Frontier

[ReNew Power Pvt. Ltd.]

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

ReNew Power Pvt. Ltd.

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

India

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

1. Deepak Gupta [redacted]
2. Piyush Kumar [redacted] and
3. Ishan Nagpal [redacted]

Brief company or organization description

ReNew Power is India's largest clean energy company with more than 8 GW of operational renewable capacity and an overall capacity of more than 13 GW (this includes committed pipeline of more than 5 GW). ReNew is listed on the NASDAQ under the symbol RNW and also has marquee investors such as Goldman Sachs, The Canada Pension Plan Investment Board, Abu Dhabi Investment Authority, JERA a JV company of two of Japan's largest utilities. We currently contribute 1.8% to India's power capacity and help avoid 1.1% of the emissions from the power sector.

It is ReNew's Purpose to *"Create a Carbon Free World by Accelerating the Clean Energy Transition".* In that endeavor we have diversified from being a pureplay renewable IPP to a utility company having investments in Green Hydrogen, Carbon Offsets, Solar Cell and Module manufacturing, Battery Energy Storage Capacities, Energy Markets, Hydropower assets, Digital services for the energy sector among others.

In our journey in becoming India's premier clean energy organization we have received several awards and accolades such as ReNew becoming the world's 1st clean energy company to be recognized as a Lighthouse by World Economic Forum in 2021.

ReNew boasts of a robust sustainability and governance culture and has a high quality and experienced team with consistent track record of success. Since the company started in 2011, we have directly and indirectly given jobs to 86000 professionals. ReNew through its various CSR initiatives has also impacted over 0.4 mn lives through our various flagship initiatives across 200 villages in the country.

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.

Paddy stubble burning is a big issue in India, which causes a spike in pollution in large swathes of northern India. Farmers resort to burning of agricultural waste, as mechanized methods of stubble removal are costly, and farmers are unable to get proper remuneration for disposing off their stubble waste safely & in an environmentally friendly manner.

Stubble burning releases huge quantities of toxic pollutants in the atmosphere including harmful gases like methane (CH4), Carbon Monoxide (CO), Volatile organic compounds (VOC) & polycyclic hydrocarbons (Figure 1).

Figure 1: Stubble Burning in Punjab, India (Source: Down to Earth)

We propose using processes such as gasification & combustion, to convert the biomass into safer products like H_2 and CO_2 (Figure 2). While the H_2 can be used for various applications like ammonia, fertilizer and ethanol production, we propose to sequester the CO_2 in deep saline aquifers with depth>800 metres, so that there is net removal of Carbon Dioxide (Figure 3). Saline Aquifers are widely available in northern India and have been studied widely for their CO_2 sequestration potential (Vishal,

[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.

October 2021).

Thus, the proposed solution will prevent large amounts of greenhouse gases, including toxic components, from entering the atmosphere. At the same time the proposed solution will safely sequester Carbon Dioxide for the long term.

The proposed location for the project is Fazilka district in Punjab, which has highly saline aquifers contaminated with fluoride.

The scale of the project is proposed to be 100,000 tonnes/year of Carbon Dioxide removal.

We are the first organization to integrate biomass gasification with deep saline aquifers storage, which will help to mitigate pollution cause due to paddy stubble burning. In addition, we can use the waste heat to generate renewable energy (not considered for commercial calculations under present proposal). This makes our solution unique.

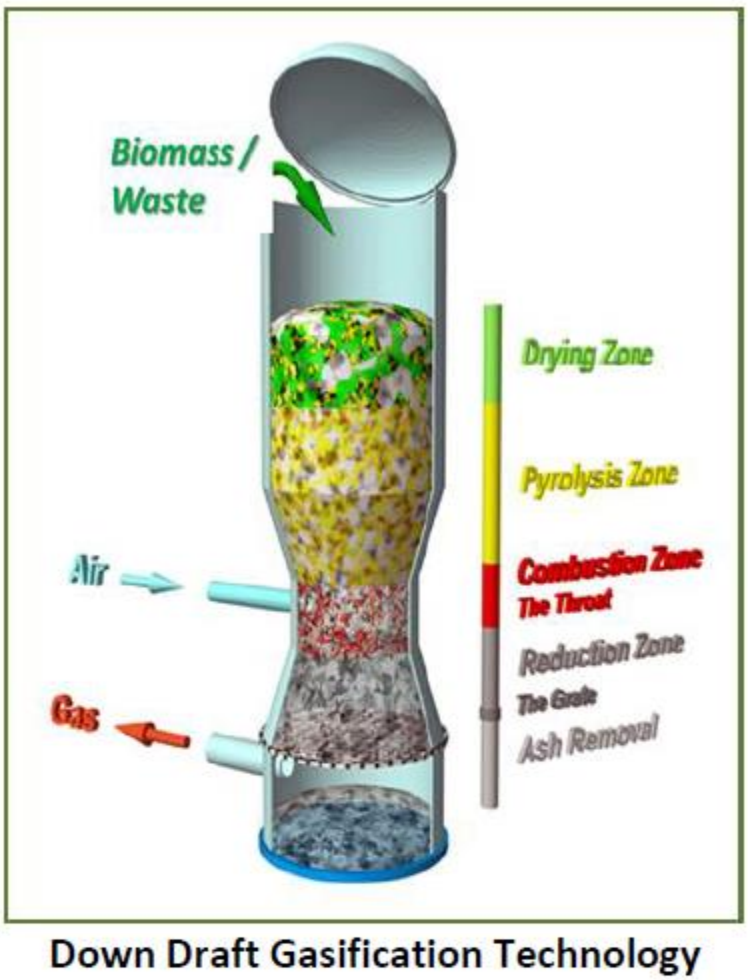


Figure 2: Biomass Gasification (Source: Gasifier Partner)

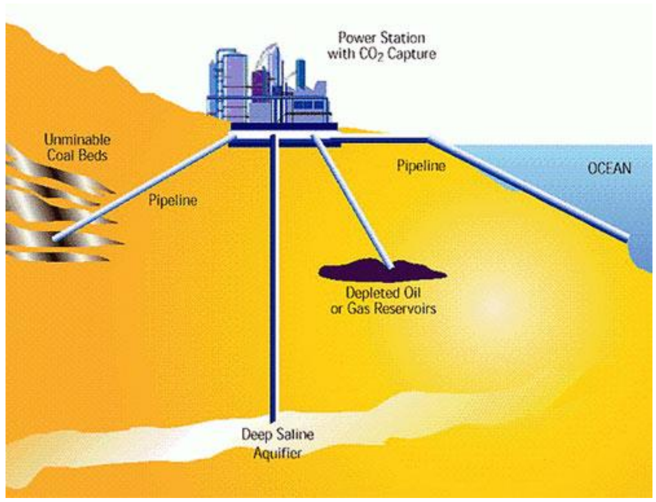


Figure 3: CO_2 injection in Saline Aquifers (Source: Earth Sciences Society)

The following system schematic in Fig. 4 depicts the main process steps of our proposed solution.

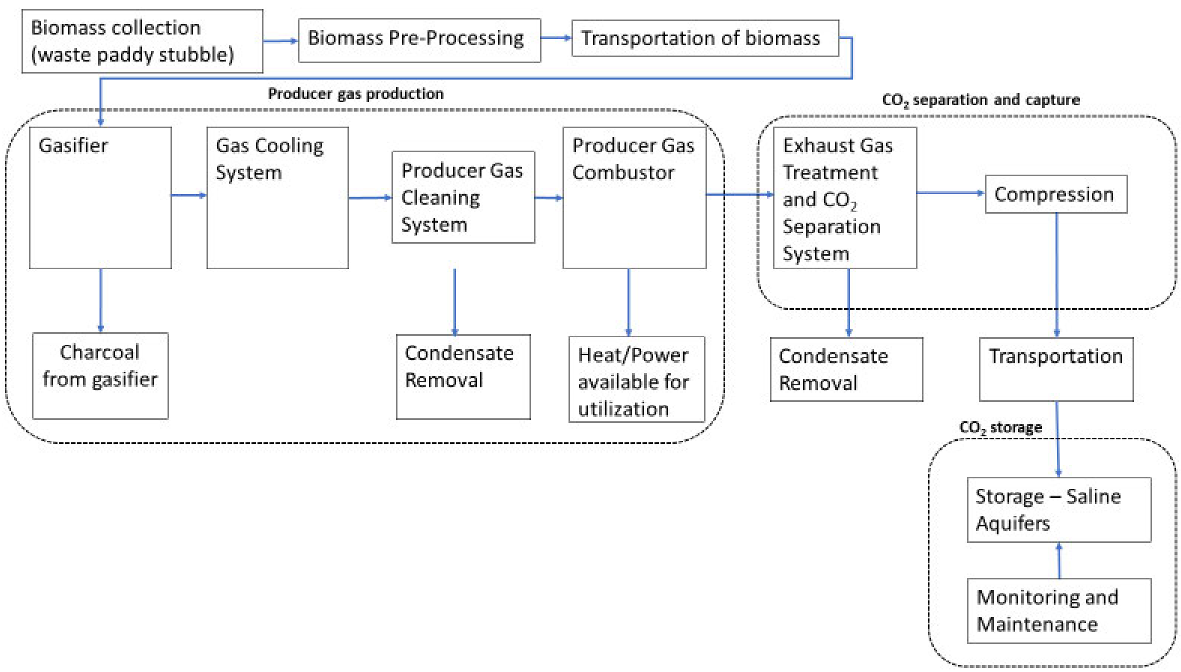


Figure 4: System schematic for Carbon Capture & Storage

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.

Our estimates for TRL levels of the different process steps are as follows:

1. Gasification – TRL 9

2. Combustion – TRL 9
3. Compression – TRL 9
4. Sequestration in saline aquifers – TRL 5

We do not have inhouse performance data, however, Gasification and Combustion of Biomass and Compression of CO_2 are well known industrial processes. Performance data is easily available from vendors who make equipment for gasification, combustion and compression. We have received the data from one of our vendors for gasification which have been provided in section 1.c.

For sequestration, literature references are available which say carbon dioxide storage essentially involves injecting CO_2 at high pressures into porous formations that are conducive for long-term storage over periods of the order 10^4 years. (Yashvardhan Verma, 2021)

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?
Gasifier Output			
Peak Rated Gas Flow (Nm3/hr)	2700		
Average Gas Calorific Value (Kcal/Nm3)	> 1,000		
Maximum Biomass Consumption (Kg/hr)	1,500		
Gasification Temp. (°C)	900 – 1,100		
Turn Down Ratio	Not less than 50% of rated capacity		

Compression parameters			
Initial pressure	0.1 Mpa		
Final pressure	15 MPa		
Cut-off pressure	7.38 MPa		

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?

ReNew has on its rolls more than 2000 multidisciplinary professionals in the field of project development, design and engineering, procurement, and construction.

Our internal in-house teams that work on the end to end project development including land acquisition, permitting and approvals, project design and engineering, project management, construction and subsequent asset management for our entire fleet under operations.

We also have a dedicated in-house technology team whose focus is to drive innovations in our business. ReNew also has developed capabilities for production of green H_2 which comprises of professionals from the oil and gas sector, which will help us in storage estimations and studies. For instance, ReNew has designed and is patenting a floater structure which supports solar panels to be placed in water bodies like ponds and lakes

ReNew has also partnered with IIT Delhi a premier technology focused institution based out of India and we have established a ReNew Power Center of Excellence located at their campus, which will help us in conducting ongoing research to finetune our project deployment strategy.

We are also undertaking discussions with some of the other leading technical institutions for support for research during the implementation phase. We have for instance similarly in the past worked with colleges in solving real world problems and are currently in that respect working on carrying out cutting edge algorithmic research with CalTech on how dynamic orientation of turbines can maximize plant output

We, however, do not have in-house geo-technical capabilities and we are focusing on getting external consulting support in the short term and developing these skills by way of recruitment in the medium to long term.

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
Gasifier unit supplier	Design, manufacturing, supply, erection and commissioning of gasifier unit	Discussing potential collaboration with high degree of confidence of a partnership.
Farming Community	Supply of rice stubble feedstock for gasifier unit	Yet to be approached only preliminary discussions however, high degree of confidence given this provides a revenue stream for rice stubble which is currently of no value and burnt resulting pollution
Saline Aquifer identification, Drilling	Geological survey, Saline Aquifer identification, Drilling of wells, Carbon Dioxide injection, Monitoring & Verification, Well maintenance	Discussing potential collaboration with high degree of confidence of a partnership.

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?

> The project development will start from Dec '22. CDR delivery is expected by May '25. Decommissioning of the facility will happen at the end of project life, which will be in May '40.

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.

> CDR is to begin in the end of Q2 2025, and will continue for 15 years, ending Q2 2040. Assumptions: Plant life is 15 years, equipment availability is 70% (assuming higher maintenance requirements than vendor specifications which state 80% availability)

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	
2024	
2025	50000
2026	100000

2027	100000
2028	100000
2029	100000
2030	100000
2031	100000
2032	100000
2033	100000
2034	100000
2035	100000
2036	100000
2037	100000
2038	100000
2039	100000
2040	50000

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	Plant and sequestration siting	Q3 2023
2	Environmental/administrative/land clearances	Q3 2024
3	Contracts finalization and equipment purchase	Q4 2024
4	Plant commissioning and startup/underground injection	Q2 2025

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

Since we will be using mature processes with commercially available equipment, we do not foresee the possibility of our processes being patented.

k. How are you going to finance this project?

ReNew Power is a leading renewable energy IPP based out of India and has been at the forefront of innovation. ReNew has an operating base of more than 8 GW with a pipeline of an additional 5 GW. Today, we satisfy the energy needs of 13 million Indian citizens while mitigating 0.5% Carbon Dioxide emissions of India. ReNew is listed on the NASDAQ under the symbol RNW and also has other marquee investors such as Goldman Sachs, ADIA, CPPIB and JERA. ReNew has been designated as a global World Economic Forum Lighthouse for cutting edge technology and innovation in the clean energy sector. We have undertaken several innovative projects such as the Round the Clock renewables where we are supplying base load renewables to the grid on round the clock basis at a cost of under 4 cents/kWh. Given our DNA of innovation we intend to pre-finance this initiative with our internal resources and R&D budget.

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 do not have any CDR buyers for this project as on date. Our focus is currently on development of project and we have not approached or engaged in discussions with buyers.

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 currently in the first of its kind project, and for this we are not working on any other revenue streams other than CDR pathway. However, the heat so generated in the process can be used for power generation which can then be sold to distribution utilities or other retail consumers around the project location.

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**
Technical Risks	
Leakage during transportation	Vehicles with properly design containers to handle pressurized CO_2 will be used

Combustor fouling	Direct combustion of biomass can lead to fouling of equipment due to presence of solid components. We are using a 2-step process in which we gasification is done at lower temperatures, which also removes the solid components of the biomass.
Project Execution risks	
a. Direct leakage pathways created by wells and mining. b. Well blow-outs (uncontrolled emissions from injection wells)	Techniques for remediating leaking wells have been developed and should be applied if necessary. Possible source of high-flux leakage, usually over a short period of time. Blowouts are subject to remediation and likely to be rare as established drilling practice reduces risk.
Natural leakage and migration pathways through a degraded cap rock as a result of CO_2/water/rock reactions.	Proper site characterization and selection, including an evaluation of the hydrogeology, can reduce risk of leakage. Detailed assessment of cap rock and relevant geochemical factors will be undertaken.
Saline water production	Desalination plants will need to be installed to process the saline water pumped out from the saline aquifers
Soil mixed with stubble can reduce efficiency of gasifier.	Before inserting the feedstock, it will be washed and dried to protect the efficiency of the gasifier.
Financial Risks	
Uncertain biomass prices	Since the stubble prices are not fixed, there can be a great variability in price with respect to source.
Carbon market volatility	Volatility of Carbon market affects the carbon credits prices significantly.
Any other risks	
Policy risk	Government may institutionalize a policy for the farming community in respect of stubble utilization which can impact our feedstock, however continuous research and development for alternate feedstocks we intend to make our process robust.

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?

> For around 70 years, abiotic resources such as depleted oil and gas fields and saline aquifers have been the primary options for CO2 sequestration. The carbon dioxide storage potential found in saline aquifers is very high, with a global capacity estimated between 300 and 10,000 GtCO2 (Dirk Van Essendelft).[2]
>
> In India, the highest carbon dioxide storage potential is in deep saline aquifers, with a capacity of 300-400 BT[3] (Rohit Shaw, 2022). These aquifers consist of water permeable rocks, saturated with salt water, which are generally not suitable for irrigation and other purposes. In one of the studies, it has been found that carbon dioxide storage, by injecting CO_2 at high pressures into porous formations, is conducive for long-term storage over periods of the order 10^4 years (Yashvardhan Verma, 2021).
>
> Based on the data available in the literature, deep saline aquifers can be considered as a permanent solution for carbon dioxide storage. The storage process can be designed to place large volumes of CO2 in forms that will not escape the aquifer any faster than fluids originally present in the aquifer[4] (Kumar, et al., 2005).
>
> Upper & Lower bounds: 1000 – 10000 years

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?

> Durability risks: While theoretical studies posit that saline aquifers can store Carbon Dioxide anywhere in the range of 1000-10000 years, obviously there is no data available for an actual project which would corroborate this.
>
> Physical risks: There are physical risks involved with leakage of Carbon Dioxide during the capture, transportation, and storage process.
>
> Socioeconomic risks: No socioeconomic risk is associated with the proposed technology as it is not resulting into relocation or rehabilitation of any kind.
>
> Uncertainties: There are various uncertainties associated with the storage process. For example, drilling can lead to fracturing in the caprock, which can lead to future leakages.

[2] https://personal.ems.psu.edu/~fkd/courses/egee580/Seqeustration_final_report.pdf

[3] https://www.sciencedirect.com/science/article/pii/S2772656822000070#:~:text=India%20holds%20a%20substantial%20geological,are%20operational%20in%20the%20country.

[4] https://onepetro.org/SJ/article-abstract/10/03/336/112541/Reservoir-Simulation-of-CO2-Storage-in-Deep-Saline?redirectedFrom=fulltext

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	1,500,000 tonnes of CDR
Describe how you calculated that value	Conservative estimate of 10 gasifiers running in parallel over 15 years, at 70% availability.

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.

Zero so far

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.

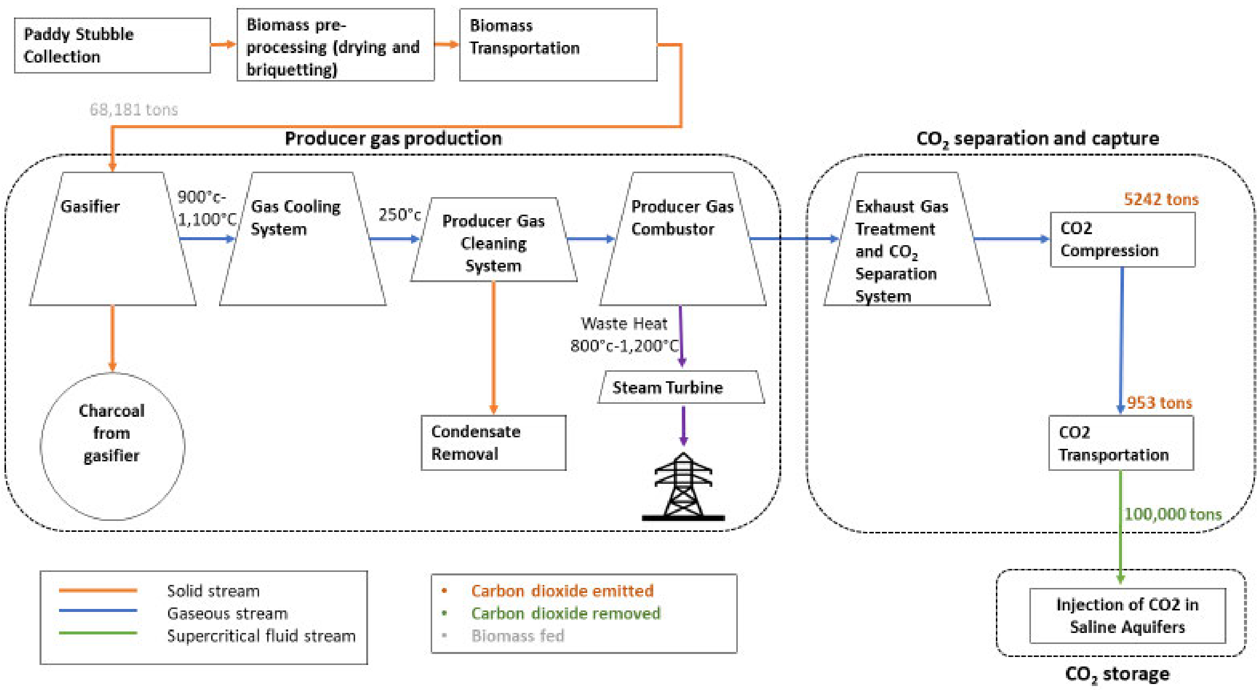
There is potential to absorb/ scrub off Hydrogen from the cooled producer gas so generated as an output of the gasification process. If hydrogen is adsorbed from cooled producer gas and not combusted, around 1400 tons of hydrogen would be generated. This Hydrogen which is green in colour as it comes from biomass and not any other fossil fuels, can lead to avoided emissions in several hard to abate sectors such as steel, petrochemicals, transport etc. We have done some preliminary estimations and it is our most conservative assumption that this Hydrogen can result in avoidance of 12,600 tons of CO_2 over project lifetime additionally.

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*	118810

described below this table)	
Emissions / removal ratio *(gross project emissions / gross CDR–must be less than one for net-negative CDR systems)*	0.079
Net CDR over the project timeline *(gross CDR - gross project emissions)*	13,81,189

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).



In this process, stubble will be used as biomass feedstock, which will be washed, dried and briquetted before feeding it into the gasifier. The ready to use stubble will then be gasified in the gasifier at a temperature between 900 – 1,100°C which will result in formation of producer gas. The producer gas will then be combusted to produce carbon dioxide. This carbon dioxide will then be compressed and transported to the sink site, which in our case will be deep saline aquifers, where with the process of drilling, a well of depth ~800 m be created. The carbon dioxide will then be injected in the well with the help of pumping. This stored carbon dioxide will then be kept under watch by installing sensors at different distances. Time laps seismic, pressure and temperature, diagnostic logs for cement integrity, fiber optics-based DAS and DTS etc. can be used to monitor leakage.

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 not considered the emissions for the process steps before the CO_2 is generated. The emissions involved in fabricating the Gasifier & Combustion equipment are not known at this stage.
>
> Also, we have not included emissions from the Gasification & Combustion stages, as all the produced CO_2 is intended to be sequestered.
>
> However, we have considered the emissions emitted during transportation of CO_2, as well as the emissions involved in well drilling. Please note that the emissions during transportation might vary with the distance between the source and the facility.
>
> Additionally, construction emissions of pre-existing equipment (drilling, pumping etc.) are not included in this LCA.

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.

Process Step	**CO_2(eq) emissions over the project lifetime (metric tonnes)**	**Describe how you calculated that number. Include references where appropriate.**
Well drilling	119150	In order to calculate the emissions generated in drilling, we have considered time of drilling, HP of drilling machine and its load factor. We have assumed that the machine will be in operating condition for 80% of the total time required for the process. (Agriculture, n.d.)
Input emissions (100 km transport)	78642.9	We used product of emissions generated per ton per km and tons of feedstock to be transported annually (Pierre-Louis Ragon, 2021)

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.

Biomass conversion:

Stubble sources and transportation distances will be kept on record for calculation. At the gasifier plant level, the mass and energy balance will be calculated using data from actual metered inputs and outputs.

CO_2 sequestration:

Monitoring, measurement and verification (MMV) in CCS project is carried out at surface and subsurface for conformance, containment and well integrity. An observation well will be dug which will contain sensors which will monitor the parameters of the sequestered CO_2 on a real time basis. In addition, Injection of CO_2 will be metered and will be assessed over regular time intervals. Different technologies are available and will be sued for surface leakage and subsurface leakage and plume movement.

This is a preliminary and initial plan for MRV, which will be improved in the project development process and we will continue to work on finalizing our process, we will also continue to engage with Frontier in the entire MRV process, should our application for pre-purchase be accepted.

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.)*

We will use InSitu Fluid Analyzer system for direct measurement of sequestered CO_2 at injection sites through a separately dug Observer well, which will provide us real time data for Carbon storage.

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	Mass of CO_2 injected for geologic storage - Negligible (<1%)
Leakage	Mass of CO_2 that escapes the storage system - Low (1-5%)
Energy	Emissions associated with energy use for the process - Low (1-5%)
Indirect Land Use Change	Emissions from indirect land use change - Low (1-5%)

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?

1. Storage: 1%
2. Leakage: 2.5%
3. Energy: 2.5%
4. Indirect Land Use Change: 5%
5. Uncertainty for net CDR: 11%

a. 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.?

This project will be the first project of its kind in India that will embark on the CDR pathway. It is our belief that if CDR has to become successful, there have to be at scale projects in the Global South not just in the Global North. Projects have to be deployed in Africa and Asia for us to be able to achieve our Global Climate Goals. It is our assumption that this project will initiate lot of interest on CDR in India and at the same time it will also address a pressing need of policy makers in India, problem of pollution in the National Capital Region (NCR). We intend to develop template models by working with environmentalists on the reduced pollution levels in NCR as a result of avoidance of stubble burning in paddy fields. A detailed impact assessment shall be commissioned by ReNew to measure the outcome of the project.

b. 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)?

> To the best of our understanding, there is not existing protocol for our project type. ReNew has in-house capabilities for carbon project development and has been working on such activities for our existing portfolio. We have an annual volume of 4.5 Mn credits that we generate from our portfolio and work towards its development. For instance we are currently working on a under development digital MRV process for our existing projects to improve the results, introduce more quality, measurability in the entire process. In this case, we will along with external partners work to develop a methodology for verification and registration of the project. We intend to also work with third party auditor for verification of delivery of credits in this project.

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).

> $**162.84** /tonne CO_2
>
> This price does not include the uncertainty discount in the net removal volume.

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

Component	**Levelized price of net CDR for this project ($/tonne)**
Capex	30.63
Opex (excluding measurement)	131.13
Quantification of net removal (field	0.75

measurements, modeling, etc.)[5]	
Third party verification and registry fees (if applicable)	0.33
Total	162.84

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?
Biomass waste	Rs 5/kg[6]		
Gasifier cost	Rs 77000000/unit[7]		

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

> a. Transportation cost – as it will be a function of multiple biomass sources
>
> b. Drilling cost – This will depend on the depth of the caprock, under which the saline aquifers are available

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.).

> There is only a slight difference in the CDR cost, which may have arisen from using the standard levelised costing formula with an 11% reduction rate unlike used in the TEA model.

[5] 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.

[6] Current USD to INR conversion is INR 82.40 to 1 USD

[7] Current USD to INR conversion is INR 82.40 to 1 USD

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.)

> - Supply chain for procuring & consolidating biomass on a regular basis, from different farmers
> - Stable biomass pricing
> - Low cost drilling and storage technology to scape up the project in a cost optimal manner. Our aim is to do large scale commercial deployments at low cost so that it becomes a reality even in the developing and LDC countries without significant external support.

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.

> Farming community in the northern Indian state of Punjab is one of our key stakeholders. Pollution problem of the National Capital region in the winter months is exacerbated due to burning of rice stubble/ straw so as to clear the land for sowing of the wheat crop. With our preliminary discussions and secondary desktop research so far with the farming community, we have understood that farmers have to spend extra money to remove the crop residue such as expensive new equipment, leaving them to fall back on the crude but low-cost method of burning of stubble and straw.
>
> This project aims to engage with farmers and providing them with alternate sources of income that will incentivize them to invest in equipment for clearing stubble and not burning it. We have identified our stakeholders and also have a broad strategy of engagement in place, as a result of our existing experience in nature based carbon interventions such as agroforestry, sustainable land management practices etc. where we have designed and in-practice models of engagement with the rural community particularly farming communities.

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.*

We have not currently engaged with stakeholders and communities for this project. However, for other projects our engagement plan includes multiple levels of engagement to bring farming community on board and make them a part of the overall project design. Our Project shall include a buy-in from the community and shall include tangible co-benefits for the community during the implementation. Our framework of working with the community includes working with and creating Farmer Producer Organizations (FPOs) which are local Self Help Groups of the farmers with a designated CEO from among the community. Such FPOs are designated to take up commercial activity on behalf of the farmers. To further make it robust, we intend to combine FPOs into federations at district levels for providing them strength as a cohesive community.

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?

As discussed above, we have not conducted any engagement for the present proposed project particularly, however, we have iterated our engagement strategy for communicating with the farming community and subsequently created a plan for our other projects. In the said engagement plan, we have designed a framework where various levels of the community come together to create an organization design that eventually becomes a self-sustaining unit working for the overall benefit of the stakeholders. The self-sustaining unit works towards creating an ecosystem for community upliftment, rewards & recognition, revenue sharing etc. It is our intention to plough back a significant share of Carbon revenues from the Frontier pre-purchase back into the communities for their overall development.

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 are engaging with communities of several million women folk that are part of farming communities for our existing projects and therefore we are confident of replicating our learnings and engagement plans from those interventions into this project.

7. Environmental Justice[8]

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.

> This project by design has a positive impact on the environment as it seeks to address a key problem for Delhi in terms of the pollution that rice stubble creates. Air pollution was the top risk factor for death in India in 2019, killing an estimated 1.67 million people, according to the Global Burden of Disease report. Over half the cases of chronic obstructive pulmonary disease (COPD) in India is attributable to ambient and household air pollution, according to a 2018 Lancet Global Health research paper. In developed countries, 80% of COPD is caused by smoking. A study from the All India Institute of Medical Sciences (AIIMS) shows that there is a nearly 20% increase in the number of patients seeking emergency care for acute respiratory symptoms even when the air quality is slightly bad with PM2.5 levels recorded between 50 and 100 micrograms. At its peak -- between October and January when Delhi records a PM2.5 levels of around 800 micrograms – this number goes up significantly. The sheer health benefit of this project particularly for the marginalized in Delhi who do not have access to modern equipment such as air purifiers and masks is extremely positive.

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

> The project shall create several opportunities for a positive impact not just on wider Indian population including the marginalized as a result of reduction in pollution but also on the communities in the project area that get additional livelihoods and revenue from stubble removal as well as employment generated as a result of project operations.
>
> One possible negative impact could come from the drilling operations required to access saline aquifers. Drilling through caprock in general can have unintended & unforeseen consequences, although in our case the choice of location within the state of Punjab lies in Zone 2 seismic zone, which is considered to have the lowest risk of seismic damage.

8. Legal and Regulatory Compliance

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

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[8] 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

We have not received any legal opinions on our solution thus far, as we have not foreseen the need for seeking any such opinions for our project design.

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 the deployment of the project, particularly storage of carbon so sequestered, we shall need to seek permits for storage in underground saline aquifiers or used oil wells as the case maybe in the scaleup stage. These permissions shall be issued by statutory authorities in India and given our strong advocacy strength as an organization, we are confident that we will be able to receive those well in time. We also believe that the solution that we are proposing is an Achilles Heel for the government agencies and such interventions will be well appreciated as they intend to solve the problem at its core.

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?

We do not envisage that the solution shall be subject to regulation under any international regimes.

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 regimes for storage of carbon which this project ultimately aims to do, do not exist in India. This will be a first of its kind project and therefore we will have to work with policy makers on designing regulatory and policy programs for supporting such removals based projects.

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.

We do not intend to receive any tax credits during the proposed delivery window for Frontier's purchase.

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))*	1,124,063 Tonnes
Delivery window *(at what point should Frontier consider your contract complete? Should match 1(f))*	May 2040
Levelized Price ($/metric tonne CO_2) *(This is the price per tonne of your offer to us for the tonnage described above)*	$182.97 Tonnes CO2

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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?

Biomass will be the stubble and residue straw from paddy farmers in Punjab and Haryana which are northern states in India and are considered to be the rice bowl of India.

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

We are not growing biomass. The biomass will be sourced from the farmers growing wheat and rice in the respective states. This biomass as has been explained at various places in the application is currently burnt by farmers resulting in emissions. We have as described above in the section on engagement strategy existing and on-going relationships with the farming community for other nature based carbon projects. We will leverage those relationships to foster new agreements with paddy growing farmers and get into supply agreements during the project development phase.

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?

The waste biomass will be collected from the farmers and transported in lorries/trucks to the site. The carbon emissions involved during the transportation process as have been estimated and provided in Section 3(g) of the application are 78642.9 tonnes. With scale, we intend to use more efficient sources of transportation such as green EV network for our biomass thereby reducing the emissions. Such plans have not yet been put in place.

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	Areas where rice and wheat are grown in Punjab and Haryana	Currently being burnt as there is no alternate usage/ revenue source.

Processing	N/A	
Long-term Storage	N/A	

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.

Biomass stubble burning is a significant source of air pollution in many parts of the world being only the 3rd after industrial and vehicular emissions. On a global scale, stubble burning constitutes about one-fourth of the total biomass burning (inclusive of forest fires).

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)

Governments of Punjab, Haryana, Uttar Pradesh and Delhi have been asked to allocate a subsequent amount of their budget to provide crop residue management machinery to the farmers. Apart from this other means are being followed to manage the crop residue.

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?

All the methods proposed will incur cost to farmers but this method will generate extra revenue and employment opportunities in the villages. Since the area under agriculture is vast the current methods proposed will not be enough to manage the crop residue. But CDR project will involve door step collection of biomasses from the farmers and hence will be very effective.

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)?

The project does not involve growing of biomass but will procure it from the existing sources. Storage of biomass is not a part of this project because the raw material will be burnt in gasifiers. Therefore, all the complex interactions and risks are eliminated.

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?

> We will be injecting supercritical carbon dioxide. No other compound other than CO_2 will be sequestered.

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

> No, we do not facilitate enhanced oil recovery.

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?

> To store carbon dioxide safely and permanently, we need deep saline aquifers, which contain undrinkable salt water. Theses aquifers contain brackish water that has excessive salt which are of no use (Rohit Shaw, 2022). A suitable CO_2 reservoir needs a layer of porous rock at the correct depth of around 800 m to hold the CO_2, sufficient capacity and an impermeable layer of caprock to seal the porous layer underneath. The reservoir can be identified by carefully studying the geology of the site. After the site is identified, with the help of drilling, the CO_2 can be stored in the aquifer.
>
> Once the CO_2 is trapped via pumping under the caprock, three additional mechanisms namely, residual trapping, dissolution trapping and mineral trapping will show that the safety of CO_2 storage sites actually increases over time. In residual trapping, some of the CO_2 injected in the smaller pores simply move even under pressure. In dissolution trapping, a portion of CO_2 dissolves in the salt water. This CO_2 rich water becomes heavier than the surrounding liquids and migrates downwards where it reacts to form minerals such as those found in limestones. This is known as mineral trapping.
>
> A site with potential to store carbon dioxide in deep saline aquifers will be required. To inject carbon dioxide, a well needs to be created through drilling and then CO_2 can be injected through a pump. (Platform, 2010)

To ensure that the CO_2 storage site functions well, a rigorous monitoring will be undertaken at the site selection stage and will continue as long as necessary. This monitoring will be continued even after the well is closed. Borehole data can help monitor seepage. Sensors installed at the storage site can help monitor any sort of leakage. Time lapse seismic data, pressure and temperature data, diagnostic logs for cement integrity, fiber optics-based DAS and DTS etc. can also be used to monitor data.

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

NA

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

0.01–0.1 kg/s

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 leakage in the storage container can impact protected groundwater aquifers, shallow soil zones, and the atmosphere. Such leakage can potentially contaminate drinking water and other subsurface resources, harm vegetation, and lead to increased atmospheric emissions. Possible leakage pathways include transmissive faults and fractures, although these can often be avoided through careful site selection and characterization and/or through active pressure management of the storage site. A more common leakage pathway for CO_2 leakage is along defective wells, particularly in regions with an extremely large number and density of wells.

This can be mitigated by monitoring the site at the initial stage of site selection process and continuing it for as long as required.9

[9] https://www.eps.mcgill.ca/~courses/c590/2017/Celia_et_alWaterResourcesRes(51)2015_CO2-storage_saline-aquifers.pdf

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

There is no uncertainty other than leakage once the site has been identified after detailed study of the geologic behaviour of the chosen site.