Frontier

Arbor Energy and Resources

Carbon Dioxide Removal Purchase Application

Fall 2022

General Application - Prepurchase

(The General Application applies to everyone; all applicants should complete this)

Company or organization name

Arbor Energy and Resources Corporation

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

Los Angeles, California

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

Brad Hartwig

Brief company or organization description

Arbor is a planetary renewal company. We develop negative emission technologies that promote resource circularity and environmental restoration.

1. Project Overview[1]

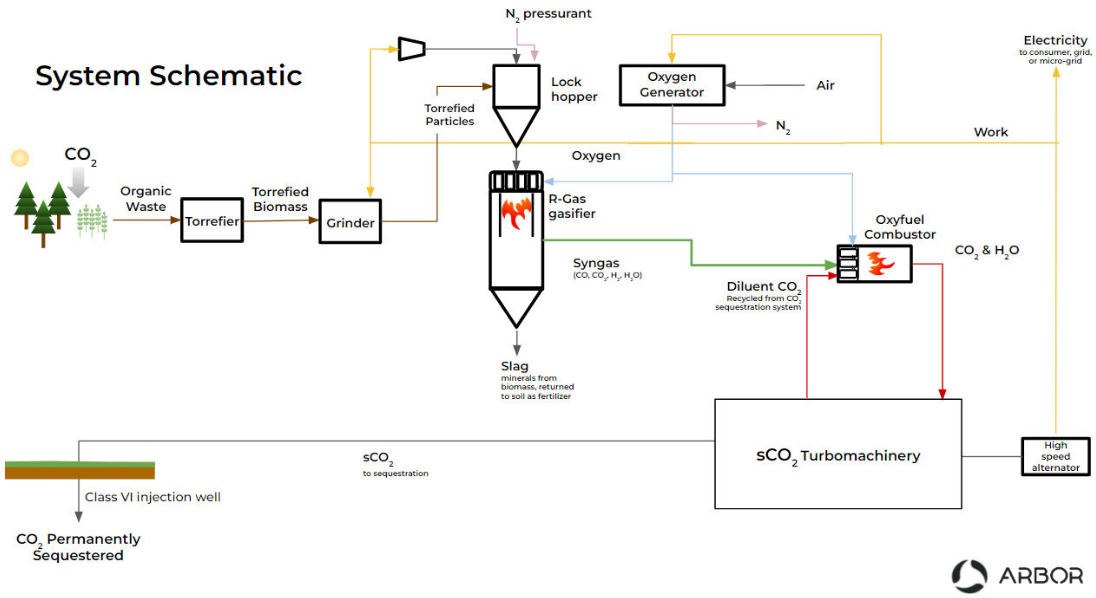
a. Describe how the proposed technology removes CO_2 from the atmosphere, including as many details as possible. Discuss location(s) and scale. Please include figures and system schematics. Tell us why your system is best-in-class, and how you're differentiated from any other organization working on a similar technology.

Arbor is developing a clean-sheet BiCRS (Biomass with Carbon Removal and Storage) solution that produces carbon-negative electricity and freshwater, while addressing the shortcomings of traditional BECCS (Bioenergy with Carbon Capture and Storage). Conceptually, the technology relies on plant photosynthesis to naturally scrub CO_2 from the atmosphere. Via staged-combustion, the biogenic carbon is oxidized (becoming CO_2 once again) and is immediately sequestered in a Class VI injection

[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.

well or used for carbon upcycling. Unlike traditional BECCS, our system will be compact and modular, utilize only locally available organic waste streams, and leverage advanced rocket engine technology for close to 100% carbon capture efficiency. (Here we define *carbon capture efficiency* as the percentage of CO2 leaving the system that gets captured and stored; traditional BECCS offers a 90% capture efficiency and in practice is often only 50-60%.) Our system will enable gigatonne-scale carbon removal while being ecologically restorative and socially responsible. Arbor is on a mission to achieve a CDR capacity of 10 Gt/yr by 2050.

At the heart of Arbor's system are four core technologies: upstream torrefaction & pulverization, compact entrained flow gasification, oxy-fuel combustion, and high-pressure turboexpansion. Each of these technologies have been demonstrated in isolation, but their integration is both novel and revolutionary. The high-level schematic is shown below. Notably, torrefaction is conducted at the source of biomass, and the modular power system produces zero emissions. All plant auxiliaries are powered by the system itself.



A quick breakdown of the advantages of each core technology are as follows:

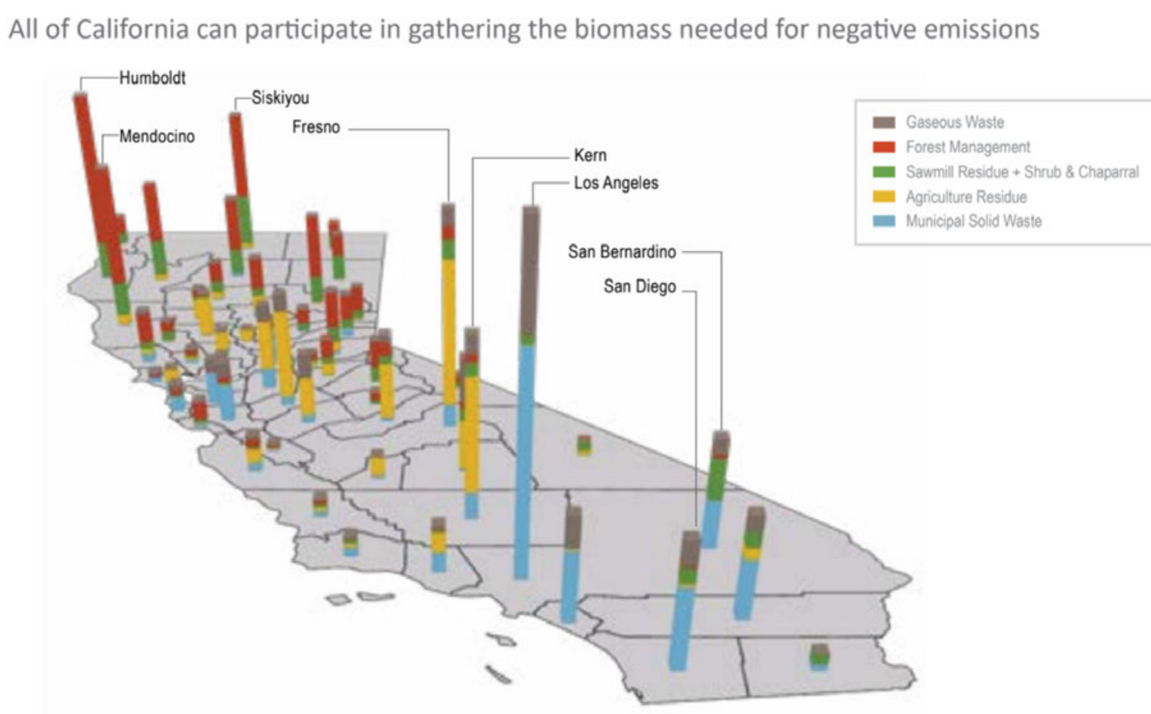
Torrefaction: Where normal BECCS systems are constrained by tight feedstock requirements, which limit scalability, we are leveraging torrefaction to turn disparate waste streams into a more uniform fuel. Torrefaction allows Arbor to use low-grade, heterogeneous waste feedstocks which are abundant and have limited value. The resulting biocarbon also has a 3x higher carbon density and 2x higher energy density enabling cost-effective transportation. Lastly, biocarbon can be finely pulverized for advanced gasification and is hydrophobic so it can be stored indefinitely. All biomass waste can be torrefied into biocarbon briquettes or pellets.

Compact Gasification: Standard biomass boilers, or even modern gasification technologies, are massive. These systems require long lead times, on-site construction over years, and comprise a majority of the cost of any bioenergy project. We are developing a compact oxygen blown entrained flow gasifier in partnership with GTI Energy that is 1/10th the size of traditional systems and can be pre-fabricated using metal additive manufacturing. Arbor works at a smaller scale with better performance because the system operates at extremely high temperatures and pressures. These conditions also crack all tars and phenols and result in high-purity syngas along with >99% carbon conversion efficiency. (Here we define *carbon conversion efficiency* as the percentage of carbon in the gasifier feedstock that gets converted to syngas; traditional fixed bed gasifiers achieve only a ~92%

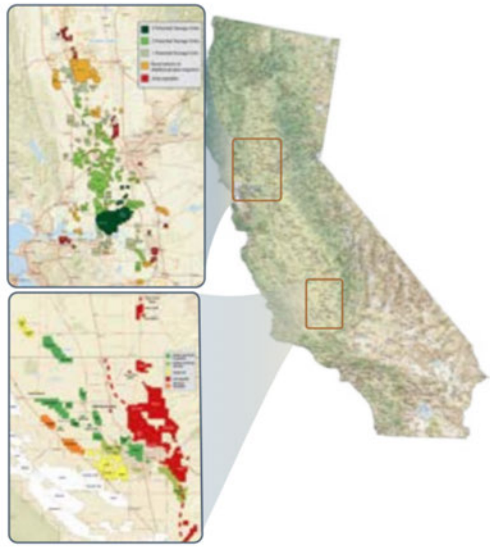
carbon conversion efficiency.)

Oxy-Combustion, sCO_2 Cycle, and Physical Footprint: Traditional BECCS uses post-combustion carbon capture with sorbents that have a high energy penalty for regeneration. Instead, we are leveraging rocket engine injector design for advanced oxy-combustion so that our exhaust can be sequestered without the need for post-combustion scrubbing. Because the system doesn't produce emissions, smoke stacks are obsolete. Similar to the gasifier, we are developing ultra-compact turbomachinery, based on advanced rocket engine turbopumps. By operating at extremely high pressures, the CO_2 exhaust behaves like a liquid and enables a machine that is 1/20th the size of a comparable conventional gas turbine. Again, smaller systems allow the use of metal 3D-printing which can eliminate part count by over 100x, completely eliminating failure modes and further reducing cost. Arbor's system can achieve true modularity, which will enable us to rapidly deploy systems to reach gigatonne-scale. Furthermore, because land is not dedicated to growing crops for our systems, the physical footprint of our units can be extremely small. We are targeting <1 acre per 1 million tonnes/yr removal.

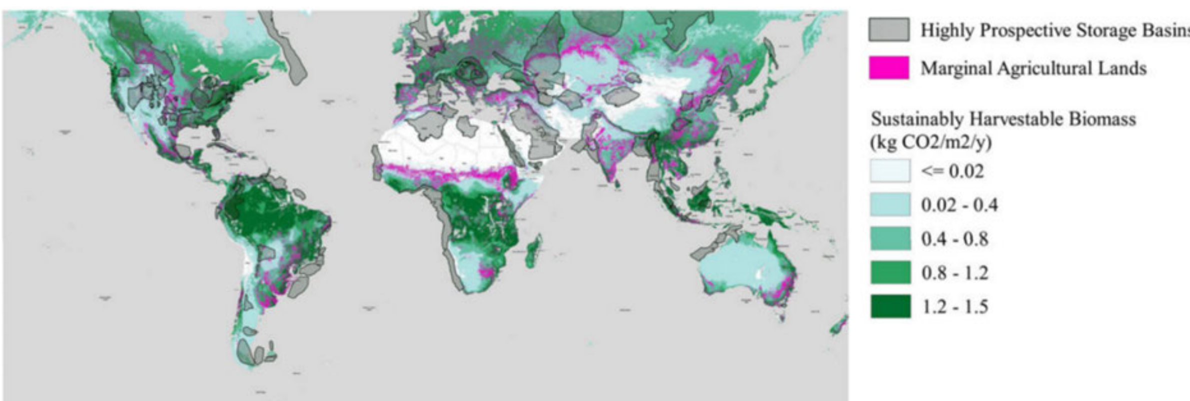
Our plans for siting focus on locations that have good pore space for Class VI injection wells, as well as ample organic waste available locally. The overlap of these site requirements includes more CDR opportunities than one might initially imagine. Deployment of Arbor's first systems will likely focus on 3 core geographies within the US. The first is CA's central valley (from Redding to Bakersfield). CA is anticipated to produce 56 million tons of organic waste annually by 2045, all requiring sustainable disposal solutions. The state's rampant wildfires are further accelerating policies for selective forest management, which will result in large quantities of forest residues. A relative scale for the amount and types of organic waste produced regionally in CA is shown below.



Additionally, CA's deep sedimentary rock formations offer world-class storage basins. The state's Class VI injection wells are expected to meet the highest standard for durability while having capacity exceeding 17 billion tonnes. Two ideal regions for carbon storage are shown in the figure below.



The other two prime geographies under consideration for our first system deployment include the mid-west's corn belt (which includes Iowa, Illinois, Indiana, Nebraska, Kansas, Kentucky, Michigan, Minnesota, Missouri, Ohio, North Dakota, and South Dakota) and the gulf coast (which includes Texas, Louisiana, Mississippi, Alabama, Florida). A complete map of global siting options is shown below, including where sustainably harvestable biomass overlaps favorable storage basins. In sum we estimate 8 GT of CO_2 can be sequestered annually with 5.5 B tons of biomass sitting near favorable storage locations globally.



Arbor is also putting a premium on how our projects look and what they offer to the communities in which they operate. We have partnered with Heatherwick Studios, a preeminent design firm who's skills span beautiful solarpunk architecture to futuristic vehicles that actually clean the air as they drive. Our projects will provide permanent jobs to the rural and underserved populations that can benefit most from the economic development. These considerations will all be crucial components to public acceptance of a project. Beyond acceptance, however, they embody the reasons we are in business: to build a truly sustainable civilization, and offer a model for resource circularity, planetary stewardship, and human kindness.

In summary, traditional BECCS lacks feedstock and location flexibility, suffers from egregiously high capital costs, is inherently non-modular, struggles with community acceptance, and is too slow to deploy. By contrast, Arbor is developing a BiCRS solution from a clean-sheet to overcome these hurdles. According to the Lawrence Livermore National Laboratory, there will be an estimated 5.5B metric tons of organic waste sustainably available for BiCRS annually by 2050. With Arbor's system, this would amount to 8 Gt CO_2e removed annually from the atmosphere, while producing 14 PWh of electricity each year (over half of current global demand). Perhaps just as notable, powering DAC with Arbor's BiCRS system could enable an additional 9 Gt CO_2 removal annually (utilizing both the electricity and waste heat). In total, BiCRS + DAC could offer 17 Gt CO_2e removal per year by 2050 while actually promoting food security, rural livelihoods, and biodiversity. There is similarly a large opportunity to restore millions of acres of degraded lands via regenerative carbon crops, effectively monetizing planetary renewal. We are not aware of any BiCRS company that is thinking as holistically about the environmental crisis or is as uniquely qualified to tackle it.

Sources of figures in order of appearance:

Baker, S., et all, "Getting to Neutral: Options for Negative Carbon Emissions in California"

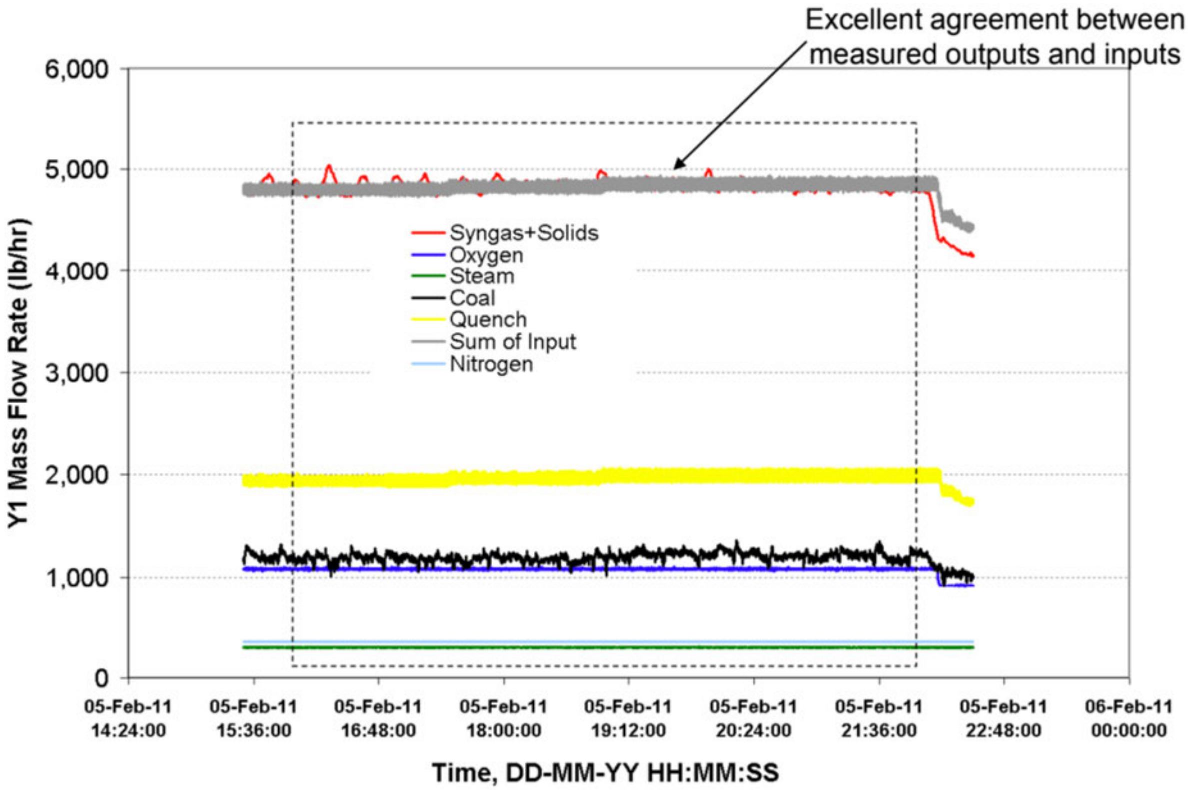
Sandalow, D., et all, "Biomass Carbon Removal and Storage (BiCRS) Roadmap"

Turner, P.A., et all, "The Global Overlap of Bioenergy and Sequestration Potential"

b. What is the current technology readiness level (TRL)? Please include performance and stability data that you've already generated (including at what scale) to substantiate the status of your tech.

Overall, we calculate our technology readiness level to be roughly TRL 5. Oxy-combustion with an sCO_2 cycle has achieved TRL 7 by NET Power and compact entrained flow gasification has achieved TRL 7 by GTI Energy (with whom we are working). Torrefaction has achieved TRL 9 by a few groups (i.e. Airex, NextFuel, etc.). At Arbor, we are developing these systems in-house to make them cheaper, modular, and increasingly flexible. We consider these internally-designed components to be TRL 3 or 4, but expect to rapidly achieve TRL 6-7 (i.e. in 2 to 3 years) and TRL 9 shortly thereafter (4 years). We selected TRL 5 as a compromise to highlight that our technology risks are engineering/execution in nature, as they have been categorically demonstrated.

The below diagram (produced by GTI Energy) shows the stability of gasification with standard coal from 2011. We are using this same reactor but with torrefied biomass (often referred to as biocoal).



GTI Energy has also demonstrated successful gasification of a wide range of coals with varying ash contents ranging from less than 1% to over 25% as shown in the figure below. This flexibility is very important for biomass waste which is often quite heterogeneous.

	Illinois #6 Coal	Oil Sands Petcoke	Joliet Petcoke	Alberta sub-bit coal
Proximate Analysis (wet)				
Moisture Content, %	5.73	0.43	0.23	7.46
Volatile Matter, %	37.35	13.29	12.26	28.52
Ash, %	9.32	3.21	0.3	23.86
Fixed Carbon, %	47.6	83.07	87.21	40.16
Total	100	100	100	100
Ultimate Analysis (dry)				
Ash	**9.89**	**3.23**	**0.3**	**25.78**
C	73.68	84.55	88.66	57.66
H	4.96	3.47	3.79	3.4
N	1.32	1.59	1.64	0.85
S	3.46	6.47	6.45	0.17
O	6.69	0.69	0	12.14
Total	100	100	100.84	100
HHV, Btu/lb (dry)	12,690	14630	15070	9869
Slag Fluid Temp, °F	**2270**	**2660**	**2600**	**2656**

At the pilot scale, a carbon conversion efficiency of 91% has been achieved. This validates a greater than 99% conversion efficiency at commercial scale, anchored to robust kinetics models. Torrefied biomass has a higher volatile content (70% or more) than coal and is expected to gasify more easily.

c. What are the key performance parameters that differentiate your technology (e.g. energy intensity, reaction kinetics, cycle time, volume per X, quality of Y output)? What is your current measured value and what value are you assuming in your nth-of-a-kind (NOAK) TEA?

Key performance parameter	**Current observed value (units)**	**Value assumed in NOAK TEA (units)**	**Why is it feasible to reach the NOAK value?**
Capital Cost ($/ton-yr^{-1} CO_2)	$920/ton-yr^{-1} CO_2	$110/ton-yr^{-1} CO_2	We are building much smaller systems (more compact because of far higher pressures), standardizing all components for our system, drastically reducing part count through additive manufacturing, and building the hardware in-house. We are eliminating the mark-up associated with contractors and subcontractors (which are part of a typical supply chain) and will reach never-before-seen economies of scale. Our team is also highly skilled in bringing complex systems down the cost curve from our work at SpaceX. Unlike most DAC systems, our capital cost includes the cost of all associated energy infrastructure, since our systems also produce energy. Combining our BiCRS system with DAC could yield a value as low as $80/ton-yr^{-1} CO_2
Turboexpander Operating Pressure (bar)	N/A	350 bar	Our team has extensive experience designing and building rocket engine turbopumps which operate at far higher pressures (>400 bar)
Capture Efficiency (%)	N/A	100%	Because we are performing oxy-combustion rather than post-combustion flue gas capture, we will not need a flue stack and will capture all of our system's CO_2 emissions without further energy input.

d. Who are the key people at your company who will be working on this? What experience do they have with relevant technology and project development? What skills do you not yet have on the team today that you are most urgently looking to recruit?

Arbor's team was hand-picked to rapidly create the technology needed for a carbon-negative world. It is impossible to overstate the unique qualifications this team has to develop these systems and I am truly humbled by both their unrivaled experience and commitment to Arbor's vision.

Brad Hartwig (CEO): Brad worked as a Manufacturing Engineer at SpaceX where he was instrumental in the development of the Draco rocket engine for human spaceflight. He later was a Flight Test Engineer and Test Pilot for experimental aircraft at Kitty Hawk, before going back to grad school for his M.S. at UC Berkeley (Energy Infrastructure and Climate Engineering). He holds a B.S. from USC in Aerospace Engineering, where he was part of the USC Rocket Propulsion Lab (the first student group to send a rocket to space). He founded Arbor in December 2021 with the goal of reversing humanity's climate footprint and building a truly sustainable civilization.

Andrés Garcia-Clark (CTO): Andrés was the former Principal Turbomachinery Engineer at SpaceX (having led development of the Raptor engine turbopumps) and was previously a Sr. Design Engineer and engineering leader for gas turbines at GE. He boasts over 20 years of industry experience in rocket engine design and industrial power systems and was part of GE's Edison Leadership Development Program. He holds an M.S. from the Georgia Institute of Technology and B.S. in Mechanical Engineering from the University of Puerto Rico - Mayagüez.

Seth McKeen (Head of Combustion): Seth was a former Sr. Propulsion Engineer with 12 years of SpaceX experience across 4 engine development programs. He specializes in combustion and injector design, high temperature gas dynamics and engine testing. Seth is also our resident expert in AI-driven generative design which enables component and system-level design optimization that was previously impossible. He holds an M.S. in Astronautical Engineering and a B.S. in Aerospace Engineering from USC and University of Boston respectively.

Sutton Guldner (Head of Business Development): Sutton was previously an Energy Project Manager for Shell in their deep-water oil & gas division and then in their biofuels portfolio working waste biomass to drop-in biofuel conversion. He holds a B.S. and M.Eng. in Mechanical Engineering from Cornell as well as an MBA from Harvard with a focus on Energy & Sustainability.

Miho Beal (Head of Operations): Miho was a leader in Sales Application Engineering at GE, helping develop and commission power plants across Japan and the South Pacific. She was also part of GE's Edison Leadership Development Program. After GE, Miho led purchasing for electronic components at Rivian as a Sr. Manager and holds both an M.S. in Mechanical Engineering, and a B.S. in Aerospace Engineering from USC.

Adam Gluck (Sr. Data and Controls Engineer): Adam was the Director of Software and Launch Operations at Virgin Orbit. His experience spans setting up data pipelines for acquisition and processing of real time data, to writing software to control complex launch and abort sequences which will be invaluable for plant operations and monitoring. He previously worked at National Instruments and holds an M.S. in Space Engineering and a B.S. in Electrical Engineering from the University of Florida.

Michael Torre (R&D Operations Manager): Mike was the Sr. Manager of Raptor engine manufacturing at SpaceX. He specializes in advanced additive manufacturing, production workflow optimization, and creating a strong culture for extreme ownership and quality control. He was previously at GE as part of their Operations Leadership Development program and holds two M.S. degrees in engineering and materials/logistics management from Penn State.

Brad Boyer (Principal Turbomachinery Engineer): Brad was previously a senior technical leader in General Electric's Power division. His experience spans compressors, combustion, turbines and accessories. He has deep expertise in turbine mechanical analysis, modal analysis, and manufacturing, as well as leading entire teams in development of their most advanced power systems. Brad holds an M.S. and B.S. in Mechanical Engineering from the University of South Carolina and Alabama.

Brandon Marks (Sr. Combustion Development Engineer): Brandon has over a decade of experience across oxycombustion for supercritical CO2 cycles and rocket engine tests. He was the lead combustion analyst in the development of the oxy-combustion system for NET Power while at Parametric Solutions. Afterward, he was the Responsible Engineer for all main engine testing at ABL Space Systems before joining Arbor. Brandon holds an M.S. and B.S. in Mechanical Engineering from Texas A&M and University of South Florida.

Zeke Smith (Consultant): Zeke is the Chief Engineer at Venus Aerospace and was previously a Lead Turbomachinery Engineer for SpaceX. He spent his early career also as an engineering leader at GE working across an array of advanced power system technologies. He has deep domain expertise in the areas of advanced engine development, cycle design and analysis, and system accessories. Zeke holds two M.S. degrees in Mechanical Engineering and Applied Physics.

John Keba (Consultant): John Keba is ***the*** industry expert in turbomachinery bearing and seal design. His work spans many of the most prominent American engine development programs - including the Space Shuttle's main engines and SpaceX's Merlin and Raptor engines.

Dr. Dan Sanchez (Advisor): Dan is the Chief Scientist at Carbon Direct for BiCRS, Head of UC Berkeley's Carbon Removal Lab, a Specialist in UCB's Department of Environmental Science, Policy & Management, and known for his work in commercialization strategies for BiCRS.

Dr. Steve Fusselman (Advisor): Steve was formerly the Program Lead for Gasification Technology at Aerojet Rocketdyne. He is known for implementing rocket technology into a compact entrained-flow reactor for coal gasification as part of IGCC power stations, dubbed R-Gas which Arbor is now developing with GTI Energy for biomass gasification.

Mark Groskreutz (Advisor): Mark is the Chief Engineer at Ursa Major Technologies, former Director of Turbomachinery at SpaceX, and has extensive knowledge in turboexpanders, chillers, heat exchangers, pumps, air separation units, and business development.

Upcoming Hiring Needs:

- Biomass handling and conversion specialist
- Gasification specialist (or combustion specialist dedicated to gasification)
- Grants and government affairs specialist(s)
- Project manager

e. Are there other organizations you're partnering with on this project (or need to partner with in order to be successful)? If so, list who they are, what their role in the project is, and their level of commitment (e.g., confirmed project partner, discussing potential collaboration, yet to be approached, etc.).

Partner	Role in the Project	Level of Commitment

GTI Energy (Zach El Zahab, Tony Eastland, Bo Li, Scott Trybula, John Vega, John Marion)	Helping with development of our compact entrained flow reactor - leveraging decades of experience with R-Gas. Hosting the initial R&D for the rest of our systems at their site.	Confirmed Project Partner
ZiTechnologies (Stas Zinchik, Shreyas Kolapkar)	Contracted party helping us develop our in-house torrefaction technology. Their deep torrefaction expertise spans nearly two decades including R&D and full commercial project deployment.	Confirmed Project Partner
Placer County Water Agency (PCWA) (Tom Johnson, Tony Firenzi)	Landowner who's site we will be on, and providing power to. As part of their operations, they will create the waste feedstock used for this project. They will also provide help with community connections, permitting, and compliance.	Verbal Commitment for being a Project Partner
Sequestration Partners (Various)	Several companies building class VI injection wells in central California. Will be storage site for captured CO2	Discussing potential collaborations

f. What is the total timeline of your proposal from start of development to end of CDR delivery? If you're building a facility that will be decommissioned, when will that happen?

We are looking to commission this project by the end of 2025 and start CO2 generation then.

g. When will CDR occur (start and end dates)? If CDR does not occur uniformly over that time period, describe the distribution of CDR over time. Please include the academic publications, field trial data, or other materials you use to substantiate this distribution.

This early project will start producing carbon credits in Q4 2025, and is planned to be in continued usage as a power-generating asset for the next 20 years, with constant carbon removal over that time. The system will produce ~66k tons/yr of negative CO2 emissions on a net basis, which we are looking to sequester in a nearby Class VI injection well.

h. Please estimate your gross CDR capacity over the coming years (your total capacity, not just for this proposal).

Year	Estimated gross CDR capacity (tonnes)
2023	0
2024	0

2025	7,500
2026	60,000
2027	300,000
2028	1,500,000
2029	5,000,000
2030	16,000,000

i. List and describe at least three key milestones for this project (including prior to when CDR starts), that are needed to achieve the amount of CDR over the proposed timeline.

	Milestone description	**Target completion date** (eg Q4 2024)
1	Gasifier Demonstration	Q4 2022
2	Oxy Combustion Demonstration	Q1 2023
3	Turbomachinery (Carbon Engine) Demonstration - Full Cycle	Q1 2024
4	Project Construction Kick-off	Q3 2024
5	Project Commissioning	Q4 2025

j. What is your IP strategy? Please link to relevant patents, pending or granted, that are available publicly (if applicable).

We are pursuing a number of patents for our system but haven't filed any yet. We are looking to start filing in the coming 2-3 months. Special areas of interest for us include (non-exhaustive):

- Overall cycle
- sCO2 system accessories
- Gasification operating conditions and cycle integration
- Misc. unique system integrations

k. How are you going to finance this project?

This project will be financed through a combination of venture capital, grants, and venture debt. We have raised over $8M to date to build the team and perform subsystem technology demonstrations. Our team is looking to raise a Series A in the coming 9-12 months, and we are in the process of applying to a number of grants ranging from CA's Department of Conservation (DOC) to various offices within the DOE, such as BETO, ARPA-E, and OCED. We are also exploring venture debt options with Silicon Valley Bank. Together, this capital should facilitate completion of our R&D facility and demonstration plant. We are looking for as many sources of revenue as possible so we can in parallel be working on development and deployment of our true first-of-a-kind project which we assess will be capable of removing close to 1,000,000 tonnes of CO2 per year.

In future projects we will also seek financing from the DOE's LPO as well as traditional banks for project finance.

Some of our notable investors include Lowercarbon Capital, Global Founders Capital, Countdown Capital, 11.2 Capital, Cantos Ventures, Climate Capital, and strong angel investors.

l. Do you have other CDR buyers for this project? If so, please describe the anticipated purchase volume and level of commitment (e.g., contract signed, in active discussions, to be approached, etc.).

We are in early discussions with a number of CDR buyers including Microsoft, Patch, Watershed, and a few unnamed major tech companies. We have not signed any contracts yet. We have a long list of additional buyers we will be approaching in the coming months.

m. What other revenue streams are you expecting from this project (if applicable)? Include the source of revenue and anticipated amount. Examples could include tax credits and co-products.

We are looking to monetize the 45Q tax credit ($85/ton), the electricity our unit produces (~$0.19/kWh per California's BioMAT program), as well as the fresh water we produce (tbd, in discussion with project partners)

n. Identify risks for this project and how you will mitigate them. Include technical, project execution, ecosystem, financial, and any other risks.

Risk	Mitigation Strategy
Technology Risk	We are developing several technologies which have been demonstrated elsewhere in limited capacity. Our first line of mitigation is assembling a world-class team of experts that have either been a part of those projects or are uniquely qualified through relevant work at SpaceX and GE.
Project Execution Risk	The Placer County Water Agency (PCWA) has been extremely supportive and cooperative. Because this first project is being hosted on their site, their continued support and involvement is paramount at this early stage. They are also helping us understand the permitting and CEQA (California environmental quality act) processes that our project does and doesn't have to do as part of being on a brownfield site. This is hugely helpful for our first commercial project, as permitting can bring up costly surprises.
Financial Risk	We have strong investor backing and engagement but are always looking to bolster our financial situation. This includes discussions with potential future investors and routine meetings with DOE and DOC members who can facilitate awareness/generation of Funding

	Opportunity Announcements (as well as strategic public-private partnerships). We are also engaging external groups like Climate Finance Solutions and Boundary Stone Partners to bolster our likelihood of being awarded grants and build out our government affairs competencies.
Partner Risk	We still need to sign contracts with our offtake partners for our CO2 removal. The purity of the CO2 will meet all pipeline specifications (i.e. ISO 27913) for injection into nearby Class VI wells. We have begun conversation with a number of companies that offer injection services including Oxy and DTE Energy who have offered their support in CA where our first demonstration project will be. Two wells of particular interest for this project are being developed in Sacramento and Yuba City.

2. Durability

a. Describe how your approach results in permanent CDR (> 1,000 years). Include citations to scientific/technical literature supporting your argument. What are the upper and lower bounds on your durability estimate?

> Our process takes biomass which would either be burned or decay into CO2/methane in a matter of months/years, oxidizes it into sCO2, and permanently sequesters the carbon in geologic formations. Storage will take place in an EPA class VI injection well, via a project partner who will own and operate the well, and monitor for leakage. Many companies doing this work have been involved in oil and gas exploration, and use state of the art geologic science to identify, characterize, utilize, and monitor the best formations for carbon sequestration. In areas with good geology, the same processes that keep oil and gas trapped for millions of years are now effectively being put into use for indefinite carbon storage. In our research, the lowest estimate for retention over at 1,000 year time frame for an injection site that is properly managed is 99.2%. As high as 100% is achievable.
>
> Dees, John P., Hannah M. Goldstein, A.J. Simon, Daniel L. Sanchez. "Leveraging the bioeconomy for carbon drawdown,"
>
> IEA 2016, "20 years of carbon capture and storage." IEA, Paris https://www.iea.org/reports/20-years-of-carboncapture-and-storage (2016).
>
> Miocic, J.M., Gilfillan, S.M.V., Frank, N. et al. 420,000 year assessment of fault leakage rates shows geological carbon storage is secure. Sci Rep 9, 769 (2019). https://doi.org/10.1038/s41598-018-36974-0
>
> National Academies of Sciences, Engineering and Medicine (NASEM). "Negative Emissions Technologies and Reliable Sequestration: A Research Agenda." Washington, DC: The National Academies Press. (2019) https://doi. org/10.17226/25259.

b. What durability risks does your project face? Are there physical risks (e.g. leakage, decomposition and decay, damage, etc.)? Are there socioeconomic risks (e.g. mismanagement of storage, decision to consume or combust derived products, etc.)? What fundamental uncertainties exist about the underlying technological or biological process?

The science and mechanics of geologic sequestration are quite well understood, and the principles are widely used even today in Enhanced Oil Recovery, which itself stores 60 million tons of carbon a year in the US alone. Class VI wells have strict MRV guidance to ensure that they are performing. Even with that, two main risks are still outstanding. The first would be failure of the well itself, whether due to accidents, neglect, or factors outside of the well operator's control. This would be covered contractually, and would have to be offset by payment by our chosen project partner, and "re-captured" by other projects in our portfolio or others. The second, larger, risk is the political future of CCS in the United States, specifically in the eyes of public perception. There are movements against the usage of this technology, which have sought to ban the practice. The concerns of communities stem from potential for groundwater contamination, accidental release, or pipeline aversion. While ultimately CCS has more tailwinds than headwinds, these facts will have to be considered before new deployments are undertaken.

3. Gross Removal & Life Cycle Analysis (LCA)

a. How much GROSS CDR will occur over this project's timeline? All tonnage should be described in **metric tonnes** of CO_2 here and throughout the application. Tell us how you calculated this value (i.e., show your work). If you have uncertainties in the amount of gross CDR, tell us where they come from.

Gross tonnes of CDR over project lifetime	1,316,000 tonnes
Describe how you calculated that value	This project will produce ~180 tonnes of CO2 per day Assuming the system is down for a couple of weeks each year for maintenance, a conservative estimate is 80% uptime. Taking into account our conservatism factor (90%) to address un-derisked uncertainties, and an operational life of 20 years, we get 1,316,000 tons.

b. How many tonnes of CO_2 have you captured and stored to date? If relevant to your technology (e.g., DAC), please list captured and stored tons separately.

0

c. If applicable, list any avoided emissions that result from your project. For carbon mineralization in concrete production, for example, removal would be the CO_2 utilized in concrete production and avoided emissions would be the emissions reductions associated with traditional concrete production. Do not include this number in your gross or net CDR calculations; it's just to help us understand potential co-benefits of your approach.

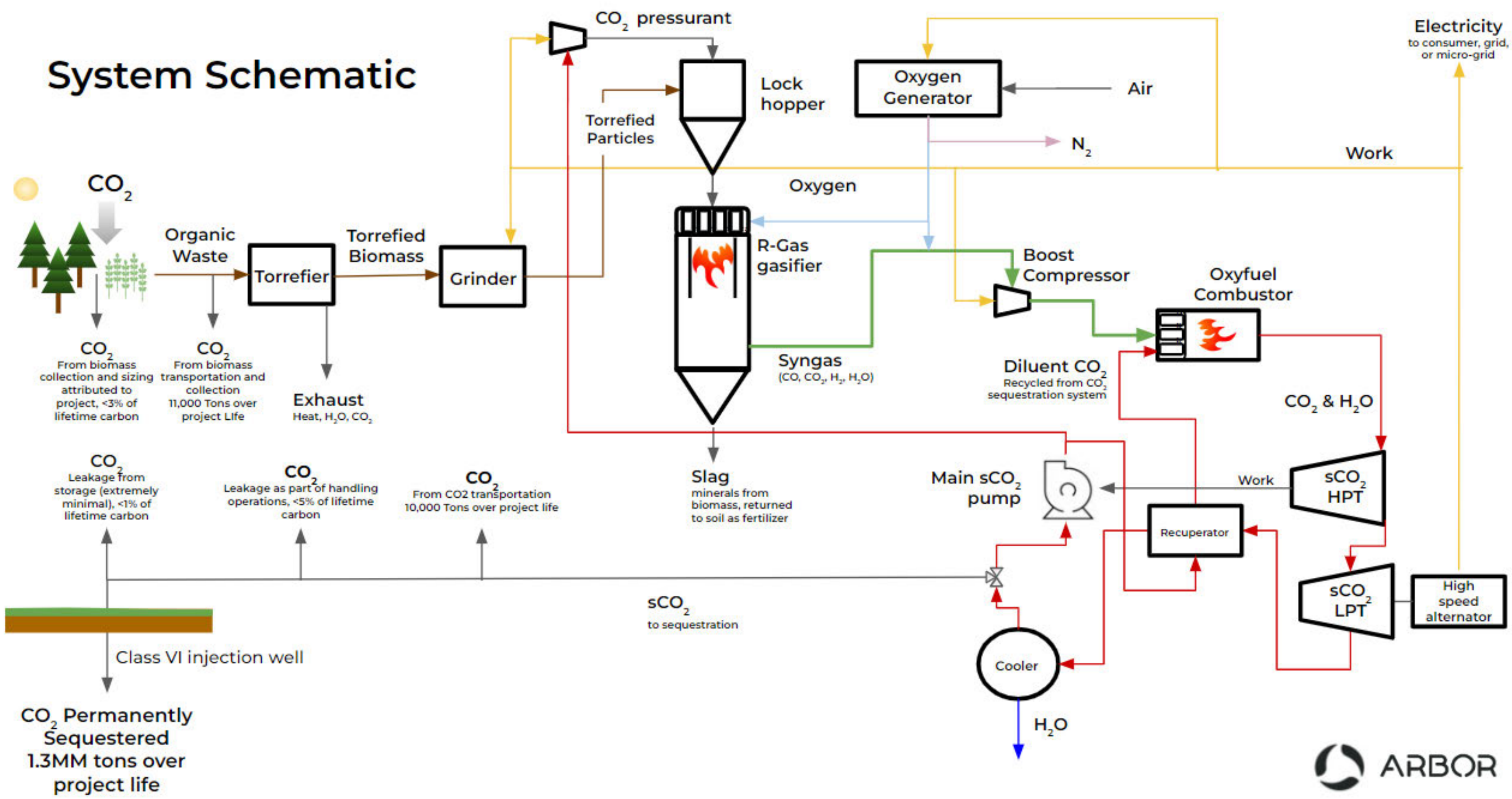
This project will displace conventional power-generation facilities, and the carbon-associated with counterfactual power production. The current local grid, powered by natural gas, produces 0.91 pounds of CO2 per kWh. Our 5 MW system will avoid 2 tons of CO2 emissions per hour. (0.91[lb] * 5000[kWh] / 2200[lb/tonne]) Over the course of this project's lifetime, resulting avoided emissions would be 320,604 tonnes (2[ton/hr] * 24[hr/day] * 334 [operating days/yr] * 20[yrs of service])

d. How many GROSS EMISSIONS will occur over the project lifetime? Divide that value by the gross CDR to get the emissions / removal ratio. Subtract it from the gross CDR to get the net CDR for this project.

Gross project emissions over the project timeline *(should correspond to the boundary conditions described below this table)*	21,000 tons
Emissions / removal ratio *(gross project emissions / gross CDR–must be less than one for net-negative CDR systems)*	21,000 / 1,316,000 = .015
Net CDR over the project timeline *(gross CDR - gross project emissions)*	1,295,000 tons

e. Provide a process flow diagram (PFD) for your CDR solution, visualizing the project emissions numbers above. This diagram provides the basis for your life cycle analysis (LCA). Some notes:

- The LCA scope should be cradle-to-grave
- For each step in the PFD, include all Scope 1-3 greenhouse gas emissions on a CO_2 equivalent basis
- Do not include CDR claimed by another entity (no double counting)
- For assistance, please:
  - Review the diagram below from the CDR Primer, Charm's application from 2020 for a simple example, or CarbonCure's for a more complex example
  - See University of Michigan's Global CO_2 Initiative resource guide
- If you've had a third-party LCA performed, please link to it.



f. Please articulate and justify the boundary conditions you assumed above: why do your calculations and diagram include or exclude different components of your system?

We have included the entirety of our system, the supply chain to get it there, and the supply chain of our produced carbon. As waste feedstocks, this generated biomass would otherwise be discarded/burned as our counterfactual, although we have measured carbon emitted with its generation and are still looking into how much of that to accredit to our project. The additional emissions from our project focus on the harvesting, size reduction, and trucking of feedstocks/outputs, with leakage taken into account as a net multiplier. CO2 coming off the torrefier is considered carbon neutral, as it is biogenic in nature, and it's counterfactual would have been decaying and release into the atmosphere.

g. Please justify all numbers used to assign emissions to each process step depicted in your diagram above. Are they solely modeled or have you measured them directly? Have they been independently measured? Your answers can include references to peer-reviewed publications, e.g. Climeworks' LCA paper.

Process Step	CO_2(eq) emissions over the project lifetime (metric tonnes)	Describe how you calculated that number. Include references where appropriate.
Harvesting and size reduction of biomass	<3% of project carbon	Discussions with forestry contractors on their fuel usage during operations (They use 600 gallons of diesel to creat 300 BDT of biomass, which is a 1.5% impact on LCA). Note that this is extremely conservative, as it implies we are accrediting all the creation of our biomass to our project, despite the fact that most of it would be created anyways as part of forestry management operations.
Trucking of biomass	11,000 Tons	Using diesel trucks, 8 mi/gal, feedstock consumption rate, trucking distance to feedstock sources and back, truck bulk freight capacity (20 tons). We are also exploring using electric or RNG trucks to bring this number down further, or even mobile point-source capture through Remora.
Trucking of carbon	10,000 Tons	Using diesel trucks, 8 mi/gal, carbon production, trucking distance to injection site and back, truck liquid freight capacity (20 tons). We are also exploring using electric or RNG trucks to bring this number down further, or even mobile point-source capture through Remora.
Leakage in Carbon Handling	<5% of carbon handled	Conversations with sequestration partners for standard losses they've seen with other partners. Note that these are not "emissions", rather losses on overall gathered carbon, discussed in the MRV section
Leakage from Storage	<1% of carbon sequestered	Research into the permanence of sequestration (see section 2). Note that these are not "emissions", rather losses on overall gathered carbon, discussed in the MRV section

4. Measurement, Reporting, and Verification (MRV)

Section 3 above captures a project's lifecycle emissions, which is one of a number of MRV considerations. In this section, we are looking for additional details on your MRV approach, with a particular focus on the ongoing quantification of carbon removal outcomes and associated uncertainties.

a. Describe your ongoing approach to quantifying the CDR of your project, including methodology, what data is measured vs modeled, monitoring frequency, and key assumptions. If you plan to use an existing protocol, please link to it. Please see Charm's bio-oil sequestration protocol for reference, though note we do not expect proposals to have a protocol at this depth at the prepurchase stage.

We plan to directly measure the carbon dioxide that leaves our system on its way to be sequestered. Since the only carbon input into our system is the feedstock, we can match all of our output to originally being biogenic, and count that towards CDR. We plan to have vehicle fleet tracking, so that as credits are created, they are appropriately being discounted by all of our emissions activity. We also plan to get reports from our partners on a) how much of our carbon is going down-hole, b) any leakage from the reservoir, and c) changes to operations in upstream harvesting and chipping. The first of these points (a) will let us know how much is lost in carbon handling, the second (b), how much is lost in long term storage, and (c) if there are changes in equipment requiring more/less fuel. Since these will rely on our partners, we will need to understand their monitoring plans for their sequestration sites, so that we can accurately discount our sequestered carbon.

b. How will you quantify the durability of the carbon sequestered by your project discussed in 2(b)? If direct measurement is difficult or impossible, how will you rely on models or assumptions, and how will you validate those assumptions? *(E.g. monitoring of injection sites, tracking biomass state and location, estimating decay rates, etc.)*

This will rely on reporting from our project partners on the durability of our carbon that they sequester. They will obtain this information from a mixture of well modeling, monitoring infrastructure, and geological properties.

c. This tool diagrams components that we anticipate should be measured or modeled to quantify CDR and durability outcomes, along with high-level characterizations of the uncertainty type and magnitude for each element. We are asking the net CDR volume to be discounted in order to account for uncertainty and reflect the actual net CDR as accurately as possible. Please complete the table below. Some notes:

- In the first column, list the quantification components from the Quantification Tool relevant to your project (e.g., risk of secondary mineral formation for enhanced weathering, uncertainty in the mass of kelp grown, variability in air-sea gas exchange efficiency for ocean alkalinity enhancement, etc.).
- In the second column, please discuss the magnitude of this uncertainty related to your project and what percentage of the net CDR should be discounted to appropriately reflect these uncertainties. Your estimates should be based on field measurements, modeling, or scientific literature. The magnitude for some of these factors relies on your operational choices (i.e., methodology, deployment site), while others stem from broader field questions, and in some cases, may not be well constrained. We are not looking for precise figures at this stage, but rather to understand how your project is thinking about these questions.
- See this post for details on Frontier's MRV approach and a sample uncertainty discount calculation and this Supplier Measurement & Verification Q&A document for additional guidance.

Quantification component Include each component from the Quantification Tool relevant to your project	**Discuss the uncertainty impact related to your project** Estimate the impact of this component as a percentage of net CDR. Include assumptions and scientific references if possible.
Storage	*0%: Uncertainty around the storage mechanism is addressed in “leakage” below*
Leakage	5%: Uncertainty here is in lost CO2 as part of trucking, site storage, and handling operations. These losses are attributed to slip across seals, and are hard to identify until we have operational data. Geologic storage, on the other hand, is very secure with lowest estimates still maintaining 99.2% retention after 1000 years.
Materials	3%: We are still working with project partners to identify the carbon intensity of our fuel. Since our feedstock is created as a by-product of forestry management, most of the fuel used to generate our feedstock would have been consumed as part of that process. However, to be robust, we would still like to accurately attribute the appropriate amount to our project. Even in a conservative case, this impact is assumed to be small.
Energy	0%: This project will have a very clear energy production, at a metered facility
Secondary impacts of energy demand	0%: This project is displacing conventionally produced electricity
Storage Monitoring and Maintenance	1%: We will need numbers from our project partners on how much carbon they expect to expend monitoring our storage

d. Based on your responses to 4(c), what percentage of the net CDR do you think should be discounted for each of these factors above and in aggregate to appropriately reflect these uncertainties?

10%

e. Will this project help advance quantification approaches or reduce uncertainty for this CDR pathway? If yes, describe what new tools, models or approaches you are developing, what new data will be generated, etc.?

Yes. In these early steps, it is easy to imagine all feeds as waste feeds, and use conservatism in other figures to justify any potential deviation from this plan. However, we are very interested in understanding the true carbon intensity of our projects, as it will guide the placement of future assets. We want to deploy tools to help us understand the availability, distance, and ease of collection for these waste biomasses, which will be integrated into forest managers tool kits as they execute on their own work. Ultimately, these tools would help us better predict carbon emissions from waste collection on forest (and later agricultural) lands based on forest density, slope, altitude, biome, and water features.

We will further look to leverage a robust auditing process to ensure the feedstock is truly waste and continually update our models of counterfactuals to build a more comprehensive CDR assessment. We aspire to use our purchasing power to influence adoption of more selective forestry that optimizes for the greatest positive impact at both the local and planetary levels.

f. Describe your intended plan and partners for verifying delivery and registering credits, if known. If a protocol doesn't yet exist for your technology, who will develop it? Will there be a third party auditor to verify delivery against that protocol or the protocol discussed in 4(a)?

Our current plan is to use a hybrid of two protocols, that most of the major verifiers either already have or are in the process of developing: Biochar and DAC. Biochar protocols cover the first half of our process, as the "biomass to site" aspect of our carbon accounting very much reflects the operations of our project. This includes the amount of carbon entrained in biomass by region, the emissions associated with harvesting this biomass, and the emissions associated with trucking. Once the biomass reaches our site, we would like our methodology to very-closely resemble DAC, as the uncertainty the protocols help address is around process efficiency, durability of geologic storage, and emissions from trucking. We would plan to have a comprehensive protocol audited by 3rd party auditors before being put into place. This is still very much in development, as the most robust way to capture all of our emissions under one protocol is needed.

5. Cost

We are open to purchasing high-cost CDR today with the expectation the cost per tonne will rapidly decline over time. The questions below are meant to capture some of the key numbers and assumptions that you are entering into the separate techno-economic analysis (TEA) spreadsheet (see step 4 in Applicant Instructions). There are no right or wrong answers, but we would prefer high and conservative estimates to low and optimistic. If we select you for purchase, we'll work with you to understand your milestones and their verification in more depth.

a. What is the levelized price per net metric tonne of CO_2 removed for the project you're proposing Frontier purchase from? 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), but we will be using the data in that spreadsheet to consider your offer. Please specify whether the price per tonne below includes the uncertainty discount in the net removal volume proposed in response to question 4(d).

$500/ton

b. Please break out the components of this levelized price per metric tonne.

Component	Levelized price of net CDR for this project ($/tonne)
Capex	$350/ton
Opex (excluding measurement)	$75/ton
Quantification of net removal (field	$50/ton

measurements, modeling, etc.)[2]	
Third party verification and registry fees (if applicable)	$25/ton
Total	$500/ton

c. Describe the parameters that have the greatest sensitivity to cost (e.g., manufacturing efficiencies, material cost, material lifetime, etc.). For each parameter you identify, tell us what the current value is, and what value you are assuming for your NOAK commercial-scale TEA. If this includes parameters you already identified in 1(c), please repeat them here (if applicable). Broadly, what would need to be true for your approach to achieve a cost of $100/tonne?

Parameter with high impact on cost	Current value (units)	Value assumed in NOAK TEA (units)	Why is it feasible to reach the NOAK value?
Gasifier CAPEX	$8MM/MW (i.e. $8MM/MW * 5MW = $40MM)	$0.6MM/MW (i.e. $0.6MM/MW * 25 MW = $15MM)	We expect a rapid decrease in the price of gasification systems as we bring that technology out of the lab and into the real world. Our current price represents a cost estimate from an R&D facility, which will drastically go down as we move manufacturing in-house.
Biomass cost	$11.5/MMBTU	$5.75/MMBTU	In our submitted TEA, we assumed we could always find waste feedstock at $100/ton, which is quite conservative. We have explored many scenarios and think we could site plants to be continuously fed with feed <$20/ton, a typically seen value for agricultural waste. $5.75/mmbtu represents a cost of $50/ton
Transportation and Injection of Carbon	$60/ton	$15/ton	For this project, we are looking to truck our carbon a short distance to one of the first injection sites in the state. Future projects will look to be located on pipelines or other carbon infrastructure, which will also cost less as class VI well drillers optimize their operations

d. What aspects of your cost analysis are you least confident in?

Biomass costs. While we assumed very conservative figures in the TEA, the cost, availability, and

[2] This and the following line item is not included in the TEA spreadsheet because we want to consider MRV and registry costs separately from traditional capex and opex.

implications on uptime of waste feedstocks is highly variable, both geographically and seasonally. We're looking to develop tools to help us accurately predict these costs, as well as considering operational changes that could change the very ecosystem by which these feedstocks are handled, aggregated, and utilized.

e. How do the CDR costs calculated in the TEA spreadsheet compare with your own models? If there are large differences, please describe why that might be (e.g., you're assuming different learning rates, different multipliers to get from Bare Erected Cost to Total Overnight Cost, favorable contract terms, etc.).

The main discrepancy in our values is that the guidance given on the TEA spreadsheet was to ignore the value of co-products, both of which we produce, and view as important to ourselves and project partners. Our unit not only creates electricity which we can sell (for a higher-than average price if we keep our units small and in California through the Biomat program), but also 45Q credits, which add $85/ton of each ton of carbon sold. These two factors taken together, can add $175/ton of value for each ton we sequester, allowing us to charge less for credits, pay more for feedstock, and increase the attractiveness of our project.

f. What is one thing that doesn't exist today that would make it easier for you to commercialize your technology? (e.g., improved sensing technologies, increased access to X, etc.)

A more robust and predictable supply chain for waste products, both for forestry residues and agriculture residues. A wider network of carbon infrastructure (pipelines, injection sites).

6. Public Engagement

In alignment with Frontier's Safety & Legality criteria, Frontier requires projects to consider and address potential social, political, and ecosystem risks associated with their deployments. Projects with effective public engagement tend to:

- Identify key stakeholders in the area they'll be deploying
- Have mechanisms in place to engage and gather opinions from those stakeholders, take those opinions seriously, and develop active partnerships, iterating the project as necessary

The following questions help us gain an understanding of your public engagement strategy and how your project is working to follow best practices for responsible CDR project development. We recognize that, for early projects, this work may be quite nascent, but we are looking to understand your early approach.

a. Who have you identified as relevant external stakeholders, where are they located, and what process did you use to identify them? Please include discussion of the communities potentially engaging in or impacted by your project's deployment.

For our projects in California's Sierra Nevada Range, community outreach is key. We are not the first biomass technology to have tried a deployment in these rural and underserved communities and we are well aware many of these projects have failed due to a mishandled public engagement approach. For these projects, community stakeholders include: county government, CalFire, local air boards, forestry groups both public (USFS) and private (SPI), landowners (again both public and private, and at large scale and small scale), forestry contractors, community fire-safe-councils, electric utilities (PG&E), water agencies, watershed managers, NGO's, Native Groups, and of course, residents.

For our first project, we identified these groups manually, speaking with community leaders and asking for input and referral to further community stakeholders. This highlighted an opportunity, as we expand, to develop impactful processes to help us identify and engage stakeholders speedily.

b. If applicable, how have you engaged with these stakeholders and communities? Has this work been performed in-house, with external consultants, or with independent advisors? If you do have any reports on public engagement that your team has prepared, please provide. *See Project Vesta's community engagement and governance approach as an example and Arnestein's Ladder of Citizen Participation for a framework on community input.*

Our engagement with these groups has been in house as well as through external consultants, project partners, and independent advisors. At this stage we are planning to meet with more individually, as well as start to plant more publicly-accessible opportunities for community input. We have made several trips out to these communities to look at sites, examine forestry management operations, and discuss potential projects with partners, as well as attended local conferences in the region for forestry management and feedstock usage, which has introduced us to an even wider network of stakeholders.

c. If applicable, what have you learned from these engagements? What modifications have you already made to your project based on this feedback, if any?

By examining other, similar projects in the areas we look to deploy, we've learned a great deal about the community challenges those projects faced, and both the good and bad ways those projects have handled those issues. This was a large part of our decision to find a local project partner with whom to co-locate, instead of pursuing a greenfield site. We've also made site modifications to reduce the noise impact on surrounding homes. We're currently considering a second project site, based on input that that community is more receptive to the work we are doing, and has more to benefit from our deployment.

d. Going forward, do you have changes to your processes for (a) and (b) planned that you have not yet implemented? How do you envision your public engagement strategy at the megaton or gigaton scale?

We still have very far to go to make our processes of community engagement not only robust, but also agile. Due to our small project size (as far as infrastructure projects go), we need to codify processes that are not only effective, but also fast, or community engagement will become a very large part of project costs. We are constantly evaluating innovative ways to do this to allow us to deploy quickly, but also ensure that we don't fall into the traps that have befallen projects, especially in the bio-energy space.

7. Environmental Justice[3]

As a part of Frontier's Safety & Legality criteria, Frontier seeks projects that proactively integrate environmental and social justice considerations into their deployment strategy and decision-making on an ongoing basis.

a. What are the potential environmental justice considerations, if any, that you have identified associated with your project? Who are the key stakeholders? Consider supply chain impacts, worker compensation and safety, plant siting, distribution of impacts, restorative justice/activities, job creation in marginalized communities, etc.

> Deployment into California's Sierra Nevada range will involve many environmental justice considerations, which we hope to not only positively contribute to, but also harness to increase project resilience. Many of the communities under consideration for project siting fall under the federal Justice40 status of disadvantaged, defined as communities that are marginalized, underserved, and overburdened by pollution. At the state level, many of these communities fall under AB1550's classification of Low-Income communities, and given our sequestration potential in the San Joaquin valley, it is likely our operations will impact the many pockets of SB535 Disadvantaged communities there. The collapse of the Californian Timber industry has left the Sierra Nevada communities economically hobbled, and with growing wildfire risk, these communities are being especially unjustly exposed to the downsides of climate change. In the valley, The main stakeholders in these scenarios would be the local communities and governments in which we site our projects, as well as those that gather our feedstocks.

b. How do you intend to address any identified environmental justice concerns and / or take advantage of opportunities for positive impact?

> We see great potential for positive impact with our projects in the Sierra Nevada. The merchanting of carbon brings economic potential to these projects, allowing us to pay a higher price for feedstocks. Since these feedstocks are generated by forestry management practices, we can incentivise areas that would otherwise be untreated. Not only does this lessen wildfire risk, expanding local resilience, but all these actions are labor intensive, creating jobs in these communities. These managers are local experts, and letting them do this work instead of bringing in workers is not only good for community relations and environmental justice, but is good for operations. In a way, we see ourselves as a sustainable change from the former timber industry to selective forestry which offers sustainable economic development and climate resilience.
>
> In addition to these local benefits, our assets generate electricity and fresh water, which can help expand rural electrification, access to opportunity, and even lessen water burden in areas stricken by drought. Unequal access to these resources has left the area vulnerable, and rectifying it is a key environmental justice target.

[3] For helpful content regarding environmental justice and CDR, please see these resources: C180 and XPRIZE's Environmental Justice Reading Materials, AirMiners Environmental and Social Justice Resource Repository, and the Foundation for Climate Restoration's Resource Database

8. Legal and Regulatory Compliance

a. What legal opinions, if any, have you received regarding deployment of your solution?

> Mass deployment, especially in California, will heavily rely on governmental buy-in, both at the local communities where we source our projects, to state-level legislation that affects feedstock economics and availability. While there is nothing that makes our projects non-starters, there are risks if these stakeholders are mismanaged, and opportunities if they are managed correctly. As we are on a brownfield site, the current site owners have indicated that that should drastically streamline our permitting and CEQA process, as only construction permits will be needed, not site permits.

b. What permits or other forms of formal permission do you require, if any, to engage in the research or deployment of your project? What else might be required in the future as you scale? Please clearly differentiate between what you have already obtained, what you are currently in the process of obtaining, and what you know you'll need to obtain in the future but have not yet begun the process to do so.

> For this project, we will need CEQA review, which will heavily take into account feedback from the local air quality district. We are already engaging the Air district, and they are very excited due to our lack of smokestack inherent to our design. We will also have construction permits necessary for project execution, but this process should be simplified and assisted by PCWA, who are experienced with the site, local authorities, and community needs.

c. Is your solution potentially subject to regulation under any international legal regimes? If yes, please specify. Have you engaged with these regimes to date?

> EU regulation has strict rules on what feedstocks are truly considered "waste" feedstocks, and monitor how land use changes in their determination of LCA. We would seek to align ourselves with these methodologies (and others as they are developed), both in the name of conservatism and limiting liability.

d. In what areas are you uncertain about the legal or regulatory frameworks you'll need to comply with? This could include anything from local governance to international treaties. For some types of projects, we recognize that clear regulatory guidance may not yet exist.

> Regulatory frameworks that dictate LCA calculations/methodologies as they arise and influence our deployment. Certain jurisdictions view usage of waste biomass differently, and allow companies to claim differing carbon negativities from their use

e. Do you intend to receive any tax credits during the proposed delivery window for Frontier's purchase? If so, please explain how you will avoid double counting.

> For this deployment, only 45Q would be under consideration, which is focused on the physical processes of carbon capture and storage, and not on CDR. Other systems (eg. LCFS, voluntary markets) do not view this as double counting, and we have not received guidance to the contrary

9. Offer to Frontier

This table constitutes your **offer to Frontier**, and will form the basis of contract discussions if you are selected for purchase.

Proposed CDR over the project lifetime (tonnes) *(should be net volume after taking into account the uncertainty discount proposed in 4(c))*	1000 tonnes to Frontier
Delivery window *(at what point should Frontier consider your contract complete? Should match 1(f))*	Q4 2025 - Q4 2026
Levelized Price ($/metric tonne CO_2) *(This is the price per tonne of your offer to us for the tonnage described above)*	$500/tonne

Application Supplement: Biomass

(Only fill out this supplement if it applies to you)

Feedstock and Physical Footprint

1. What type(s) of biomass does your project rely on?

> This project will rely on forestry residues created by forestry management plans. Later projects could use other waste feedstocks, such as agriculture residue, MSW, residential green waste, or any other organic waste.

2. How is the biomass grown (e.g., kelp) or sourced (e.g., waste corn stover)? Do you have supply agreements established?

> For forestry residue, both public and private forestry managers and landowners create forestry management plans in line with initiatives from county to federal levels of government. These initiatives aim to protect natural lands and their communities from forest fires, and increase resilience to future fire threats. Once these plans are executed, a significant amount of biomass is created (anywhere from 10-40 tons/acre depending on time since last treatment), while some of this biomass has commercial use, a large majority (if not all of it depending on why the land was treated) is either left to decompose or is collected and burned. We will source our feedstocks by working with the aforementioned forestry managers and landowners, factoring in which land most urgently needs to be addressed, the economic viability of addressing such land, and the proximity of the land to our facilities. These parties are eager to address as much land as possible, and are excited about how the monetization of carbon credits associated with our projects could justify the treatment of lands previously seen as un-economic. For this project specifically, we may work with an intermediate party as well, to streamline the delivery logistics to our project site.
>
> For this feedstock, we currently do not have supply agreements in place, but we are in conversations with PCWA who are prepared to provide us with the needed waste feedstock from their own forestry management operations..

3. Describe the logistics of collecting your waste biomass, including transport. How much carbon emissions are associated with these logistics, and how much does it cost? How do you envision this to evolve with scale?

> Current economic challenges of getting the product to market present some uncertainty now as to what a mature feedstock logistics ecosystem could look like in the future. The current system of how these feedstocks are collected and moved is a "worst case" scenario in our model. In the name of conservatism, we have taken a small percentage hit to our net carbon produced to account for uncertainty in carbon emitted while creating our feedstocks, although arguments could be made that our feedstocks would be created as a result of other's activities anyway. Given the cost and availability

of more modern electric/hydrogen machinery, as well as our degree of separation from the groups collecting our feedstocks, we do not foresee this small contribution to our CI changing materially in the near future.

The movement of biomass, typically by diesel truck, has an impact on both the operational cost of our project as well as the longer-term LCA, and through both directly affects project economics. In our current model, each additional mile of truck transport costs us XXX and adds XXX tons of carbon to our LCA. Looking to the future, the more projects in an area are bought online, the higher the potential for lower-carbon and lower-cost options for logistics. For example, a single 1MW project could not justify the operational and cost complications of using rail to move feedstock, but a cluster of larger projects could make use of that.

4. Please fill out the table below regarding your feedstock's physical footprint. If you don't know (e.g. you procure your biomass from a seller who doesn't communicate their land use), indicate that in the table.

	Area of land or sea (km^2) in 2022	**Competing/existing project area use (if applicable)**
Feedstock cultivation	NA	NA
Processing	<1 Acre for a processing facility that could continuously feed a 5MW unit	Other industrial customers
Long-term Storage	NA (sequestered geologically)	Pore space for other carbon-capture projects

Capacity

5. How much CDR is feasible globally per year using the biomass you identified in question 1 above? Please include a reference to support this potential capacity.

From 9-17 GT/yr, depending on how DAC is co-located with our systems. Based on conservative feedstock estimates from Sandalow, D., et all, "Biomass Carbon Removal and Storage (BiCRS) Roadmap", combined with internal performance metrics.

Additionality and Ecosystem Impacts

6. What are applications/sectors your biomass feedstock could be used for other than CDR? (i.e., what is the counterfactual fate of the biomass feedstock)

For forestry residue, non-merchantable wood is left to decompose, or locally aggregated and burned to reduce its role feeding wildfires. In the current California economic ecosystem, there is a massive surplus of forestry residue from natural lands management which cannot economically reach markets.

By reducing wildfire risk, we are actually increasing systemic resilience to these climate threats, while at the same time generating clean power.

7. There are many potential uses for waste biomass, including avoiding emissions and various other approaches to CDR. What are the merits and advantages of your proposed approach in comparison to the alternatives?

Most usage of waste biomass currently is in the realm of either pure CDR (eg. conversion to bio-oil, bio-char, physical sequestering) or for creation of lower-CI products (eg. combustion in a boiler, conversion to biofuels, displacing non-waste feedstocks in animal feed). Our approach does both of these simultaneously, creating what would be considered carbon neutral products while capturing and sequestering the associated CO2, to make them truly carbon negative. This allows us multiple paths to monetization, increases community buy-in, broadens the potential project partners, and diversifies our income streams for a more robust financial model. This approach also expands community involvement, as we provide opportunities for local industry to grow, decarbonize, and contribute to the management of their own communities. By generating electricity instead of consuming it, we have found a lot of industrial partners interested in the possibility of co-location, and while this does increase the complexity of our stakeholder quilt, it also provides invaluable local experience in permitting, offtake, employment, and regulatory management.

8. We recognize that both biomass production (i.e., growing kelp) and biomass storage (i.e., sinking in the ocean) can have complex interactions with ecological, social, and economic systems. What are the specific, potential negative impacts (or important unknowns) you have identified, and what are your specific plans for mitigating those impacts (or resolving the unknowns)?

For forestry residues, the current lack of viable usage for the biomass has already significantly affected the lives of these rural communities. These communities traditionally relied on logging for economic prosperity, which has been heavily regulated, driving opportunity out of these areas. While we view our technology as providing a future of sustainable jobs that work in tandem with forestry management, we have to acknowledge the challenges in creating a truly sustainable ecosystem. The current fire-prone climate in which we find ourselves is the direct result of what was in the past viewed as "best practice". We must be humble and adaptive, while continuing to base our projects on the most up to date science on forestry management. At the same time, by creating economic value, we also have to ensure that this doesn't lure in groups who are not aligned with our mission of helping to heal the forests. This will come down to careful selection of project and operations partners, and by close engagement with the community both during project execution and asset life that we are still fulfilling our original purpose. If done properly, selective forestry is considered one of the few truly sustainable economic endeavors that isn’t limited to a micro-scale.

Frontier

Application Supplement: Geologic Injection

(Only fill out this supplement if it applies to you)

Feedstock and Use Case

1. What are you injecting? Gas? Supercritical gas? An aqueous solution? What compounds other than C exist in your injected material?

Supercritical CO2 which will have a chemical makeup of class VI injection spec (>95mol%CO2) or better, in addition to strict requirements for other post-combustion products

2. Do you facilitate enhanced oil recovery (EOR), either in this project or elsewhere in your operations? If so, please briefly describe.

No

Throughput and Monitoring

3. Describe the geologic setting to be used for your project. What is the trapping mechanism, and what infrastructure is required to facilitate carbon storage? How will you monitor that your durability matches what you described in Section 2 of the General Application?

Our injection sites will be in one of several proposed locations in San Joaquin Valley in central California. This area has seen large interest in its subsurface properties for geologic sequestration: Porous formations that can hold large quantities of carbon, capped by impermeable rock to keep it in place, with several levels of confining formations acting as redundancy. As far as infrastructure goes, as class VI wells, these future sites will have requirements on the surface and subsurface monitoring of their performance, the reporting of which will be contractually agreed upon with our project partners.

4. For projects in the United States, for which UIC well class is a permit being sought (e.g. Class II, Class VI, etc.)?

VI

5. At what rate will you be injecting your feedstock?

As produced: 180 tons/day by truck into injection site, and later by pipeline for future projects

Environmental Hazards

6. What are the potential environmental impacts associated with this injection project, what specific actions or innovations will you implement to mitigate those impacts? How will they be monitored moving forward?

The class VI wells we plan to use have stringent EPA requirements to be sited, permitted, built, and monitored (EPA-HQ-OW-2008-0390). This is all to address the environmental impact of such wells, with a particular focus on making sure they do not impact underground water reservoirs. Since our project partners will be owning and operating the injection sites, we will have contractual requirements for them on permanence, leakage, and how often and in what way we can audit their reporting.

7. What are the key uncertainties to using and scaling this injection method?

The availability and creation of new injection sites. Building injection sites is in itself a long, multi-stakeholder project, involving multiple levels of government and regulatory bodies. Most notably, in California, an area where there is immense interest for us for future deployments, no class VI wells have been built to-date, presenting a key risk to project construction if they cannot come online in time. A project built without a sequestration site lined up is a stranded asset, or may require further trucking, which will dig into the LCA. Currently, several different companies are in permitting to construct these wells, and we follow their project updates with great interest.