# Reverse Carbon Mining Project

## 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

RCMP Solutions GmbH, (The Reverse Carbon Mining Project)

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

Austria, Europe.

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

Manuel Schleiffelder

Brief company or organization description

We put coal back underground and document this process in the form of digital evidence.

## 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.

**A HIGH QUALITY CDR-PRODUCT WITHOUT COMPROMISES**

“Reverse Carbon Mining” (RCM) is about extracting carbon from excess biomass in the form of a stable char and putting it back underground. Since the carbon in plants comes from the photosynthesis of atmospheric CO2, we effectively remove carbon from the atmosphere as long as we can keep the plants re-growing. The issued certificate/product is linked to a unit based Chain of Custody (CoC), a

[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.

complete Life Cycle Analysis (LCA), and a measured amount of elemental Carbon buried on a dedicated spot.

Figure 0-1: Physical chain of RCM

## FOCUS ON CORE COMPETENCE: GUARANTEEING HIGH QUALITY

In the beginning we thought that we would have to implement the complete physical chain by ourselves, but then we found partners who are already operating (TRL9) facilities covering most of these steps. Pyrolysis/torrefaction/charring is not only an already mature technology, together with our partners we are also involved in simplifying the approach (as far as possible), improving the machinery, and making the overall process more (energy output) efficient.

[more details in the confidential addendum]

Now, we (the RCM Team) are in the situation that we can focus on our core business, which comes down to what is currently handled as MRV (measurement, reporting and verification). With the simple and straightforward **RCM strategy** (Figure 0-1)**,** the well-defined **RCM product** and the unit based tracking though our **RCM platform**, we have the advantage that most of the parameters that go into our calculations (LCA, CoC, Unit-Parameters) can actually be measured and do not have to be modeled or interpolated from statistical values.

## THE RCM TRACKING PLATFORM

The main service that we provide through our platform is an application that allows operators (source, transport, pre-treatment, torrefaction, and sinks) to generate **a digital chain of evidence** from their process. That timestamped data allows us to extract a robust chain of custody (CoC) and calculate a unit-based LCA to determine net negativity. Finally before entering storage, the weighted char will be sampled. A laboratory determines moisture/carbon/ash fractions. On a longer interval we will also determine volatile components (at least C/O & C/H ratios) to reassure process quality/integrity.

Although we use Blockchain technology to timestamp and anchor the digital process evidence, our system has nothing to do with speculative cryptocurrencies. On a later stage it might be beneficial to integrate aspects of digital ownership and visibility on an open distributed database (for 3rd party verification) to the certificates we issue. However, this is not our primary concern at the pilot stage.

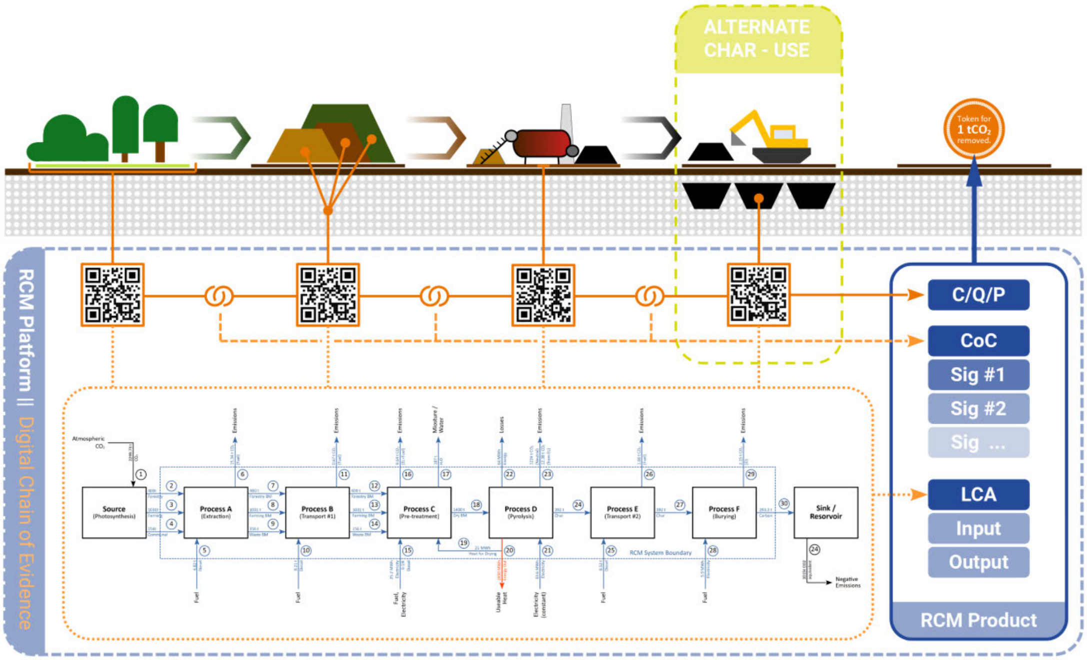


Figure 0-2: RCM Platform || Digital Chain of Evidence

## CORNERSTONES

There are three important cornerstones that shape the discussion around our approach. There are the advantages of burying the biogenic char, the trilemma around biomass sourcing (and a perspective), as well as the relation between CDR and energy.

### The advantage of burying excessive biomass in form of coal

We see a distinct advantage in storing the extracted CO2 in the form of elemental carbon instead of compressed gas. Especially in the densely populated areas of central Europe, geological storage of compressed CO2 is not welcomed (largely even prohibited), needs a huge upfront investment (for prospecting, maintenance and surveillance), will thus likely not be very decentralized, and implies long transport distances.

We are aware, and fully support that high-quality biochar is used as a soil amendment (where ecologically and economically beneficial), but it is not a betterment for every soil and yields an inferior CDR product. Our initial focus is therefore to promote the simpler concept with the following advantages:

- For burial we can utilize biogenic chars of lower quality (biochar regulations are quite strict), increase the scope of sources, and boost scalability.
- Dependent on char properties, the mean residence time in the upper soil is limited, but it is very stable below the microbially active layers (fully pyrolyzed char has much fewer volatile components than typical hard coal deposits).
- Contrary to raw biomass, buried char won't decompose under wet conditions and thus won't emit further GHGs. The char even acts as an environmentally friendly remedy/filter for spills of

carbohydrates, heavy metals and microplastics (e.g. reclamation of contaminated areas), whereas ash/slag from biomass burning facilities needs special waste treatment.
- A char deposit in a dedicated location remains verifiable for the foreseeable future.

Nevertheless, we need to protect such a depot against aeration and seam fires. The question of "reversal" strongly depends on where we bury the char. As we currently plan to introduce it to former deep shaft mines (backfilling in mine reclamation areas), only deliberate extraction would be an issue. Similar to geological storage of compressed/liquefied CO2, legal precautions are needed and possible (e.g., there is a special land-register in EU countries). We are **not yet allowed** to create local deposits (closer to the surface) because of EU waste legislation (originally in place to prohibit burial of raw biomass because of fowling, but extends to everything that contains carbon). But we are confident that this can be changed in the near future, because there is no scientific reason against, and it will allow for a much more scalable & decentralized approach compared to geological (mining) sites. Even if such a biogenic char deposit were, e.g., unburied by a disaster like a landslide/flooding incident, the CO2 would be released extremely slowly (>1000 Years; comparable to soil amendment).

**Responsible biomass sourcing: the biomass trilemma**

Even if we started to do Bio-Energy Carbon Capture (BECCS) on every residential (34EJ) and industrial (18EJ) biomass-burning facility today, we would not be able to achieve the average 328 Billion tons of CO2 net removed by 2100 as foreseen in IPCC's AR6. And, economic CCS (at least on smaller facilities) is still not in sight. But, regardless of how we extract carbon from biomass, we will need a massive buildout of biomass harvesting/utilization infrastructure, and a focus on net primary production (NPP; re-growth of plant mass) in the coming decades. All the scalable CDR alternatives require significant amounts of energy to achieve the same potential (and energy abundance is not in sight as well).

At the same time, rational voices are calling for a reduction of biomass usage in favor of Natural Climate Solutions (NCS) and biodiversity protection. Both are fundamental cornerstones for a sustainable future on earth. A depletion of natural carbon sinks through land use change (e.g., deforestation) or over-extraction is a significant source of emissions and potentially invalidates bio-based CDR efforts in the area. On the other hand, the build-up of NCS is very slow and inefficient, as most of the carbon in the dead biomass is set free by microbial digestion. Also, there is a stagnation point in old-grown biomes where the amount of carbon released from dead plant mass equals the yearly uptake through photosynthesis. A further problem is the volatility of natural sinks through pests, droughts, fires, and wrong farming practices. To make matters worse: there is also controversy between NCS and biodiversity goals since afforestation is not always beneficial for biological niches, and carbon farming practices often imply the application of chemical agents (e.g., herbicides).

We call this conflict between the three points of view "the biomass trilemma" (as depicted below). If we favor biodiversity, we give up necessary CDR potential; a priority on NCS might reduce diversity while still being very slow and volatile; purely using efficient energy crops for technological CDR is a threat to biodiversity as well as to natural sinks. And so on.

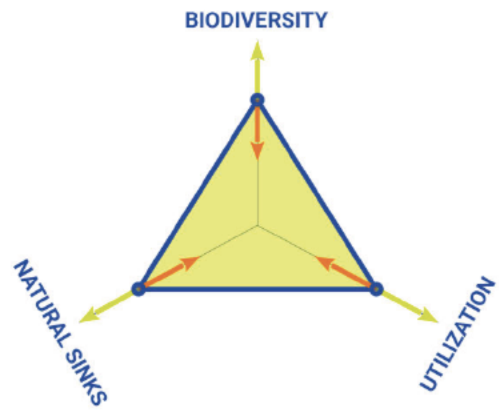


Figure 0-3: The Biomass Trilemma

Now, we think that with the right amount of documentation and oversight in the form of a strict Chain of Custody (CoC), a Life Cycle Analysis(LCA), and verification of re-growth, it should be possible to utilize biomass for climate action without losing sight of the other two aspects. Extraction on a periodic but sustainable level from locally adapted and near-natural ecosystems (e.g., local crops & local tree species) would be preferable to extensive use of agricultural land for super-efficient energy crops. Cautious forestry even improves resilience to fire and pests. In the same way, a healthy soil structure with an ample humus layer is crucial for productivity. Still, the potential for permanent CDR is much greater if a small percentage (e.g., 10%) of the NPP is utilized through technical processes (CCS, pyrolysis). **Therefore, digital documentation “from the cradle to the grave” is the most critical element of the RCM strategy**.

Of course, we need protected nature reserves where we reduce human intervention to a minimum. Likely many more of them in the form of insulated lifeboats for biodiversity. But, with our romantic view of nature in mind, we must not lose sight of the necessity to increase and utilize the earth’s net primary production potential to battle climate change. Otherwise, in the end, all the protective measures will have been in vain.

Thus our main source of biomass is from agricultural by-products, however we think that in the near future more sources will follow (see below).

**CDR as prime application for biomass: the energy dilemma**

The utilization of biomass for energy production has a long tradition here in Europe. The Russian invasion in Ukraine even accelerated adoption. However, since electricity from biomass is expensive, we are confident that cheaper means to produce this energy (e.g., solar, wind, nuclear) will prevail in the near future. Thus we do not really see a concurring use in bio-energy, but more an earlier stage boosting infrastructure development. If we first produce energy from biomass (with a 70% penalty) and then fuel CDR with this energy it would be very inefficient: Thus, if we agree that the amount of permanent CDR proposed by the IPCC is required to meet the climate goals, then the prime application for biomass is CDR not energy.

For example, from the Austrian (a very small country) bio-energy-potential we can estimate a total CDR potential through RCM while still getting halve of the energy (from syngas CHP) by applying the following factors:

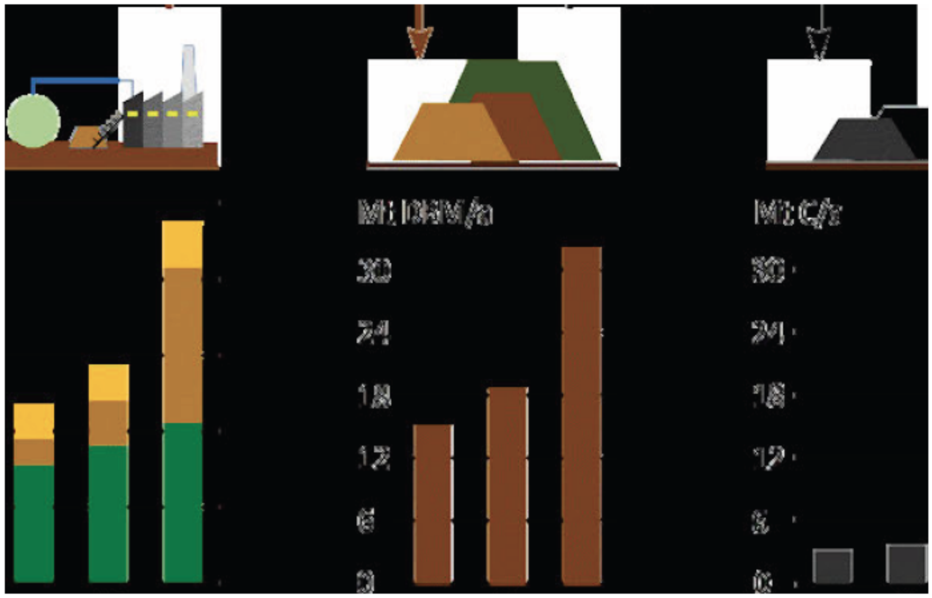

Figure 0-4: From biomass potential to CDR potential.

These 18Mt of CO2 removed per year are equal to about 25% of current yearly Austrian CO2 emission. That would be substantial.

Through the pyrolysis process that we use, we get roughly 50% of the solar energy stored in the plant-mass in the form usable syngas (thermal/CHP), and the other 50% remain in the char. The thermal losses of the pilot plant were measured to be about 3.2% with room for optimization. With BECCS, one could potentially extract a higher percentage of CO2 and get more process energy. But only at substantially higher investment expenses and with extreme infrastructure requirements. Even though CCS is traded as a mature technology (for natural gas/CO2 separation), there is only one large-scale plant (with considerable bad press) in service. Other projects (EGEXI, DRAX) are in planning state, but will very likely not extend to broad deployment any time soon. Thus, with RCM we have a solution that can start cost competitive production today, can operate in much smaller decentralized units, and thus distributes the value creation from CDR to a broader public.

[more details about the pyrolysis process in the confidential addendum]

**** The terms pyrolysis, torrefaction and charring are used synonymously throughout this document.***

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.

Different project aspects have different technology readiness:

- Biomass extraction infrastructure/machinery is at TRL9.
- Pyrolysis/Torrefaction plants are at TRL9 [secret addendum].
- Transport of Biomass as well as Char is also TRL9
- Introduction of char into deep shaft mine cavities is in a testing stage TRL6 [addendum]
- Crawler to reach remote underground cavities is in concept stage TRL3 (but not necessary for this project)

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| • The RCM Plattform is in an early development stage TRL3 |

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?** |
|---|---|---|---|
| Permanence | Permanent | Permanent | Because we bury the char below the microbial active soil layers. |
| Scalability | Singular non-optimized Plants<br>Singular Sink | Multiple optimized plants (e.g., larger communes).<br>Decentralized Sinks. | With higher production numbers pyrolysis/torrefaction plants will be much cheaper. Future decentralized sink locations for RCM will greatly reduce transport costs and emissions. |
| Definition | 273kgC -> 1tCO2 (process footprint offset separately) | Same | Will stay the same. |
| Verification | Tracking Platform MVP | RCM Platform | The initial tracking platform will require a significant amount of human labor/intervention in its Minimal Viable Product (MVP) Stage. Automation of measurement, verification and control steps (unit based as well as statistical) will increase performance. |
| Energy Output | Only for biomass drying. | Income from heat/electricity sales.<br>(up to 100€/tCO2 @ 3ct/kWh) | In future plants we want to utilize the energy from syngas for district heating or industrial applications. The generated income will reduce costs per ton of CO2 removed. |
| Social Impact | CDR Income only for initial project partners. | CDR income for multiple project partners | The goal is to initiate a decentralized branch of the future permanent CDR industry. Thereby distributing CDR income to rural- and or structurally weak areas. Worldwide rollout possible wherever a minimum if legal security is given. |
| Investment Expenses | New equipment; low quantity.<br>(~90€/t CO2) | (~20€/tCO2) | Due to uncertainties and novelty of the approach current capital costs are much higher than they will be in the future. Also, harvesting infrastructure will get more |

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| | | | economical the higher the overall capacity factor. |
| Biomass Expenses | Dry/Chopped/Pelletized Biomass (~200€/t $CO_2$). | Biomass will be cheaper (~60€/t$CO_2$). | Current Energy crisis drives biomass prices. In the future there will be cheaper energy sources than biomass. Larger/more cost effective extraction infrastructure will greatly reduce costs as well, as stated above. |

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?

**Jürgen Brandner** is responsible for the implementation of the supply chain, the technical integration of the tracking application and the interfaces to existing systems. He has a background in mechanical- & systems engineering.

**Manuel Schleiffelder** is responsible for the design, development and implementation of the RCM platform as well as product development. He has a background in software and space systems engineering.

**David Unterholzner** is responsible for financing, corporate development and media relations. Previously, he worked in management consulting/corporate development.

As CDR in general, biomass use and char burial are still controversial issues in Europe, we need to increase our media presence to inform people about RCM's opportunities. In addition, we will hire software developers to implement the MVP for the pilot project.

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 |
|---|---|---|
| Lignum Renewable Energy GmbH | Source & Sink operator. | MOU/LOI |
| Next Generation Elements GmbH | Pyrolysis/Torrefaction specialist. | MOU/LOI |

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?

All process steps will take place in already existing facilities. However we need time to organize sourcing, production slots, and transport of biomass. The largest Workpackage is the development of

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| the MVP tracking platform. Current estimate for delivery is Q4/2024 |

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.

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| Current biomass prices and costs for machine/infrastructure leasing are the driver. Basically we need a (financial) outlook for CDR offtake to be able to start sourcing the biomass. From there we can produce continuously, even though biomass is a seasonal commodity, since it can be stored in dry form. |

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 | 1 000t |
| 2024 | 5 000t |
| 2025 | 10 000t (to here with existing infrastructure) |
| 2026 | 50 000t (from here depends on buildout through market growth, and financial backing) |
| 2027 | 100 000t |
| 2028 | 250 000t |
| 2029 | 500 000t |
| 2030 | 1 000 000t |

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 | Biomass sources secured. | Q2 2023 |
| 2 | Biomass tracking platform MVP ready. | Q4 2023 |
| 3 | Start of char introduction to mining facility. | Q2 2024 |
| 4 | MVP token/certificates issued | Q4 2024 |

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

> Our main service is a platform and thus patents are not directly applicable. However we want to be a first mover, promoting and servicing the RCM niche.
>
> We have a hardware appliance currently under development that shall simplify tracking of loose (ground/chipped/pelletized) biomass streams. However, this will likely not be part of the pilot MVP, and IP strategy is not finished yet.
>
> Another development effort is the instruments used to introduce the char into deep shaft mines. Technology is being developed in a joint effort with our partners.

k. How are you going to finance this project?

> We finance the MVP pilot with the help of an investor and in-kind contributions of partners. An advanced market commitment from Frontier would greatly speed up the process, since Europeans are still skeptical with regards to the voluntary carbon market for high quality permanent removals.

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 talked to several carbon marketplaces and registered interest for our product, even though they do not yet know how to categorize it. This is also the reason why we strive to set a precedent with this MVP pilot project.

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 do not expect additional revenue streams for the pilot project since the energy from the pilot plant is mainly used for internal electricity and drying demand. However, in a future facility with heat/energy offtake we foresee significant additional income. The same goes for possible income streams from backfilling material for mine reclamation sites and decontamination effects of the char.

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 |
|---|---|
| Energy Crisis | The biomass market (even for agricultural by- and joint-products) is highly volatile due to the current energy crisis. Other than that, many mining sites in eastern europe that we talked to are in the process of reopening (going from reclamation efforts back to production). Mitigation through diversification, especially in non-energy related mining efforts (e.g. |

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| | talkum). |
| Partner Agreements | Due to the project structure a breach in partner agreements could lead to delays. However we are in the process of diversifying that risk potential by inviting other operators in the torrefaction/pyrolysis space. |
| Software Development | Due to the booming economy (swing back after corona) in the last year it was hard to find qualified persons. However, we assume that this will change in the course of the next year. |
| Legal | There is a risk that legalization (EU waste regulations) more decentralized carbon depots will take longer than projected. That would limit our scaling speed and ultimate potential. Legal advisors found that national exemptions are possible. Thus more outreach and lobbying will be required. |

## 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?

Biogenic char with low O/Corg and H/Corg molar ratios is very stable even as a soil amendment [2-4]. Although certain abiotic processes help to break up the char particles, we are very confident that biochar decomposition in soils is primarily driven through microbial activity[1]. We do not (yet) know of any research dedicated to biogenic char burial below the microbially active layers. However, judging from natural hard coal deposits it is mostly geological phenomena that induce losses (e.g., landslides, erosion, tectonic movement and thereof induced aeration).

Thus the **lower bound estimate** - only in case of disasters of geologic magnitude, when the char is un-buried - is that of biochar added to soils (>1000 Years).

And the **upper bound estimate** - which should be the regular case - is millions of years.


1. Wang, J., Xiong, Z. and Kuzyakov, Y. (2016), Biochar stability in soil: meta-analysis of decomposition and priming effects. GCB Bioenergy, 8: 512-523. https://doi.org/10.1111/gcbb.12266
2. Spokas, K.A.: Review of the stability of biochar in soils: predictability of O:C molar ratios, Carbon Manag. 1 (2) (2010) pp. 289 - 303.
3. Lehmann, J.; Abiven, S.; Kleber, M.; Pan, G.; Singh, B.P.; Sohi, S.P.; Zimmerman, A.R.: Persistence of biochar in soil, in: J. Lehmann, S. Joseph (Eds.), Biochar for Environmental Management: Science, Technology, and Implementation, Routledge, New York, 2015, pp. 235 -283.
4. EBC (2012-2022) 'European Biochar Certificate - Guidelines for a Sustainable Production of Biochar.' European Biochar Foundation (EBC), Arbaz, Switzerland. (http://european-biochar.org). Version 10.1 from 10th Jan 2022.

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?

There is a risk of deliberate extraction and utilization(e.g., burning) dependent on the depth location of the deposit. In countries/areas with sufficient legal security this can be mitigated through blocking statements in the land-register. A utilization on a greater magnitude is hardly something that would go unnoticed. Satellite surveillance of deposit location can be implemented at a later stage.

In case of a loss of civilization, e.g. in a nuclear (terrestrial or comet/space induced) winter a utilization would hardly be a climate risk but rather an asset.

## 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.

| | |
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| Gross tonnes of CDR over project lifetime | 1106t |
| Describe how you calculated that value | From our own LCA model (dependent on biomass type, amounts, machinery use and energy consumption), for an illustration see Process Flow Diagram below. |

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.

We (the RCM Team) produced about 200kg of biogenic char in pyrolysis test runs and buried minor quantities for burial tests. Partners are producing biogenic char on a regular basis.

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.

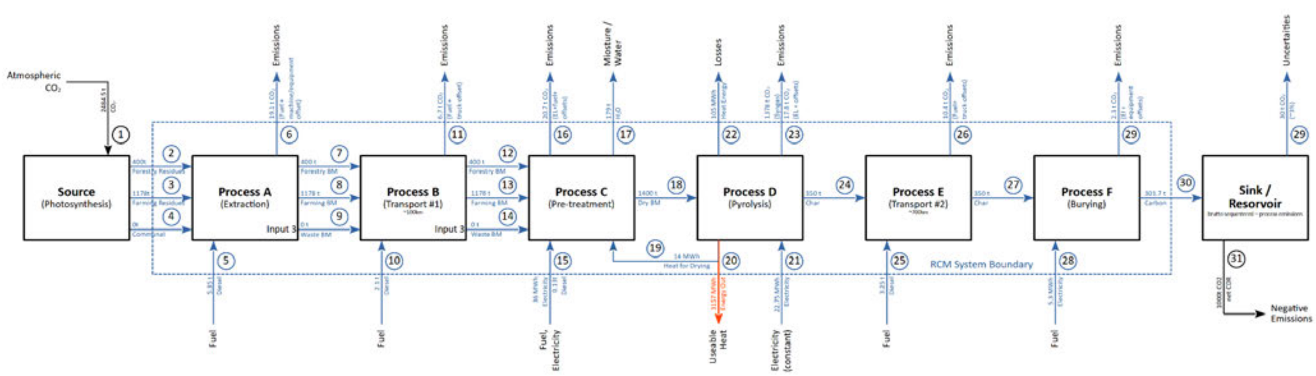
The pyrolysis process yields significant amounts (~50% of biomass input caloric value; dependent on biomass type) of "renewable" energy.

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)* | **106t** CO2 process emissions (incl. 3% net CDR uncertainty discount).<br><br>1378t CO2 through "CO2-Neutral" bruning of the syngas.<br><br>(both dependent on biomass type/mix) |
| Emissions / removal ratio *(gross project emissions / gross CDR–must be less than one for net-negative CDR systems)* | **0,096** |
| Net CDR over the project timeline *(gross CDR - gross project emissions)* | **1000t** CO2 |

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?

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| We assume to use residual biomass from existing/natural biomes or existing processes, specifically |

forestry residues, farming joint- or by-products as well as (here not included) certain forms of communal/industrial leftovers. Thus we do not include land-use, since we do not plan to induce land use change and only utilize a small percentage (<10%) of the net primary production of these biomes.

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. |
|---|---|---|
| Extraction | 19.1 | Typical values for machinery/equipment for forestry and agriculture. |
| Transport | 6.7 + 10.4 | Typical values for truck fuel consumption and vehicle offsets. |
| Pre-processing | 20.7 | Typical values for biomass processing machinery (from brochures) |
| Pyrolysis | 18.7 | Interpolated values from measurements on test facility (external experts [addendum]) |
| Burying | 2.3 | Interpolated values from tested machinery components. |

## 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.

Our digital chain of evidence (MVP pilot) shall include at minimum:

1. Identify/define harvesting area
2. Define harvesting method/machine/equipment
3. Measure harvested mass/volume and moisture (interface/on site/on transport/optical)
4. Optional: hand over to transport (start & end position)
5. Optional: hand over to pre-processing (site interface: input/output)
6. Torrefaction/pyrolysis process parameters (site/machine interface: input/output)
7. Measure processed char mass/volume and moisture (interface/on site/on transport/optical)
8. Optional: hand over to transport (start & end position)

9. Char sampling for laboratory measurements (carbon fraction; moisture; optional H/C, O/C))
10. Sink introduction process parameters (mass input/output)
11. Measure processed slurry volume stream (interface)

The final RCM Platform application shall include additional tracking features (unit based identification), automated validity checks (timing/statistics) and a biome re-growth validation.

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.)*

The durability of the carbon introduced to the sink locations is defined by the degree of torrefaction. This is actively defined by biomass-type adjusted pyrolysis parameters and measured through laboratory H/C, O/C determination. The main concern here is that partly charred biomass could start to fowl in wet conditions.

12. Validation of storage assumptions through continued firedamp measurements in the mine shaft. however, we do not expect significant emissions from fully torrefied char since firedamp emissions usually only arise in more bituminous coal deposits). Additionally sampling and laboratory analysis of pit-water.

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**<br>Include each component from the Quantification Tool relevant to your project | **Discuss the uncertainty impact related to your project**<br>Estimate the impact of this component as a percentage of net CDR. Include assumptions and scientific references if possible. |
|---|---|

| | |
|---|---|
| *(1) STORAGE* | *[Low] Quantity of stored carbon can be measured before (volume/mass) and after (volume) the introduction device (slurry mixer/pump). Together with laboratory analysis of the char (carbon content/moisture) the quantity of stored biomass carbon can be determined with high certainty.* |
| (1) LEAKAGE | [Low] Leakage out of a deep shaft mine (for this project) is highly unlikely. In a mine with active pit water extraction (not planned for this project) fine char particles could be lost through pumped water. However, those fully torrefied char particles being extracted to a stream or ocean would still be sedimented somewhere and remain stable for a very long time. |
| (1) FEEDSTOCK storage counterfactual | [Very Low] In our opinion this time delay is not relevant if the storage solution is permanent, and the biome of origin retains its net primary productivity. E.g., the pelleted wheat straw - envisaged as the largest component for this project - will re-grow in the next year if we make sure that we only extract a sustainable amount of NPP (<10%) and keep the soil healthy. |
| (1) FEEDSTOCK use counterfactual | [Very Low] Bio-energy is a comparably expensive form of energy, especially if it comes to lesser forms e.g., straw. Even in Europe a lot of these agricultural by-products just rot away. In the long run, we will have cheaper & cleaner forms of energy. And, if we agree that we need those quantities of permanent CDR required by the IPCC to reach our climate goals anyway, then the tradeoff would be between using energy for CDR and using biomass for CDR. However, making energy from biomass, and then using that energy for CDR would be very inefficient. |
| (1) Indirect land use change | [Very Low] We do not promote (nor use) energy crops for our CDR solution. Our goal is to extract a sustainable amount of biomass from existing proactive biomes (e.g., straw, forestry residues). |
| (1) MATERIALS | [Very Low] All material consumption (infrastructure, machines, equipment) are discounted in our LCA. |
| (1) ENERGY | [Low -> Negative] All the energy consumed(fuel/electricity) in the process has been accounted for in the LCA.<br>A conservative $CO_2$ footprint for electricity (~366g$CO_2$/kWh; average Germany) was used. In the future the energy generated from the pyrolysis plant should exceed the consumed energy by far. |
| (1) STORAGE M/M | [Very Low] We expect that storage of char below the microbially active soil layers (and especially in deep shaft mines as for this project) is permanent. However, the site will be monitored through existing infrastructure (firedamp; pit water). For future decentralized char depos a form of automated site integrity monitoring e.g., from space is planned. |

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?

> As noted above, we do not expect additional unaccounted losses through components (1) to (8). However we introduced a "general uncertainty discount" of 3% to account for any measurement- or process deviations in the early pilot.

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.?

> This MVP pilot project is all about setting a precedent and the standard for qualification. In a later stage of the RCM platform will have a wider range of tools and analyses to improve sequestration certainty (and reduce the uncertainty discount). E.g., through automated unit-based tracking of biomass piles, re-growth verification, site monitoring and so on...
> Quantification for RCM is alway on measurement basis (amount of carbon stored, derived from mass flow and carbon content).

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)?

> We are currently developing that protocol for credit/certificate issuing. The general plan is to incorporate the digital evidence generated from the process in an immutable digitally signed token. Ideally later on, every 2ng and 3rd party should be able to do a verification from that data. However, we are aware that an extensive third party verification is necessary for the pilot project and thus are currently talking to stakeholders in the carbon accounting / marketplace field.

## 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 \$/tonne $CO_2$ |

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

| Component | Levelized price of net CDR for this project (\$/tonne) |
|---|---|
| Capex | 180 \$/tonne $CO_2$ |
| Opex (excluding measurement) | 200 \$/tonne $CO_2$ |
| Quantification of net removal (field measurements, modeling, etc.)[2] | 100 \$/tonne $CO_2$ |
| Third party verification and registry fees (if applicable) | 20 \$/tonne $CO_2$ |
| **Total** | 500 \$/tonne $CO_2$ |

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 & Extraction (Capex+Opex) | 190\$/tCO2 | 50\$/tCO2 | Biomass prices are extremely high because of the current energy crisis and will go down in the long run. Energy production from biomass will become less attractive when other sources for clean electrical energy get tracktion (wind, solar, nuclear, ...). An established extraction infrastructure on a larger scale will also reduce costs. |
| Transport (Capex+Opex) | 50\$/tCO2 | 20\$/tCO2 | With more decentralized char depots available in the future, the overall transport distances will be greatly reduced. |
| Pre-Processing & Pyrolysis (Capex+Opex) | 120\$/tCO2 | 40\$/tCO2 | Larger plants specialized for continuous torrefaction with a high capacity-factor (8000h/a) will greatly reduce costs. |

[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.

| | | | |
|---|---|---|---|
| Energy generation | 0$/tCO2 | -50$/tCO2 | Current facilities are not connected to heat sinks beyond plant internal CHP & drying. Fully connected to district heating or a industrial application additional income can be generated (here calculated at 1,5ct/kWh heat energy because of seasonality) |
| Sink | 15$/tCO2 | 10$/tCO2 | Decentralized depots will help to lower prospecting and monitoring costs. |
| Platform fee & Overhead | 125$/tCO2 | 30$/tCO2 | Initial MVP development costs as well as manual efforts in early MRV. The fully automated future version will greatly reduce RCM overhead (management) and platform fees. |

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

- Biomass costs
- Energy sale income
- Future (decentralized) sink costs

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 TEA sheet is not ideal for our CDR proposal, because most of the capital intensive steps are handled/performed by partners with different investment types and project durations. Thus we had to estimate a "bare erected cost" scenario that roughly matched the total of the values from our partners (and therefore the breakdown values are set to 0).

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 legal framework for decentralized depots (may be easier outside of Europe).

## 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.

- We are in constant exchange with our partners - be it biomass production, pyrolysis plant operators or on-site burial. Since we will accompany their processes digitally, we constantly question their needs and demands.
- We provided feedback to the call for evidence regarding "carbon removal" of the European Commission, and we applied to become part of the Expert Group discussing future legislation.
- Our public outreach lacking - e.g., to promote our approach and get the CDR diskussion going in Europe.

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 direct contact with our stakeholders and their production processes. This enables the high quality of our product.
All partners are located in Central Europe and are directly or through professional organizations (such as The International Biomass Torrefaction Council (IBTC)). We are also interested in the European Regional Development Fund (ERDF), which supports investments in growth and employment in former mining areas.

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?

Originally, we wanted to take care of the production of the biomass, pyrolysis and burial of the coal ourselves. Through contact with the stakeholders, we learned that actually the digital tracking part is the missing piece. This meant that we could now focus on our core competence.
Due to the complexity of our project and the fact that we accompany many processes, we have to constantly respond to feedback from our partners.

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 need to increase public outreach.<br>We want to formalize stakeholder/partner communication.<br>Public engagement would be more in the form of a service provider. |

## 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.

| |
|---|
| The origin of the biomass we use is certainly one of the most critical issues. However, as we want to sell a high-quality and transparent product, the responsible selection of biomass (see "Biomass Trilemma", section 1) is part of our business model.<br>Through our decentralized approach, we will enable the related added value generated (job creation and development opportunities) in less developed regions. This applies specifically to regions that used to benefit from mining. |

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

| |
|---|
| The core of our business model is the quality of the origin, processing and burial of biomass. This is done via our tracking platform. In this respect, it is indispensable that our partners meet high standards of environmental protection.<br>Enabling and promoting a new value chain (worldwide tradeable commodity) also open for smaller stakeholders.<br>Allow the broader public to participate in direct climate action (e.g., by supplying their green waste to their communal RCM plant). |

## 8. Legal and Regulatory Compliance

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

| |
|---|
| According to European Waste Legislation, nothing may be buried that contains more than 5% carbon. Therefore, as a first step, we will bury the char in abandoned mines (through our advisory board, and the ÖBIKA association).<br><br>Biomass extraction standards forestry/agriculture (through local University, IBTC association) |

[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

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.

| |
|---|
| There is no formal permission to engage in research or deployment necessary except the aforementioned European Waste Legislation. We are in talks with the University of Vienna to scientifically research decentralized char deposits (e.g., as a filter for road run offs). |

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?

| |
|---|
| No, as far as we know, there is no international regulation regarding the burying of char. |

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.

| |
|---|
| We have to comply with the European Waste Legislation - which in turn doesn't apply to mine reclamation. Legal constraints regarding the mining sites are handled by partners. |

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.

| |
|---|
| No. |

## 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 |
| **Delivery window** *(at what point should Frontier consider your contract complete? Should match 1(f))* | Q4/2024 - Q1/2025 |
| **Levelized Price** (\$/metric tonne $CO_2$) *(This is the price per tonne of your offer to us for the tonnage described above)* | 500\$/tCO2 |

# 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?

| |
|---|
| Agricultural residues (e.g., pelleted wheat straw, corn stalks, non-food by-products)<br>Forestry residues (low grade chipped wood, e.g., containing bark and leaves)<br>Industrial and Communal residues (e.g., pulp/paper, greenwaste, seed scales) |

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

| |
|---|
| Partner is already running similar supply chains. But a separate agreement would be negotiated as soon as we have probable/reliable offtake. |

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?

| |
|---|
| E.g., wheat straw would be harvested with a mobile pelletizer (therefore reducing transport volume, and saving a later pre-processing step). Machinery emissions as well as offsets for the machine itself are accounted for in the LCA. Currently those pelletizers are produced in low numbers and thus have significant investment costs. Higher adoption rate, as well as a higher capacity factor would greatly reduce costs. |

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) |
|---|---|---|
| Biomass | - | We do not cultivate extra feedstock. We utilize a percentage of residues. |
| Processing | 0,025km2 facility & storage area. | Facilities for the pilot project are already in place. Ideal location for future plants is already existing biomass/industrial facilities (district heating, saw mill, large farm, …) |

| | | |
|---|---|---|
| Final Storage/Deposit | - | In $m^3$ below the surface. |

## 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.

> The potential in Austria is at 10-25% of current emissions. Which is astonishing because Austria is a small country and has a comparably high GHG footprint. On the other hand it is very rich in biomass and the biomass utilization infrastructure is very good (see chapter 1. Project Overview=.
>
> Worldwide we estimate that with utilization of 10% of Net Primary Productivity for RCM we could generate more than 10GtCO2 negative emissions per year.

## 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)

> Carbon farming.
> Bio-Energy.
> Compost.

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?

> Direct competition is BECCS, however with much higher investment costs, likely only in large centralized facilities and therefore higher transport efforts. Also, storing gaseous CO2 is problematic in densely populated areas (e.g., unwanted in central Europe).
>
> Bio-energy is a very costly and polluting form of energy (except for very remote applications) compared to other clean energy technologies.
>
> If we agree that we need CDR in large quantities, and that the most scalable approaches are either fueled by energy or biomass, then it would be very inefficient to make energy from biomass, and then use the energy to do CDR.
>
> Natural Carbon Solutions would highly profit from a combination with permanent CDR (see chapter 1. Project Overview; Biomass Trilemma).

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)?

| |
|---|
| Over extraction of biomes would reduce future net primary productivity, natural carbon sinks and biodiversity. We want to mitigate that problem through rigorous tracking of biomass streams and monitoring of sourcing areas.<br>Char deposits have to be secured against aeration and seam fires. Future prospecting efforts will require to take that in mind.<br>Otherwise beneficial effects (water retention; decontamination) |