	0.5-3.5 GtCO$_2$/yr
Durability	>1,000 years	>1,000 years	>1,000 years	20-300 years	10-100 years	10-100 years
Accountability	Simple & Direct	Complex & Direct	Complex & Indirect	V. complex & Indirect	V. complex & Removed	Complex & Indirect

Notes: Values are illustrative of ranges observed in the literature; e.g., IPCC SR15 Ch4, 2017

The burgeoning demand for carbon removal and the lack of cost-effective solutions makes Biomass Carbon Removal and Storage (BiRCS) a very attractive opportunity. Through the application of our carbon capture technology and biogenic emissions we have the ability to transform two industries, a new low-cost carbon capture technology, and flexible baseload electricity with negative emissions. Individually neither bioenergy nor carbon capture and storage have been especially successful clean energy solutions. Bioenergy is not always as clean as advertised and carbon capture on natural gas and coal has struggled to compete with zero marginal cost renewables like solar and wind. By combining bioenergy with our solution for carbon capture we address these shortcomings. A BECCS power plant consumes a biomass waste and residue as a feedstock and produces clean base-load electricity, CO2 for storage, and carbon removal credits.

Biomass with carbon capture is net-negative



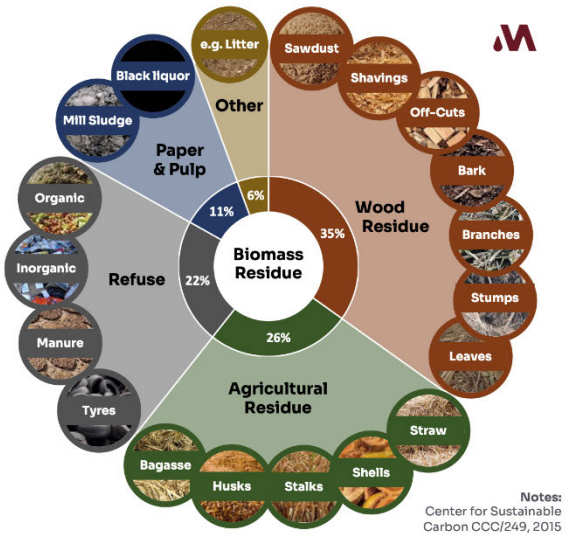
Few real-word efforts have been made to build commercial BECCS plants, partially due to the prohibitively high cost of existing carbon capture technologies. Of the existing and proposed projects most companies are considering amines - a technology that has been around since the early 1900's - or oxy-combustion-- both relatively expensive solutions and challenging for non-homogenous fuel

types. Our molten borates lower costs and make carbon capture viable. Care must be taken to ensure that the facility reliably sequesters CO2 emissions and minimizes unnecessary environmental impacts, but viable carbon capture means bioenergy can produce cost-effective negative CO2 emissions.

A core, and valid, criticism of BECCS are the issues associated with land-use change and sustainable farming practices. Carbon accounting and additionality concerns for BECCS quickly become challenging for the same reason that many natural climate solutions are challenging. While these issues can be addressed through best-in-class practices a solution is found in the use of waste streams. By leveraging biogenic wastes, the main challenge becomes cost competitiveness.

In this project, Mantel is using its patented molten borate technology to develop a new scrubber for waste-to-energy plants and a path to scalable carbon removal. The process burns a mixture of anthropogenic and biogenic fuel, producing electricity and pure CO2 for transport and sequestration. In this application, Mantel technology is being paired with Ecomaine's site in Portland, Maine where 57% of emissions are biogenic (2022). The output of the Mantel process is pure CO2 compressed to 150 bar for transportation to utilization or sequestration sites. Mantel will partner with offtakers to transport the CO2 but the lowest emission and lowest cost method (pipeline, rail, truck or ship) to be sequestered underground.

Biomass residue is a diverse resource – local nature of supply chains requires analysis on a case-by-case basis



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.

In this project, Mantel is using its technology to develop a new scrubber for waste-to-energy plants and a path to scalable carbon removal. The process burns a mixture of anthropogenic and biogenic fuel derived from municipal solid waste (MSW), producing electricity and pure CO2 for transport and sequestration. In this application, Mantel technology is being paired with Ecomaine's site in Portland, Maine where 57% of emissions are biogenic (2022 reported data). The input to this process is locally sourced municipal solid waste (MSW), a waste stream that the facility is paid to accept from local communities. The output of the Mantel process is pure compressed CO2. Mantel will partner with

offtakers to transport the CO2 by the lowest emission and lowest cost method (pipeline, rail, truck or ship) to be sequestered underground.

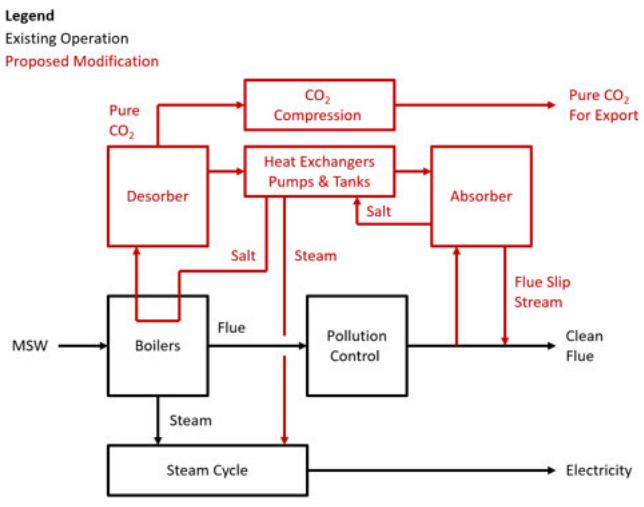
The partner: Ecomaine, originally named Regional Waste Systems, is a non-profit founded in 1976 by the municipalities of Cape Elizabeth, Portland, Scarborough and South Portland in response to a new Maine law that called for the closing of privately owned landfills. The waste-to-energy plant was built in 1988 and provided two major benefits: 1) use of municipal waste as fuel to generate and sell electricity for the financial health of the organization, and 2) reduction in the volume of trash by 90 percent to greatly extend the life of the landfill. Currently, Ecomaine has grown to include more than 65 communities under contract for services.

The Ecomaine site consumes 175,000 tons per year of MSW and exports 14 MWe. The current site has two boilers with limited footprint available for additional equipment. The site is under pressure to reduce NOx emissions in addition to CO2. Annual CO2 emissions for the site are 109,000 tons (47k anthropogenic / 62k biogenic), corresponding to 300 tons per day of CO2 emissions.

The facility exists as a service to the community to process household and commercial waste as well as community dumping site. The state and its surrounding areas are space-constrained in landfill space. The facility serves the community by processing trash and producing electricity as a by-product.

The demonstration: The initial demonstration of the technology will retrofit a portion of their existing boiler and capture 15 tons of CO2 per day - abating 6.4 tons of emissions (anthropogenic) and removing 8.6 tons (biogenic) - before accounting for indirect emissions. After accounting for the total lifecycle emissions, net CO2 removals are 6.4 tons per day.

In the proposed project, a slipstream of approximately 5% of the site's flue gas is diverted into Mantel's capture system, while the rest of the flue continues out the stack as usual. While Mantel will capture all CO2 emitted, only the biogenic CO2, which represents CO2 removal rather than abatement, will be delivered as carbon removal credits to the buyer. After the successful completion of the demonstration project, the intention is to build a full-scale carbon capture system for the site leveraging Mantel's technology. This will allow the site to continue processing MSW and removing and abating all of its emissions. The block diagram below demonstrates the intended integration of Mantel's demonstration project with the Ecomaine facility.



The market: Today, the market for waste to energy is large and growing, with current emissions of 0.12

GtCO2 per year (based on 75,000 GWh electric in 2019; 500 M tons installed capacity, ~40% biogenic as a global average, net -0.4 GtCO2 removed with 90% capture[3]. At present, a large percentage of waste is being landfilled rather than processed for its energy content. The potential for the waste to energy market is 1.26 GtCO2 per year (based on 2 billion tons of waste, 90% for waste-to-energy, 0.7 tonCO2/ton).

Moreover, this demonstration will prove Mantel's tech for bioenergy with capture and storage applications (BECCS). Biomass combustion and flue processing share many of the challenges faced by the MSW demonstration, including nonhomogeneous fuel and high levels of debris in the flue. Once Mantel's tech is de-risked in MSW applications, other sources of biogenic wastes could be addressed including agricultural and wood residues from forest management that are not economical recoverable for their energy content but in the future could be for their carbon removal potential. Furthermore, an opportunity exists to pair Mantel's point source carbon capture technology with existing processors of biomass in the pulp and paper industry.

The opportunity for processing biogenic wastes could grow to 600 million tons in the US alone, according to the US Department of Energy. Considering all removal pathways, Mantel's technology has the potential to remove billions of tons of CO2 yearly.

Mantel economics: Using a conservation approach to costing, Mantel's technoeconomic analysis calculates a cost of $888 per ton of CO2 removed for this demonstration unit. Using the same costing, Mantel NOAK unit is expected to cost $66 per ton of CO2 removed. The major drivers of cost are levelized capital cost ($592/ton for this project, $30/ton for the NOAK) and fixed OPEX ($159/ton for this project, $4/ton for NOAK) and CO2 transportation storage costs ($120/ton for this project, $15/ton for NOAK). Two major factors drive down the costs. First, this project captures just 15 tons per day, while the NOAK project will scale to 300 tons of CO2 per day. Component costs shrink on a per ton basis as the plant size grows due to economies of scale, and this helps drive down NOAK costs. Second, learning rates drive down NOAK cost. (Learning rate applies to CAPEX and OPEX only).

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.

Technical: The major technical risks associated with Mantel's technology and this application with MSW are corrosion and contamination. of the technology as a retrofit.

Contamination refers to the reduction in performance through interaction with containments and impurities. Our goal is to demonstrate the advantages of our molten borate technology for co-capturing flue gas impurities and handling aggressive environments which other sorbents cannot. The goal for the demonstration project is a <0.1%/cycle primary salt constituent losses. Impurities in the flue gas include various other acid gases (SOx, NOx, and HCl), fly ash (containing alumina, silica, alkali metals, metal oxides). The contamination risk specific to this MSW application is hydrochloric (HCl). HCl is released during the burning of solid fuels. Elevated emissions of HCl are harmful to the equipment and to people. Further lab scale testing is required to understand the interactions between Mantel's molten borates and HCl. The impurities that are captured by the circulating molten borate react to form solid precipitants. Mantel has developed a strategy to filter and recover both the molten borate constituents and the impurities. However, our filtering strategy needs to be demonstrated at scale in an industrial setting.

The second technical risk is corrosion. A high rate of corrosion of interior metal surfaces could lead to damaged containment structures and contamination of the sorbent. These effects reduce the lifetime of facility and high cost of replacement. A second impact of corrosion is the extraction of metals into the molten borate which degrades the material, such that the working capacity for CO2 capture lessens with use. In the lab we have already substantially de-risked the corrosion challenge by demonstrating corrosion rates less than 0.5mm/year, but maintaining the favorable corrosion performance in a full-scale system has not yet been demonstrated.

The final technical risk is integrating our technology into the existing Ecomaine system. The desorber, which separates CO2 from the sorbent, will be installed in the radiant section of the MSW combustion chamber. This configuration has not been demonstrated in the lab, and key challenges include high heat flux conditions and ash fouling of the desorber surfaces. Mitigating this risk will involve working with the original boiler manufacturer to design the desorber to specifications typical for MSW applications.

CO2 Offtake and Sequestration: A risk associated with this project is the offtake for CO2 sequestration. The overall ecosystem for storage is nascent and evolving. While geological injection is largely scientifically de-risked, there are still some uncertainties regarding availability of high quality, durable storage sites in close proximity to our operations. The creation of new injection sites is a long process due to high regulatory hurdles and multi-stakeholder input. Mantel is evaluating the closet partner to work with store the CO2 produced in this project. If there are no existing suitable injection sites in the near vicinity to our site in Maine or the site does not adhere to our high standards for durability and monitoring, we may need to transport the CO2 over larger distances, a worst case for which is considered in the LCA. In the short term, Mantel will rely on rail and truck to transport CO2.

Policy: Currently, the affordability and adoption of CDR is being driven by government policies including 45Q. The implementation of these policies has significantly quickened the pace of carbon capture adoption and Mantel is well positioned for the growing market. However, if a future administration were to change these policies and remove incentives for carbon capture, it could be a significant setback, not only for Mantel but for the entire ecosystem of carbon capture and storage companies.

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)*	564
Delivery window *(at what point should Frontier consider your contract complete? Should match 2f)*	December 2025
Levelized Price ($/ton CO_2)* *(This is the price per ton of your offer to us for the tonnage described above)*	888

** 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).*