Final Report
C6 Forest to Farm –
Life Cycle Assessment of Biochar

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EXECUTIVE SUMMARY

There are many benefits to the use of biochar, including but not limited to long term carbon storage, providing a use for un-utilized forest residuals from forest restoration or fire reduction projects, and soil amendments that can improve water holding capacity and reduce erosion. Soil improvement and climate mitigation are the main benefits of biochar. If they did not exist as benefits, there would be little reason to produce biochar. If the climate impacts of the biochar production process exceed the sequestration value of the biochar when applied to soil, then there will be no net climate mitigation benefit, although there may still be a benefit to soil. C6 Forest to Farm (C6F2F) requested an LCA on a proposed biochar production facility to be located in Winton, Washington in the Wenatchee Valley. Following puro.earth Puro Standard Biochar Methodology V2 2022-05-09 (puro.earth 2022), we developed a cradle-to-grave from A1-B1/Use.

The scope of this study was to develop a cradle-to-grave LCA for C6F2F biochar to evaluate the environmental footprints from harvest (A1), biomass transport (A2), the thermochemical conversion of biomass into biochar (A3), delivery of biochar to the farm (A4) and application (B1) (Figure ES1) over a one year reporting period.

The LCA used the A1-B1 parameters provided by C6F2F and modeled using the international LCA Software SimaPro according to the life cycle stages as outlined in Figure ES1. The system boundary begins with the biomass (A1) and is considered waste, so therefore has no upstream impacts from forest management and harvesting. The environmental impacts begin with loading the biomass on the truck. The B1 use phase ends after application to soil.

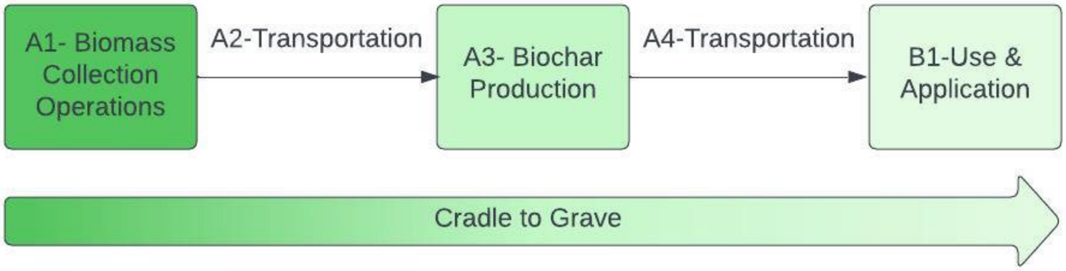

Figure ES 1 Life cycle stages for C6 Forest to Farm biochar LCA (A1-B1)

In addition to the processes in the life cycle stages in Figure ES1, the puro.earth standard required the inclusion of equipment used in the A3 – Biochar Production stage. The raw materials and quantities provided by C6F2F were depreciated over 15 years assuming equal production and efficiencies.

To determine the overall carbon benefits of biochar from cradle-to-grave, the global warming potential at each life cycle stage was calculated (Table ES1). The production of biochar has the greatest contribution (44%) from cradle-to-grave. Transportation from the forest to the facility and from the facility to use contributed around 20 percent for each transportation stage. Biomass collection had the minimal contribution at around 2 percent.

Table ES 1 Embodied carbon, CO2e per annual production of biochar (2,195 metric ton) for life cycle stages A1 Biomass collection, A2-Biomass transport, A3-Biochar production, A4-Biochar transport, and B1-Application.

Life cycle stage	A1	A2	A3	A4	B1	A1-B1
	metric ton CO2/2,195 metric ton biochar					
Global Warming Potential	8.15	85.65	191.07	73.60	79.84	438.31
Relative contribution	2%	20%	44%	17%	18%	100%

The puro.earth methodology required the reporting of a net carbon footprint or carbon dioxide removal certificates (CORCs). The four inputs into the CORCs determination are described below.

1. E*stored* is the amount of carbon dioxide sequestered over a 100-year time horizon using the amount of biochar produced. This was calculated based on the methodology by Woolf et al. (2021) and calculated using the puro.earth biochar carbon stored calculator. The parameters used in the calculator are in Table ES2. The net value for E*stored* is 6,359 mt CO_2 per year (2,195 mt of biochar) (mt=metric tons). Value is calculated using the puro_biochar_calculator.

$$E_{stored} = Q_{biochar} \times C_{org} \times F_p^{TH,T_s} \times \frac{44}{12}$$

$Q_{biochar}$ = is the amount of biochar produced over the reporting period (e.g., 1 year)

C_{org} = is the organic carbon content of the biochar produced. Expressed in dry weight of organic carbon over dry weight of biochar

$F_p^{TH,Ts}$= is the permanence factor of biochar organic carbon over a given time horizon TH in a given soil at temperature T_s

$$F_p^{TH,T_s} = c + m \times H/C_{org}$$

H/C_{org} = 0.2756 mol / mol

2. **E*biomass*** (A1) is the embodied carbon[1] arising from the production and supply of biomass to the production facility. Converting values from Table ES1, E*biomass* is 8.15 mt CO_2/year.

3. **E*production*** (A3) is the embodied carbon arising from the transformation of the biomass into biochar at the producing facility. Following ISO 14044 standards, A2 transportation is "burdened" to the destination life cycle stage. Therefore, A2 is included with A3. Converting values from Table ES1, E*production* is 277 mt CO_2/year.

4. **E*use*** (B1) is the embodied carbon that occurs along the distribution of the biochar up to its point of final use. Following ISO 14044 standards, A4 transportation is "burdened" to the destination life cycle stage. Therefore, A4 is included in B1. Converting values from Table ES1, E*use* is 153 mt CO_2/year.

Table ES 2 Parameters used to determine the carbon content of biochar (E*stored*).

Parameter name	Value	Unit
Organic carbon content of biochar	91.00%	%, dry weight
Hydrogen content of biochar	2.09%[2]	%, dry weight
Annual average soil temperature at site of biochar use	15	°C
Time horizon of sequestration	100	years
Biochar production over reporting period	2,194.66	mt, dry weight
Biochar supply-chain emissions	0.15	mt CO_2-eq/mt dry biochar
Permanence factor $F_p^{TH,Ts}$	86.44%	%
Carbon dioxide stored per mt of biochar	2.90	mt CO_2 / mt dry biochar
Carbon dioxide stored over reporting period (E_{stored})	6,359.19	mt CO_2

The amount of CO_2 removed over 100-year period by the cradle-to-grave biochar production is 5,921 mt CO_2e. More carbon is removed (stored) than is emitted during its life cycle.

$$CORCs = Estored - Ebiomass - Eproduction - Euse$$

$$\boldsymbol{CORCs(Annually) = 6,359.19 - 8.15 - 276.72 - 153.44 = 5,920.87\ mt\ CO2e}$$

$$\boldsymbol{CORCs(for\ 1\ mt) = 2.90 - 0.004 - 0.13 - 0.07 = 2.70\ mt\ CO2e}$$

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[1] This value is directly derived from the LCA and consist of all greenhouse gas emissions characterized to carbon dioxide equivalents associated with all life cycle stages of the biochar in the system boundaries of this study.

[2] Average of biochar samples from Douglas-fir (2.20%) and Ponderosa pine (1.97%)

BACKGROUND

Biochar as a bio-based product offers unique aspects for contributing to the circular economy that life cycle assessment (LCA) is meant to support. The most consistent major contribution to climate mitigation arises from carbon storage in the biochar, and the categories of avoided emissions from fossil energy, soil, or alternative biomass waste disposal methods. Biochar produced at higher temperatures is more condensed and less degradable by soil microbial processes, therefore, it will store carbon for a longer period. This condensed carbon is commonly called “fixed carbon.” The ability of biochar to sequester carbon depends on the physicochemical qualities of the biochar (carbon and ash content, carbon recalcitrance, surface area and other attributes) and on soil environmental conditions.

An additional benefit for biochar production is the benefit to the forest from residue removal and conversion, which can reduce fire risk and support forest restoration and resilience. Systems that produce the biochar product have the unique potential to provide a valuable soil amendment that can be used to enhance soils or remediate areas degraded by compaction, erosion, or pollution. Biochar fits nicely into the concept of a circular economy as its production can bring benefits back to the land base.

Biochar as defined by the International Biochar Initiative is “A solid material obtained from thermochemical conversion of biomass in an oxygen-limited environment.” Biochar can be described as a charcoal-like substance that contains a 50 percent or higher content of recalcitrant carbon by dry mass. Biochar is a unique forest product because of its potential for multiple environmental benefits accruing not only from its final end use, but also from both avoided emissions during the production process, and from carbon sequestration in soil. However, in order to realize all the promised benefits of biochar, it must be analyzed as a system, not just a product. Only rigorous LCA can determine if a particular biochar product has resulted in avoided greenhouse gas emissions during its production.

In most cases, biochar systems will show the greatest benefits if waste feedstocks are used. Waste materials that have a disposal “cost” are usually the most economically viable to use. The challenges may come from the physicochemical nature of the feedstocks themselves (for example, wood species and moisture content) or from the difficulty and logistics of collecting and transporting the feedstocks. For instance, forest residues are distributed across the landscape and must be collected.

Soil improvement and climate mitigation are the main benefits of biochar. If they did not exist as benefits, there would be little reason to produce biochar. Both are dependent on the final use of biochar, including post-processing and application methods. If the climate impacts of the biochar production process exceed the sequestration value of the biochar when applied to soil, then there will be no net climate mitigation benefit, although there may still be a benefit to soil. The projected use of the C6F2F biochar is to incorporate it into agricultural compost. Biochar has shown to be to be a valuable tool for compost production where it has shown promise to improve the composting process, reduce odors, and produce a higher quality compost with beneficial results in plant growth tests e.g., by increasing nitrogen retention (Hagemann et al. 2017)[3]. This report covers an LCA of C6 Forest to Farm's (C6F2F) proposed biochar production facility, to be located in Winton, Washington in the Wenatchee Valley.

METHODOLOGY

Life Cycle Assessment

Life-cycle assessment (LCA) has evolved as an internationally accepted method to analyze complex impacts and outputs of a product or process and the corresponding effects they might have on the environment. LCA is an objective process to evaluate a product's life cycle by identifying and quantifying energy and materials used and wastes released to the environment; to assess the impact of those energy and materials uses and releases on the environment; and to evaluate and implement opportunities to effect environmental improvements. LCA studies can evaluate full product life cycles, often referred to as "cradle-to-grave," or incorporate only a portion of the product's life cycle, referred to as "cradle-to-gate," or "gate-to-gate." This study can be categorized as a cradle-to-grave LCA, as it includes biomass collection though the use of biochar.

As defined by the International Organization for Standardization (ISO 2006a)[4] (ISO 2006b)[5], LCA is a multiphase process consisting of 1) Goal and Scope Definition; 2) Life Cycle Inventory (LCI); 3) Life Cycle Impact Assessment (LCIA); and 4) Interpretation (Figure 6). These steps are interconnected, and their outcomes are based on goals and purposes of a particular study.

The LCIA process characterizes and assesses the effects of environmental releases identified in the LCI into impact categories such as global warming, acidification, carcinogens, respiratory effects, eutrophication, ozone depletion, and smog. For assessing the environmental impacts of biochar production, the TRACI (Tool for the Reduction and Assessment of Chemical and other Environmental Impacts) impact method was used. TRACI is a midpoint-oriented LCIA methodology developed by the U.S.

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[3] Hagemann, Nikolas, et al. "Organic coating on biochar explains its nutrient retention and stimulation of soil fertility." *Nature communications* 8.1 (2017): 1089.

[4] International Organization for Standardization ISO. 2006a. Environmental management—Life-cycle assessment—Requirements and guidelines. ISO 14044:2006/AMD 1:2017/ AMD 2:2020. International Organization for Standardization, Geneva, Switzerland. 46 pp.

[5] International Organization for Standardization ISO. 2006b. Environmental management—Life-cycle assessment—Principles and framework. ISO 14040. International Organization for Standardization, Geneva, Switzerland. 20 pp.

Environmental Protection Agency specifically for the U.S. using input parameters consistent with U.S. locations (Bare 2012). TRACI is available through the LCA software (http://www.pre-sustainability.com/simapro).

The LCIA establishes the link between the LCI results and potential environmental impacts. These impact indicators provide general, but quantifiable, indications of potential environmental impacts.

Scope of Work

The scope of this study was to develop a cradle-to-grave LCA for C6F2F biochar to evaluate the environmental footprints from harvest (A1), biomass transport (A2), the thermochemical conversion of biomass into biochar (A3), delivery of biochar to the compost facility (A4) and application (B1) (Figure 1). Carbon footprint as well as other environmental indicators will be reported for biochar production using excess forest feedstocks directly related to wildfire risk reduction activities. The LCA was performed in accordance following ISO standard for performing LCAs (ISO 140140/14044 2006) (ISO 2006a,b) and Puro Standard Biochar Methodology (PSBM) (puro.earth 2022). The primary data collected from C6F2F and secondary data fuel, energy, and ancillary materials and fuels were modeled using the SimaPro Software (Pre 2022)[6].

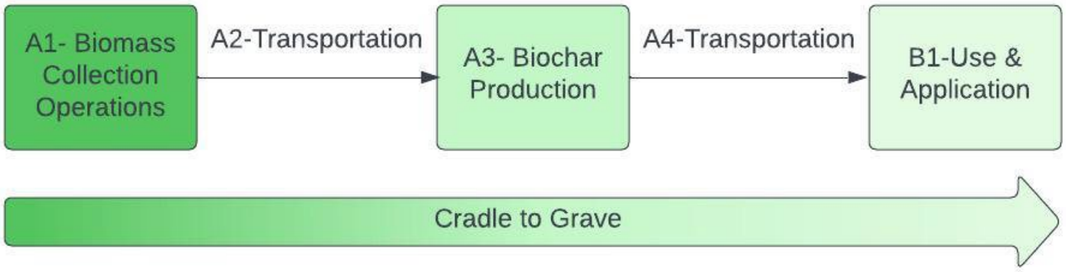

Figure 1 Life cycle stages for C6 Forest to Farm biochar LCA (A1-B1)

System Boundaries

The system boundary for the LCA of biochar begins with the collection of the biomass and ends with the application of biochar mixed with agricultural compost (Figure 1).

Functional Unit

The functional unit for this C6F2F biochar LCA is 2,195 metric ton (mt) (2, 419 short tons) of marketable biochar, which is the projected annual production amount. The functional unit for reporting based on the puro.earth (2022) standard is 1 mt.

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[6] Pré Consultants, B.V. 2022. Simapro 9.4 Life-Cycle Assessment Software Package. Plotter 12, 3821 BB Amersfoort, The Netherlands. Http://www.pre.nl/.

Data Collection, Quality, and Assumptions

Both primary and secondary data were used for the C6F2F biochar cradle-to-grave LCA. Primary data was obtained directly from C6F2F starting at collection and ending with application (Table 1). All machinery used and fuel consumption rates were provided. Biomass conversion to biochar factors were provided along with biomass and energy flows through the production process. As per the puro.earth methodology, fixed production equipment used in A3 is included and was depreciated over 15 years. The data quality of the primary data is considered to be high quality and falls within previous biochar production LCA input values (Puettmann et al. 2018). All secondary LCI dataset comply with ISO 14040/44 standards for relevance, geographical origin, age, and data quality[7] [8].

Table 1 Life cycle data source by module

Data Type	Data source
A1 - Biomass collection	C6F2F
A1 - Equipment	C6F2F/CORRIM
A2 - Transport	C6F2F/DataSmart/USLCI
A3 - Production	C6F2F/DataSmart/ USLCI /UW
A4 - Transport	C6F2F/DataSmart/ USLCI
B1 – Use/Application	C6F2F/DataSmart/ USLCI

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[7] International Organization for Standardization ISO. 2006b. Environmental management—Life-cycle assessment—Principles and framework. ISO 14040. International Organization for Standardization, Geneva, Switzerland. 14040:2006/Amd1:2020. 20 pp/8 pp.

[8] International Organization for Standardization ISO. 2006a. Environmental management—Life-cycle assessment—Requirements and guidelines. ISO 14044:2006/Amd1:2017/Amd:2:2020. International Organization for Standardization, Geneva, Switzerland. 46 pp/8 pp/12 pp/.

A1-Biomass Collection

All forest residues were considered waste and therefore forestry operations related to management and harvesting were excluded from this LCA (Figure 2). The A1 life cycle stage excludes all pre-harvest forest operations and thinning activities. It includes collecting and the loading of biomass on trucks for transportation to the biochar production facility.

Biomass collection parameters are in Table 2 and include harvest acres per day, quantity of biomass removed per acre, working hours per day, and days per year of collection operations. The values in Table 2 are based off a required annual 10,241 mt (11,289 short ton)of biomass. Primary data used for input into the LCI are in Appendix A.

Figure 2 Typical biomass "waste" pile

Table 2 Process inputs for the collection of woody biomass for biochar production (source C6F2F).

In-Forest Operation Parameters	Unit	Value
Typical harvest rate	acres/day	10
Typical biomass loading	green tons/acre	20
Typical daily harvest	green tons/day	200
Daily logging operations	hours/day	10
Yearly logging operations	days/year	57
Average haul distance	miles	25
Green tons needed per ton of biochar	green tons/tons	4.67
In-Forest Operation Parameters	**Unit**	**Value**
Typical harvest rate	hectare/day	4.05
Typical biomass loading	mt/hectare	44.83
Typical daily harvest	mt/day	181.44
Daily logging operations	hours/day	10
Yearly logging operations	days/year	57
Average haul distance	kilometer	40.23
Green mt needed per mt of biochar	mt/mt	4.67

There are several vehicle types used for forest operations to collect and load the biomass (Table 3). The main in forest equipment was a John Deere (2954D) loader used for loading biomass on the pulp trailers. The loader moved over 10 thousand green mt and operated 265 hours per year. Water, fuel, and service trucks were also used for forest operations related to biomass collection.

Table 3. In forest and road vehicle type and use for collecting, loading, and hauling of biomass from forest to production

	Fuel type	Annual run time (Hours)	Annual travel distance (miles)	Annual Biomass green short tons	Module
Loader	Diesel	265		11,289	A1
Log truck with pulp trailer	Diesel		47,439	11,289	A2
Water Truck	Diesel		2,850		A1
Fuel Truck	Diesel		2,850		A1
Service	Diesel		2,850		A1
	Fuel type	**Annual run time (Hours)**	**Annual travel distance (kilometers)**	**Annual Biomass green metric tons**	**Module**
Loader	Diesel	265		10,241	A1
Log truck with pulp trailer	Diesel		76,346	10,241	A2
Water Truck	Diesel		4,587		A1
Fuel Truck	Diesel		4,587		A1
Service	Diesel		4,587		A1

A2 Biomass Transportation

The modeling of this module includes the fuel consumption required to transport green biomass from the loading point to the biochar facility (A3). Average haul distance from forest to plant is estimated at 40.2 kilomerter (25 miles) (80.4 kilometers round trip) (Table 2). The green biomass was transported using log trucks with pulp trailers (Figure 3). The total transported biomass from forest to plant in one year is 10,241 mt with an annual mileage over 76,346 (Table 3). Additional equipment traveled annually 4,587 kilometers per vehicle.

Figure 3 Pulp hauler. Source Elaine Oneil, CORRIM

A3 Biochar Production

When the biomass (logs) arrived at the production facility, they are unloaded, debarked, ground, and screened (pre-processing). This equipment uses either diesel fuel or electricity to operate. The A3 module includes all mass and energy flows during biochar production. All material and energy flows for biochar production were provided by C6F2F and served as the LCI input data (Appendix B). Secondary data for fuels and energy were obtained from the US LCI[9] or DataSmart databases[10].

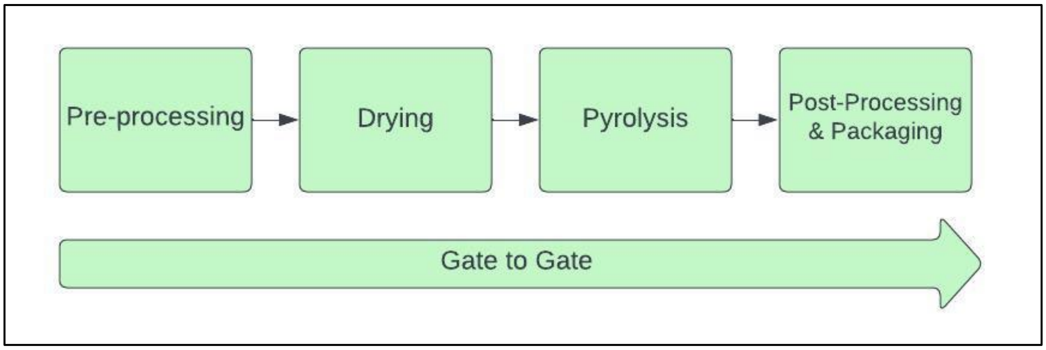

Figure 4 A3 – Biochar production unit process system boundary

According to puro.earth methodology (puro.earth 2022), the production of biochar (A3) should include all relevant activities such as:

- Biomass handling on site (transport or conveying of the biomass within the facility)
- Drying, chipping, comminution, and/or sieving of the biomass
- Operation of the pyrolysis reactor and post-pyrolysis equipment (e.g., combustion chamber for pyrolysis gases and oil, flue gas treatment systems) or operation of the gasifier reactor and post-processing equipment
- Biochar quenching and other post-processing operations (e.g., packaging, activation)
- Biochar handling on site (transport or conveying of the biochar within the facility)
- Mobile unit fuel consumption is associated with the operation of the mobile carbonizer, near location collection and handling of the biomass, but also the transport of the fuel to the location where the mobile unit is operated. ***Note:*** *this is not relevant for C6F2F's system configuration.*

In addition, A3 must include equipment manufacturing, equipment installation, and use. For example, the operation of the pyrolysis reactor includes manufacturing and installation of the reactor, material, and energy inputs for operating the reactor, and the direct air emissions from the stack of the reactor.

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[9] https://www.lcacommons.gov/lca-collaboration/search/page=1

[10] LTS. 2020 Datasmart LCI Package http://ltsexperts.com/services/software/datasmart-life-cycleinventory/

A4 Product Transport

Includes transportation of biochar to compost production site by truck (e.g., farm). Six Washington locations are being considered for delivery of biochar (Table 4). Equipment types and fuel consumption is provided by C6F2F. Due to customer sensitivity, details of the locations and input parameters for transport to the locations are not shared in this version of the report. For more information, contact C6 Forest to Farm.

Table 4 Location of application, mass of biochar transported, and delivery and distance (A4)

Location of Delivery	Biochar mass (short tons/year)	Distance from Winton, WA (miles)	Compost total mass (short tons/year)	Percent allocation
Location 1, WA	180	81	7,000	5.27%
Location 2, WA	308	70	12,000	9.01%
Location 3, WA	308	87	12,000	9.01%
Location 4, WA	1,157	102	45,000	33.85%
Location 5, WA	1,285	150	50,000	37.60%
Location 6, WA	180	126	7,000	5.27%
Totals	3,418		133,000	100.00%
Location of Delivery	**Biochar mass (metric tons/year)**	**Distance from Winton, WA (kilometers)**	**Compost total mass (metric tons/year)**	**Percent allocation**
Location 1, WA	163	130	6,350	5.27%
Location 2, WA	279	113	10,886	9.01%
Location 3, WA	279	140	10,886	9.01%
Location 4, WA	1,050	164	40,823	33.85%
Location 5, WA	1,166	241	45,359	37.60%
Location 6, WA	163	203	6,350	5.27%
Totals	3,101		120,656	100.00%

B1 – Application and Use

This life stage includes the application of biochar with compost. The application proposed is co-composting with bulk agricultural compost (Table 4). The ratio of biochar in compost is 2.57 percent.

BIOGENIC CARBON

It is known that tree growth and fuel combustion result in various fluxes of CO_2. The appropriate methodology for assessing these fluxes is the Global Warming Potential (GWP). Values are factored to a mass of carbon dioxide equivalents (e.g., kg CO_2 eq.). GWP compares the amount of heat trapped by a certain mass of the gas in question to the amount of heat trapped by a similar mass of carbon dioxide. GWP is an indicator that reflects the relative effect of a greenhouse gas in terms of climate change considering a fixed time, commonly 20, 100, or 500 years. For example, the 20-year GWP of methane is 56, which means if the same weights of methane and carbon dioxide were introduced into the atmosphere, methane will trap 56 times more heat than carbon dioxide over the next 20 years. The TRACI impact method uses a 100-year time frame.

CORCs Reporting

Puro.earth biochar methodology contains specific calculations and inclusions for reporting the net CO_2 removals over a horizon of 100 years (Section 4 of the puro.earth methodology). The equation uses the total greenhouse gas emission, reported in CO_2e (equivalents) from each of the five life cycle stages (Figure 1). These are calculated using the TRACI impact method in the SimaPro software. The CORCs also consider the carbon content (storage) in the biochar, also reported as CO2e. Using the parameters reported in Table 5 for calculating carbon storage and the GWP results for A1-B1, the CORCs can be calculated. Functional unit for reporting CORC is 1 mt of biochar. Puro.earth biochar methodology contains specific calculations and inclusions for reporting the net CO_2 removals over a horizon of 100 years.

Table 5 Parameters used to determine the carbon content of biochar (E*stored*)

Parameter name	Value	Unit
Organic carbon content of biochar	91.00%	%, dry weight
Hydrogen content of biochar	2.09%[11]	%, dry weight
Annual average soil temperature at site of biochar use	15	°C
Time horizon of sequestration	100	years
Biochar production over reporting period	2,194.66	mt, dry weight
Biochar supply-chain emissions	0.15	mt CO_2-eq/mt dry biochar
Permanence factor $F_p^{TH,Ts}$	86.44%	%
Carbon dioxide stored per mt of biochar	2.90	mt CO_2 / mt dry biochar
Carbon dioxide stored over reporting period (E*stored*)	6,359.19	mt CO_2

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[11] Average of Douglas-fir (2.20%) and Ponderosa pine (1.97%)

$$\underbrace{CORCs} = \underbrace{E_{stored}} - \underbrace{E_{biomass}} - \underbrace{E_{production}} - \underbrace{E_{use}}$$

	$CORCs$	E_{stored}	$E_{biomass}$	$E_{production}$	E_{use}
Description	Amount of net CO_2-eq removed over 100-year period by the biochar production activity	Amount of CO_2 sequestered over a 100-year time horizon by the amount of biochar produced over the reporting period.	Life cycle greenhouse gas emissions arising from the production and supply of biomass to the production facility, including direct land use changes.	Life cycle greenhouse gas emissions arising from the transformation of the biomass into biochar, at the producing facility.	Life cycle greenhouse gas emissions arising from the use of the biochar, including its distribution up to the point of final use.
Unit	tonnes CO_2-eq	tonnes CO_2-eq	tonnes CO_2-eq	tonnes CO_2-eq	tonnes CO_2-eq

Figure 5 Overall equation to calculate the amount of CORCs supplied by the biochar production activity over a given reporting period. The tonnes unit refers here to metric tons (i.e., 1000 kg). All terms are counted as positive. (E_{stored}) describes the amount of carbon dioxide sequestered over a 100-year time horizon by the amount of biochar produced. ($E_{biomass}$) describes the life cycle greenhouse gas emissions arising from the production and supply of biomass to the production facility, including direct land use changes. ($E_{production}$) describes the life cycle greenhouse gas emissions arising from the transformation of the biomass into biochar, at the producing facility. (E_{use}) describes the life cycle greenhouse gas emissions that occur along the distribution of the biochar up to its point of final use.

RESULTS

The life cycle impact assessment (LCIA) phase establishes links between the LCI inputs and potential environmental impacts. The LCIA calculates impact indicators, such as global warming potential and smog. ***These impact indicators provide general, but quantifiable, indications of potential environmental impacts.*** Environmental impacts are determined using methods obtained with the SimaPro software package and include the North American TRACI method (Bare 2012)[12] and Cumulative Energy Demand (CED).Each impact indicator value is stated in units that are not comparable to others. For the same reasons, indicators should not be combined or added. Additionally, the LCIA results are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins, or risks.

Cumulative Energy Demand is based on fuels' lower heating values (LHV). Cumulative Energy Demand (CED) is calculated from data published by Ecoinvent[13] and expanded by PRé for energy resources available in the SimaPro database. Characterization factors are given for six impact categories: 1. Non-renewable, fossil, 2. Non-renewable, nuclear, 3. Non-renewable, biomass, 4. Renewable, biomass, 5. Renewable, wind, solar, geothermal, and 6. Renewable, water. The primary fuels are categorized into non-renewable (fossil and nuclear) and renewable (biomass, geothermal, solar, wind, and hydro).

LCIA Results – TRACI

Cradle-to-grave environmental performance results are listed in Table 6 for Biochar. The LCIA results in show the absolute values for A1-Biomass collection, A2-Transportation, and A3-Biochar Production, A4-Transporation, and B1-Use/Applications. Table 6 and Figure 6 show the contribution of each life cycle stage to each impact category listed. For global warming, 44 percent of the CO_2 equivalent emissions come from A3 (191.07 mt CO_2 eq), with 2, 20, 17, and 18 percent from A1, A2, A4, and B1, respectively. Total transportation, which is for transporting biomass and biochar represents 37 percent of the total global warming impact. The distances transported were significant over the course of one year (A2=76,346 kilometers/yr. and A4=71,667 kilometers/yr.).

Table 6 Cradle-to-grave LCIA-TRACI results for 2,195 metric ton (mt) biochar, absolute basis

Impact Category	Unit	A1-Collection	A2 Transport	A3 Production	A4 Transport	B1 Use	A1-B1 Total
Ozone depletion	mt CFC-11 eq	1.20E-05	3.27E-09	1.22E-05	2.81E-09	3.05E-09	2.42E-05
Global warming	mt CO2 eq	8.15	85.65	191.07	73.60	79.84	438.31
Smog	mt O3 eq	0.63	14.00	83.62	12.03	13.05	123.34
Acidification	mt SO2 eq	0.03	0.51	3.05	0.44	0.48	4.51
Eutrophication	mt N eq	0.01	0.03	0.70	0.02	0.03	0.79

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[12] Bare, J. 2012. Tool for the Reduction and Assessment of Chemical and other Environmental Impacts (TRACI) - Software Name and Version Number: TRACI version 2.1 - User's Manual. Washington, D.C.: U.S. EPA.

[13] Wernet, G., Bauer, C., Steubing, B., Reinhard, J., Moreno-Ruiz, E., & Weidema, B. (2016) The Ecoinvent database version 3 (part I): overview and methodology. The International Journal of Life Cycle Assessment, 21, 1218–1230.

Table 7 Cradle-to-grave LCIA TRACI results for 2,195 metric ton biochar, relative basis

Impact Category	A1-Collection	A2-Transport	A3-Production	A4-Transport	B1-Use	Total A1-B1
Ozone depletion	49.66%	0.01%	50.30%	0.01%	0.01%	100.00%
Global warming	1.86%	19.54%	43.59%	16.79%	18.22%	100.00%
Smog	0.51%	11.35%	67.80%	9.75%	10.58%	100.00%
Acidification	0.68%	11.35%	67.63%	9.75%	10.58%	100.00%
Eutrophication	0.83%	3.61%	89.11%	3.10%	3.36%	100.00%

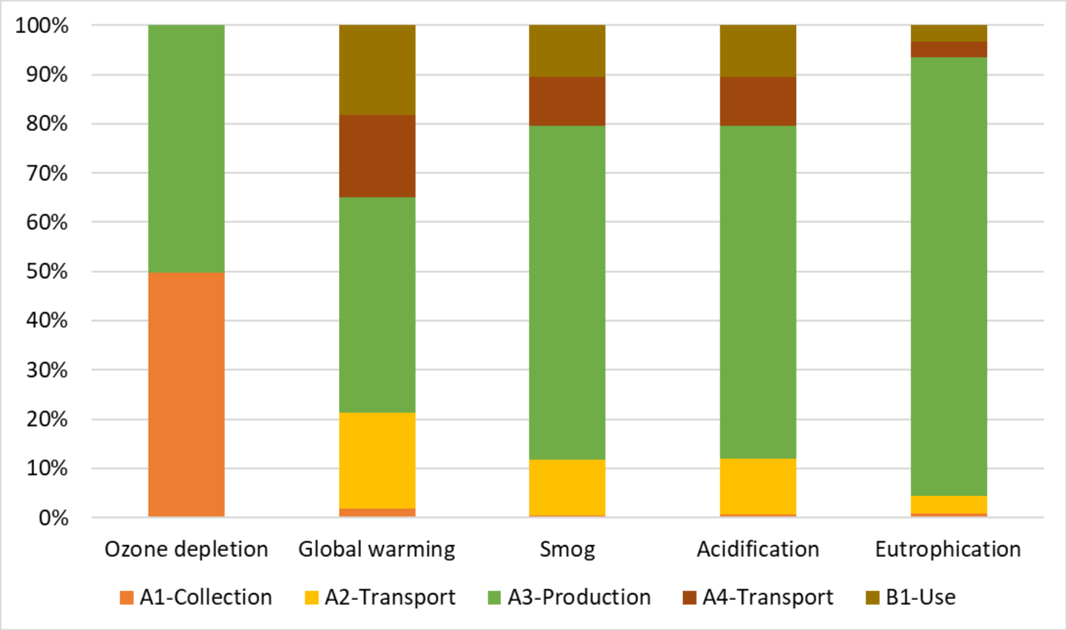

Figure 6 Cradle-to-grave LCIA results for 2,195 metric ton biochar, relative basis

LCIA results – CED

Table 8 provides indicators related to energy use. The total cradle-to-grave energy use was 11.4 million MJ/year. In-forest operations (A1) consumes 6 percent of the total energy, while biochar production (A3) consumes the majority of the total energy (67%) (Table 8). Energy for transportation (A2 & A4) consumes 18 percent of the total energy, with log hauling (A2) using 54% and biochar hauling using 46%. Application of biochar represents only 9 percent of the total energy. The production of biochar used nearly 100 percent of the renewable fuels, and 52 percent of non-renewable fuels (Table 9). Non-renewable fuels use was 68 percent of the total, leaving 32 percent of renewable fuels (Table 10).

Table 8 Cradle-to-grave LCIA-CED (LHV) results for 2,195 metric ton biochar, absolute basis

Impact Category	Unit	A1-Collection	A2-Transport	A3-Production	A4-Transport	B1-Use	Total A1-B1
Renewable s energy	MJ, NCV	714	-	3,646,822	-	-	7,741,170
Non-renewable energy	MJ, NCV	637,574	1,101,547	4,028,686	946,519	1,026,844	3,647,536
Total		638,288	1,101,547	7,675,508	946,519	1,026,844	11,388,707

Table 9 Cradle-to-grave LCIA-CED (LHV) results for 2,195 metric ton biochar, relative basis, energy source

Impact Category	Unit	A1-Collection	A2-Transport	A3-Production	A4-Transport	B1-Use	Total A1-B1
Renewable energy	MJ, NCV	0%	0%	100%	0%	0%	100%
Non-renewable energy	MJ, NCV	8%	14%	52%	12%	13%	100%
Total		6%	10%	67%	8%	9%	100%

Table 10 Cradle-to-grave LCIA-CED (LHV) results for 2,195 metric ton biochar, relative basis by life cycle stage

Impact Category	Unit	A1-Collection	A2-Transport	A3-Production	A4-Transport	B1-Use	Total A1-B1
Renewable energy	MJ, NCV	0%	0%	48%	0%	0%	68%
Non-renewable energy	MJ, NCV	100%	100%	52%	100%	100%	32%
Total	MJ, NCV	100%	100%	100%	100%	100%	100%

LCIA results – CORCs

All parameters for modeling the cradle-to-grave impacts for C6F2F biochar was provided by C6F2F. Table 5 list the parameters specific for determining the E*stored* parameter for the Carbon Dioxide Removal Certificates (CORCs) (puro.earth 2022). Results for E*biomass*, E*production,* and E*use* come from the GWP result from the TRACI impact method.

Using Equation 1, the resulting CORCs value over a 100-year period is 2.7 mt CO_2/mt biochar (Table 11) (Equation 1). Scaling this to up to the projected annual production (2,195 mt), that value rises to 5,921 mt CO_2e (Equation 2). ***More carbon is removed (stored) than is emitted during its life cycle.***

$$CORCs = Estored - Ebiomass - Eproduction - Euse$$

$$\boldsymbol{CORCs = 2.9 - 0.004 - 0.13 - 0.07 = 2.70\ mt\ CO2e}$$ **Equation 1**

$$\boldsymbol{CORCs = 6,359.19 - 8.15 - 276.72 - 153.44 = 5,920.87\ mt\ CO2}$$ **Equation 2**

Table 11 Cradle-to-grave net carbon sequestration over 100 years. Values are per metric ton(mt)of biochar and on the projected annual production.

		Net Carbon Sequestrations	
		mt CO_2/mt	**mt CO_2/2,195 mt**
	E*stored*	**2.90**	6,359
A1	E*biomass*	**0.00**	8.15
A2+A3	E*production*	**0.13**	277
A4+B1	E*use*	**0.07**	153
Sum (A1-B1)		**0.20**	438
	CORC s	**2.70**	5,921

RESULTS – PURO BIOCHAR CARBON CALCULATOR

Using a spreadsheet provided by puro.earth, the biochar carbon stored (E*stored*) can be calculated over a given timeframe, in a soil with a given annual average temperature. The following tables are from the carbon calculator provided with the puro.earth methodology, showing the biochar carbon sequestration at any given time horizon and soil temperature (Figure 7). The calculator uses the amount of biochar produced over a reporting period (1 mt in this case), the organic carbon content of the biochar (91%, Table 5), the permanence factor (see Box 1) of the biochar organic carbon (86.84%, Table 12) and soil temperature (Table 5).

Table 12 Parameters used in the puro.earth biochar carbon calculator expressing the carbon sequestration permanance over time and soil temperatures.

Parameter name	Value	Unit	Comment
Hydrogen to organic carbon molar ratio H/C_{org}	0.2756[14]	mol / mol	Calculated from input data
Slope of linear regression	-0.636	no unit	Calculated for selected soil temperature & supporting information to Woolf et al. (2021)
Intercept of linear regression	1.044	no unit	Calculated for selected soil temperature & supporting information to Woolf et al. (2021)
Coefficient of regression of linear regression	0.330	no unit	Calculated for selected soil temperature & supporting information to Woolf et al. (2021)
Permanence factor $F_p^{TH,Ts}$	86.84%	%	At given soil temperature, and time horizon selected
Carbon dioxide stored per mt of biochar	2.90	mt CO_2 / mt dry biochar	At given soil temperature, and time horizon selected
Carbon dioxide stored over reporting period (E*stored*)	6,359.149	mt CO_2	At given soil temperature, and time horizon selected, for given production period
CORCs per mt of biochar	2.75[15]	CORCs / mt dry biochar	Based on the assumed supply-chain emissions reported here.
CORCs for biochar production over reporting period	6,030.00[16]	CORCs	Based on the assumed supply-chain emissions and the expected biochar production over the reporting period.

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[14] Average Douglas-fir (0.29) and Ponderosa pine (0.26)

[15] Our value for supply chain emissions is 2.70 kg CO2e based on TRACI CO2e outputs

[16] Our value for supply chain is 5,921 kg CO2e based on TRACI CO2e outputs

$F_{pTH,Ts}$ is the permanence factor of biochar organic carbon over a given time horizon TH in a given soil at temperature T_S. It is also known as biochar carbon stability, and it is expressed as a percentage (%). At a given TH and T_s, the permanence factor F_{pTH,T_s} is only a function of the *molar* H/C_{org} ratio of the biochar and follows the linear relationship below:

$$Fp\ TH,Ts=c+m\times H/Corg$$

The *molar* H/C_{org} ratio of a biochar sample is derived from the laboratory analysis as given or calculated from laboratory analyses dividing the hydrogen *mass* content by the *organic* carbon *mass* content of the biochar and multiplying this with the ratio of carbon molar mass over hydrogen molar mass. In other words:

$$HC_{org}/(molar)=m_H(\%)m_C(\%)\times M_C(g\ mol_{-1})M_H(g\ mol_{-1})= m_H(\%)m_C(\%)\times 121.0$$

The regression coefficients c and m are a function of the time horizon TH and the soil temperature T_s. Table 1 below provides the values of these two coefficients for a time horizon TH of 100 years, and for a range of soil temperatures T_s. To select the appropriate coefficients c and m to use, the biochar producer should consider the regions where the biochar is likely to be used[12]. If a main region for biochar use cannot be defined, the global mean soil temperature of 14.9°C can be used as a default value.

Remark on $F_{p\,TH,Ts}$ values above 100%: at lower soil temperatures and with biochars having a low $HC_{org}/$, it is possible that the linear regression provides $F_{p\,TH,Ts}$ above 100%. In that case, the value should be set equal to 100%.

Table 1. Regression coefficients for estimating biochar stability for a time horizon TH of 100 years at various soil temperatures T_s. Precise temperature selection can be made using Puro's tools made available to CO_2 Removal Supplier.

Soil temperature TS	**c**	**m**
5°C	1.13	-0.46
10°C	1.10	-0.59
15°C	1.04	-0.64
20°C	1.01	-0.65
25°C	0.98	-0.66
14.9°C	*1.04*	*-0.64*

Finally, the factor 44/12 is the ratio between the molar mass of carbon dioxide and the molar mass of carbon. This factor converts an amount of carbon to its corresponding amount of carbon dioxide.

The H/C ratio for the biochar in this LCA is 0.2756[17] which would fall between 0.25 – 0.30 in the graphs (green and light blue regression lines). Using a H/C ratio of 0.29 for biochar samples produced from Douglas fir and 0.26 for Ponderosa pine and soils temperature as an average of 15°C[18] (Figure 7C). Soil temperatures can vary from 5°C – 25°C depending on the region. Using the average temperature of 15°C, after 100 years, 85-88% percent of the biochar carbon remains. After 500 years, 42-45% percent of the carbon would be present, and after 1,000 years, 22-23% percent of the carbon in the biochar remains As temperature increases, the permanence factor, $F_p^{TH,TS}$ decreases (Figure 8).

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[17] Average of Douglas-fir (0.29) and Ponderosa pine (0.26)

[18] Presentation of 15°C was determined from an average global annual cropland temperature of 14.9°C.

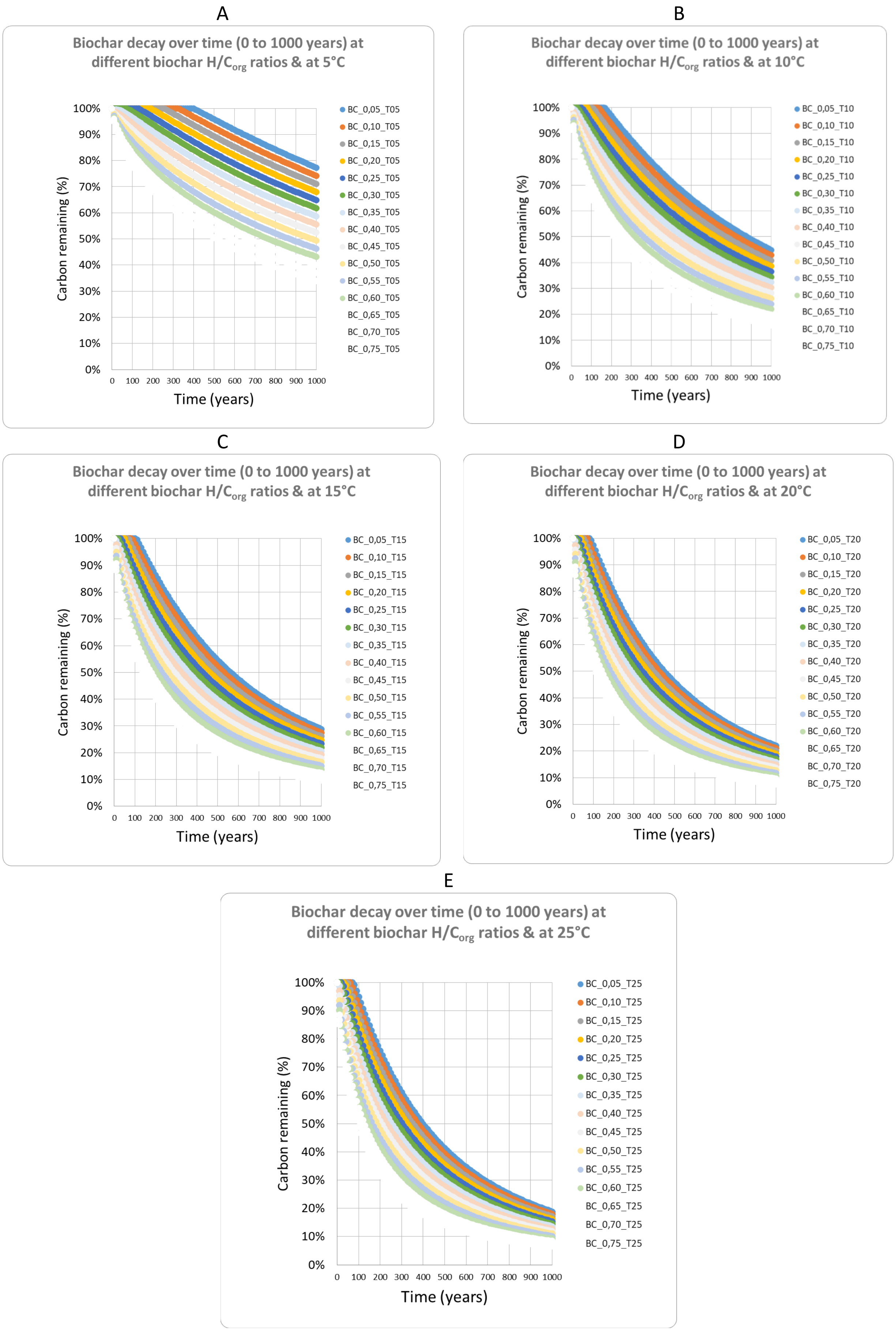
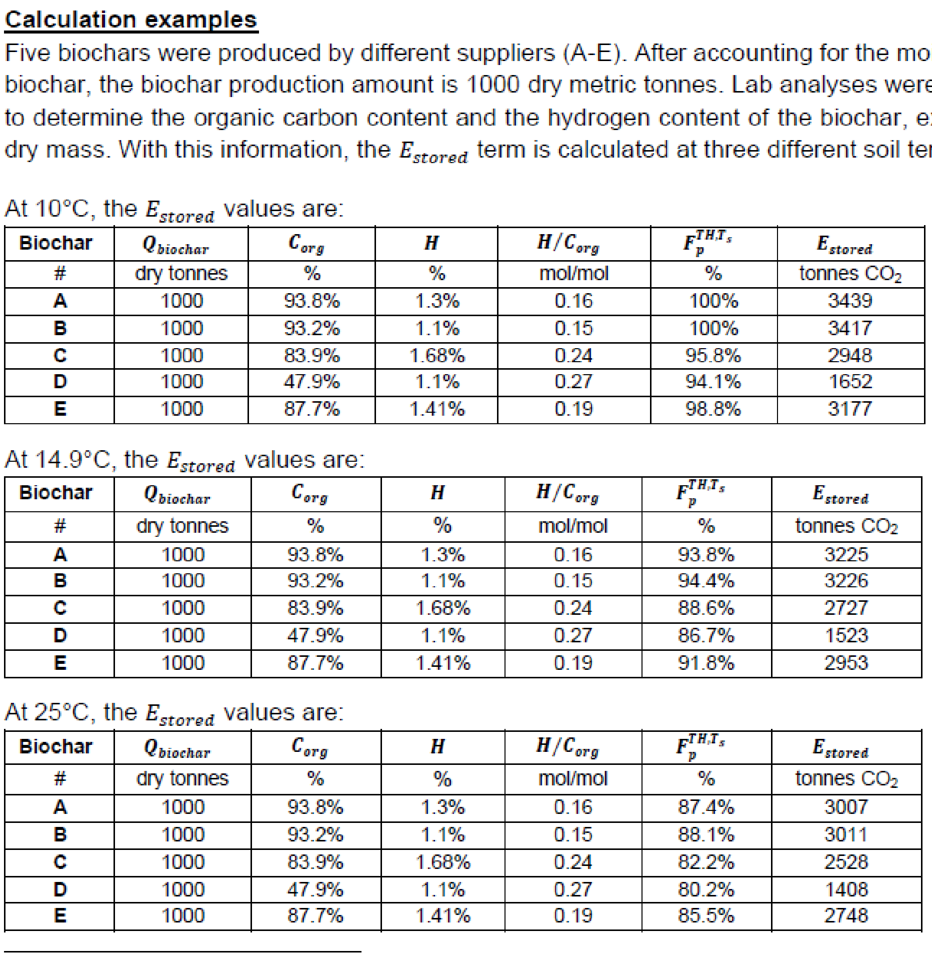


Figure 7 Biochar decay rates between 0-1,000 years at different biochar H/C_{org} mol/mol ratios at -5°C [A], 10°C [B], 15°C [C], 20°C [D], and 25°C [E]. The H/C_{org} for C6F2F biochar is 0.27 mol/mol



Calculation examples

Five biochars were produced by different suppliers (A-E). After accounting for the moisture in the biochar, the biochar production amount is 1000 dry metric tonnes. Lab analyses were performed to determine the organic carbon content and the hydrogen content of the biochar, expressed in dry mass. With this information, the E_{stored} term is calculated at three different soil temperature.

At 10°C, the E_{stored} values are:

Biochar	$Q_{biochar}$	C_{org}	H	H/C_{org}	F_p^{TH,T_s}	E_{stored}
#	dry tonnes	%	%	mol/mol	%	tonnes CO_2
A	1000	93.8%	1.3%	0.16	100%	3439
B	1000	93.2%	1.1%	0.15	100%	3417
C	1000	83.9%	1.68%	0.24	95.8%	2948
D	1000	47.9%	1.1%	0.27	94.1%	1652
E	1000	87.7%	1.41%	0.19	98.8%	3177

At 14.9°C, the E_{stored} values are:

Biochar	$Q_{biochar}$	C_{org}	H	H/C_{org}	F_p^{TH,T_s}	E_{stored}
#	dry tonnes	%	%	mol/mol	%	tonnes CO_2
A	1000	93.8%	1.3%	0.16	93.8%	3225
B	1000	93.2%	1.1%	0.15	94.4%	3226
C	1000	83.9%	1.68%	0.24	88.6%	2727
D	1000	47.9%	1.1%	0.27	86.7%	1523
E	1000	87.7%	1.41%	0.19	91.8%	2953

At 25°C, the E_{stored} values are:

Biochar	$Q_{biochar}$	C_{org}	H	H/C_{org}	F_p^{TH,T_s}	E_{stored}
#	dry tonnes	%	%	mol/mol	%	tonnes CO_2
A	1000	93.8%	1.3%	0.16	87.4%	3007
B	1000	93.2%	1.1%	0.15	88.1%	3011
C	1000	83.9%	1.68%	0.24	82.2%	2528
D	1000	47.9%	1.1%	0.27	80.2%	1408
E	1000	87.7%	1.41%	0.19	85.5%	2748

Figure 8 Calculation examples of E_{stored} at three soil temperatures (puro.earth methodology v2)

APPENDIX A – FOREST TO PLANT MATERIAL AND ENERGY INPUTS

Table 13 Forest to Plant Material and Energy Inputs

Steps in Process (#)	Equipment Used	Input Description	Input mass (short tons/hr.)	Input Device	Annual runtime (hours/yr.)	Annual travel distance (mi/yr.)	Annual Diesel Consumption Estimate (gal/yr.)	Annual Water Estimate (gal/yr.)	Output Description	Output per hour (short tons)
FP.5	Loader - John Deere 2954D	sorted logs	42.6	Diesel engine	265	-	Calculate based on FC numbers in CORRIM database	0	logs	42.6
FP.6	Log Truck w/ Pup Trailer	logs	42.6	Diesel engine	-	47439	Calculate based on FC numbers in CORRIM database	0	logs	42.6
Special Equipment[1/]	Water Truck F750	Water, Diesel	N/A	Diesel engine	N/A	2850	238	2000	N/A	N/A
Special Equipment[2/]	Fuel Truck F750	Diesel	N/A	Diesel engine	N/A	2850	238	0	N/A	N/A
Special Equipment[3/]	Service Truck F350	Diesel	N/A	Diesel engine	N/A	2850	110	0	N/A	N/A

[1/] Required support for commercial operation; conservatively include 50% of its impact for our non-commercial waste biomass; Assumptions: single 2000 gallon tank of water is charged per annum.; 6 mpg; daily round trip of 50 miles

[2/] Required support for commercial operation; conservatively include 50% of its impact for our non-commercial waste biomass; Assumptions: fuel is consumed by machines for ops, captured as appropriate below; only fuel truck engine consumption necessary here; 6 mpg; daily round trip of 50 miles

[3/] - Required support for commercial operation; conservatively include 50% of its impact for our non-commercial waste biomass; Assumptions: 13 mpg; daily round trip of 50 miles

APPENDIX B PLANT OPERATIONS MATERIAL AND ENERGY INPUTS

Steps in Process (#)	Equipment Used	Input Description	Input mass (short tons/hr.)	Input Device	Actuator Rated Output Power (hp)	Actuator Rated Output Power (W)	Typical Load (%)	Estimated Efficiency	Annual Electricity Consumption Estimate (kWh/yr.)	Annual active runtime (hr./yr)	Annual idle runtime (hr./yr)	Annual Propane Estimate (gal/yr.)	Output Description	Output Mass (short tons/hr.)
P.1	Truck scale	trucks	11.9	-					[1/]				trucks	11.9
P.2	Tipper	truck with unsorted biomass											truck with unsorted biomass	
P.3	Wheeled Loader - CAT 972m or similar	unsorted biomass		Diesel engine									sorted biomass	
P.4	Wheeled Loader - CAT 972m or similar	sorted biomass		Diesel engine									sorted biomass	
P.45	log truck	raw logs (as loaded in forest to plant above)	-	Diesel engine							49		raw logs	
P.5 - unload truck[2/]	Wheeled Loader - CAT 972m or similar	raw logs	232	Diesel engine						49			raw logs	232
P.6 - load live deck[3/]	Wheeled Loader - CAT 972m or similar	raw logs	18.0	Diesel engine						94			raw logs	18.0
P.7	Live Deck	raw logs	18.0	4 ea 3hp motor	12	8,948	25%	82%	1,718				raw logs	18.0
P.8	Chain Conveyor	raw logs	18.0	3hp gear motor	3	2,237	25%	82%	430				raw logs	18.0
P.9[4/]	Debarker	raw logs	18.0	3ea 50hp roller drives	150	111,855	65%	75%	55,838				debarked logs, bark	14.7
P.10	Grinder Infeed Conveyor	debarked logs	14.7	15hp electric motor	15	11,185	75%	92%	6,443				debarked logs	14.7

Steps in Process (#)	Equipment Used	Input Description	Input mass (short tons/hr.)	Input Device	Actuator Rated Output Power (hp)	Actuator Rated Output Power (W)	Typical Load (%)	Estimated Efficiency	Annual Electricity Consumption Estimate (kWh/yr.)	Annual active runtime (hr./yr)	Annual idle runtime (hr./yr)	Annual Propane Estimate (gal/yr.)	Output Description	Output Mass (short tons/hr.)
P.11	Horizontal Grinder	debarked logs hog fuel - overs recirc	17.3	300hp electric motor	300	223,710	75%	95%	128,857				hog fuel	17.3
P.46[7/]	Metal Collection box	metals	TBD	N/A - just a passive bin									metal	TBD
P.12	Screen Feed Conveyor	hog fuel	17.3	3hp gear motor	3	2,237	25%	82%	430				hog fuel	17.3
P.13	Chip Screen	hog fuel	17.3	5hp motor	5	3,728	50%	88%	1,432				hog fuel - overs hog fuel - keeps	17.3
P.14	Grinder Over Conveyor	hog fuel - overs	2.6	3ea 3hp gearmotors	9	6,711	25%	82%	1,289				hog fuel - overs	2.6
P.15	Grinder Keep Conveyor	hog fuel - keeps	14.7	3hp gearmotor	3	2,237	25%	82%	430				hog fuel - keeps	14.7
P.16	Hogged Fuel Storage	hog fuel - keeps	14.7	See Section "Hogged Wood Storage" Below	23.5	17,524	See Section "Hogged Wood Storage" Below	See Section "Hogged Wood Storage" Below	57,041				hog fuel - keeps	14.7
P.17	Feed Conveyor	hog fuel - keeps	1.4	1ea 3hp gear motor	3	2,237	25%	82%	4,510				hog fuel - keeps	1.4

Steps in Process (#)	Equipment Used	Input Description	Input mass (short tons/hr.)	Input Device	Actuator Rated Output Power (hp)	Actuator Rated Output Power (W)	Typical Load (%)	Estimated Efficiency	Annual Electricity Consumption Estimate (kWh/yr.)	Annual active runtime (hr./yr)	Annual idle runtime (hr./yr)	Annual Propane Estimate (gal/yr.)	Output Description	Output Mass (short tons/hr.)
P.18	Feed Bin	hog fuel - keeps	1.4	2ea 1hp gear motors	2	1,491	75%	90%	9,020				hog fuel - keeps	1.4
P.19	Rotary Shear Infeed Conveyor	hog fuel - keeps	1.4	1ea 3hp gear motor	3	2,237	25%	82%	4,510				hog fuel - keeps	1.4
P.20	Rotary Shear	hog fuel - keeps crumbled particles - overs	2.3	M24M-30e, 2-stage tower 2ea 30hp motor	60	44,742	70%	100%	252,560				crumbled particles	2.3
P.21	Orbital Screen Feed Conveyor	crumbled particles	2.3	1ea 3hp gear motor	3	2,237	25%	82%	4,510				crumbled particles	2.3
P.22	Orbital Screen	crumbled particles	2.3	Orbital Screen System Model 2448-3 0.75hp motor	0.75	559	75%	TBD	3,382				crumbled particles - fines crumbled particles - overs crumbled particles - keeps	2.3
P.23[5/]	Rotary Shear Overs Conveyor	crumbled particles - overs	0.9	1ea 3hp gear motor	3	2,237	25%	82%	4,510				crumbled particles - overs	0.9
P.24[6/]	Rotary Shear Fines Conveyor	crumbled particles - fines	0.1	1ea 3hp gear motor	3	2,237	25%	82%	4,510				crumbled particles - fines	0.1
P.25	Fines Storage Bin	crumbled particles - keeps	0.1	N/A - just a passive bin	-	-	-	-	-				crumbled particles - fines	-

Steps in Process (#)	Equipment Used	Input Description	Input mass (short	Input Device	Actuator Rated Output Power (hp)	Actuator Rated Output Power (W)	Typical Load (%)	Estimated Efficiency	Annual Electricity Consumption Estimate (kWh/yr.)	Annual active runtime (hr./yr)	Annual idle runtime (hr./yr)	Annual Propane Estimate (gal/yr.)	Output Description	Output Mass (short tons/hr.)
P.26	Crumbler Keep Conveyor	crumbled particles - keeps	1.3	1ea 3hp gear motor	3	2,237	25%	82%	4,510				crumbled particles - keeps	1.3
P.27	Surge Bin	crumbled particles - keeps	1.3	2ea 1hp gearmotors	2	1,491	75%	TBD	9,020				crumbled particles - keeps	1.3
P.28	Dryer	crumbled particles - keeps	1.0	See Section "Dryer" Below	33	24,608	See Section "Dryer" Below	See Section "Dryer" Below	148,830			297	dried particles	1.0
P.29	Reactor Feed Conveyor	dried particles	1.0	1ea 3hp gear motor	3	2,237	25%	82%	4,510				dried particles	1.0
P.30	Reactor Package	dried particles	1.0	See Section "Reactor Package" Below	N/A	N/A	N/A	N/A	446,040				cooled biochar	1.0
P.31[7/]	Syngas Metering Device	syngas	0.34	TBD	TBD	TBD	TBD	TBD	TBD				syngas	0.34
P.328/	Thermal Oxidizer	surplus syngas	0.26	combustor	N/A	N/A	N/A	N/A	N/A			284	surplus syngas	0.26
P.49	Bio-oil Storage Tank	bio-oil fraction	0.07	N/A - just a passive tote	-	-	-	-	-				N/A - holds bio-oil through this process	
P.47[9/]	Forklift - Transfer to Storage	bio-oil tote	-	drive & load handling motors	-	-	-	-	155					

Steps in Process (#)	Equipment Used	Input Description	Input mass (short tons/hr.)	Input Device	Actuator Rated Output Power (hp)	Actuator Rated Output Power (W)	Typical Load (%)	Estimated Efficiency	Annual Electricity Consumption Estimate (kWh/yr.)	Annual active runtime (hr./yr)	Annual idle runtime (hr./yr)	Annual Propane Estimate (gal/yr.)	Output Description	Output Mass (short tons/hr.)
P.51	Forklift - Transfer to Truck for Shipping	bio-oil tote	-	drive & load handling motors	-	-	-	-	132					
P.50	PLA Storage Tank	PLA fraction	0.27	N/A - just a passive tote	-	-	-	-	-				N/A - holds PLA through this process	
P.48	Forklift - Transfer to Storage	PLA tote	-	drive & load handling motors	-	-	-	-	624					
P.52	Forklift - Transfer to Truck for Shipping	PLA tote	-	drive & load handling motors	-	-	-	-	517					
P.36	Biochar Conveyor	cooled biochar	0.3	1ea 3hp gearmotor	3	2,237	25%	82%	4,510				cooled biochar	0.3
P.37	Biochar Surge Bin	cooled biochar	0.3	2ea 1hp gearmotors	2	1,491	75%	TBD	9,020				cooled biochar	0.3
P.41	Super Sack Infeed Conveyor	cooled biochar	-	1ea 3hp gearmotor	3	2,237	25%	82%	0				cooled biochar	-
P.42[10/]	Super Sack Filling Station	cooled biochar	-	1ea 1hp motor (densification)	1	746	60%		0				cooled biochar	-

Steps in Process (#)	Equipment Used	Input Description	Input mass (short	Input Device	Actuator Rated Output Power (hp)	Actuator Rated Output Power (W)	Typical Load (%)	Estimated Efficiency	Annual Electricity Consumption Estimate (kWh/yr.)	Annual active runtime (hr./yr)	Annual idle runtime (hr./yr)	Annual Propane Estimate (gal/yr.)	Output Description	Output Mass (short tons/hr.)
P.39	Trailer Loader Infeed Conveyor	cooled biochar	0.3	1ea 3hp gearmotor	3	2,237	25%	82%	4,510					0.3
P.40[11/]	Trailer Loader	cooled biochar	0.3	1ea 3hp gearmotor	3	2,237	25%	82%	4,510				cooled biochar	0.3

1/ Electricity consumption is negligible

2/ No idling during truck unloading ops; see 'Model - Plant Truck Unloading'

3/ Loader can carry multiple 'deckloads' of logs in grapple (see Model - Live Deck Loading); idles while waiting for deck to clear. BRR 2022-11-09 - removed idle time. Wait time is ~7 minutes, and this is within our control through personnel training. We can train to shut down loader while waiting.

4/ ~18% bark loss by mass

5/ 40% overs recirculating

6/ 5% fines

7/ Syngas is 35% of reactor output mass; Assume power required for metering is negligible for now; will gather data at later time.

8/ Self-firing after startup, burning process output syngas (with condensables separated); Assuming 100 lb. propane per startup (see ARTI 5-train); Terminal - flue gas is emitted to atmosphere

9/ Check out "Model - Liquids Handling" for more detail

10/ We have a LOI with a customer to take all our pilot production in bulk trucks, so this isn't included to start

11/ Assumes this is used for half the packaging, so applied half the yearly operating hours.