Life cycle assessment for WoodCache, PBC’s WCSP Terrestrial Storage of Biomass production and use for CORC calculation

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Abstract

WoodCache, PBC initiated a pilot Terrestrial Biomass Storage (TBS) project in Southern Colorado, USA in April of 2023. The goal was to gather waste wood (source biomass) from fire mitigation activities and sequester the carbon therein using an engineered pit design that would protect and store the carbon for more than 100 years, the Walsenburg Carbon Sequestration Project (WCSP). The purpose of the project was to validate the end-to-end processes in advance of several additional projects/facilities beginning operations in 2024.

WoodCache entered into a lease/easement agreement with a local landowner obtained necessary permits and began operations in Summer of 2023. Burial of 76.8 tonnes of dry biomass was completed in September. The State of Colorado Department of Public Health and Environment certified closure of the facility in November. The same month Puro released their TSB methodology.

Woodcache engaged Jesik Consulting of Pueblo Colorado to provide an engineering design and site investigation for the facility. The existing vegetation consists of native grasses, trees, shrubs, and weeds. A wood vault was built to sequester carbon. The vault floor is a 75-foot by 50-foot rectangle shape.

Wood branches and trunks from the surrounding site were collected as a fire mitigation initiative and were placed in 2 layers within the subsurface vault. All wood is either cedar/juniper or piñon pine. The wood was greater than 90-percent dry and leaves/needles were not allowed into the vault. Each wood lift was about 50-inches thick with voids backfilled with on-site soils excavated from the vault to reduce potential subsidence of the water balanced cap. A 6-inch-thick lift cap consisting of on-site soil was placed between each wood/soil lift.

The wood vault was capped with a water balanced cap using on-site sandy clay loam material. The cap thickness is approximately 4-feet thick. The vault cap top is 2- feet above the existing ground surface. Revegetation actions with native vegetation were performed to complete the cap, per design.

Considerations into the wood vault design included:

1. Wood vault temperature, moisture, and oxygen levels
2. Surface subsidence
3. Wood vault cap
4. Existing subsurface conditions
5. Soil chemistry

Maintaining low moisture levels and temperatures in the shallow wood vault are designed to be the most economical and feasible option to minimize wood decay. A thicker cap allows the vault's internal temperature to undergo smaller temperature variations and at a thickness of about 10-feet, be near the mean annual average temperature of the site. Walsenburg's mean annual temperature is 50 degrees Fahrenheit with an average annual 18-inches of precipitation. The site elevation is about 6,650 feet above mean sea level.

Several parameters such as temperature, moisture, carbon dioxide and methane gas are monitored daily in each of the subsurface layers to aid in wood decay control over time.

Regular inspections are performed to assess the physical integrity and decay-prevention welfare of the site to include high-precision gas testing below at and above the surface of the vault.

Surface Water is directed away from the wood vault by creating uphill berms again using on-site soils. These berms also provide on-site soil storage for the wood vault in the event areas of the vault subside in the future.

Regulatory and environmental approvals were granted by Huerfano County and the State of Colorado. A completion report was filed and approved at the conclusion of the activities.

The Gross Amount of CO_2 removed was measured as follows:

Gross weight of bio-mass	76.8 tonnes	Weighed on calibrated scales
X Measured Dry Matter Factor	93.4%	Lab Validated samples
= Gross Dry Biomass	71.7 tonnes	Calculated
X Organic Carbon Content	52.7%	Lab Validated Samples
X Conversion Factor	3.667	Puro Methodology
= Gross Amount of CO_2	**-138.6** tonnes	Calculated
= CO_2 per tonne Dry Biomass	-1.93	Calculated

Supply Chain Emissions are calculated from actual consumption of fuel, usage of equipment, and materials using standard carbon emission factors thru facility closure. Monitoring and management emissions for 100 years are estimated and calculated.

Final CORC calculation:	-138.6	tCO_2 removed
	48.4	tCO_2 re-emission
	20.7	tCO_2 Supply – Chain (6%)
	- 69.5 t	CO_2 CORCs requested

Table of Contents

Glossary

List of abbreviations repeatedly used across the report. Abbreviations shall also be defined upon first use in the main report.

CH4 - Methane
CO2 –Carbon Dioxided
CORC – CO2 Removal Certificates
CVAS – Cumberland Valley Analytical Services
EIA – Energy Information Administration (US)
GWP – Global Warming Potential
LCA – Life Cycle Assessment
LCIA – Life Cycle Impact Assessment
NFTA -
TSB – Terrestrial Storage of Biomass
WCSP - Walsenburg Carbon Sequestration Project

1. Introduction

This study was commissioned by WoodCache, PBC, a Terrestrial Storage of Biomass operator in the United States. The principles of WoodCache have performed all aspects of this exercise.

The Project being assessed is the Walsenburg Carbon Sequestration Project (WCSP) in Walsenburg, Colorado, a town in Huerfano County. The goal was to gather waste wood (source biomass) from fire mitigation activities and sequester the carbon therein using an engineered pit design that would protect and store the carbon for more than 100 years, the Walsenburg Carbon Sequestration Project (WCSP). The purpose of the project was to validate the end-to-end processes in advance of several additional projects/facilities beginning operations in 2024.

2. Goal and scope definition

2.1. Goal of the study

There are multiple objectives for this study:

- Calculate the Net Carbon equivalent removed through a trial TBS project for Puro CORC application
- Establish the boundaries of the TSB product system for full-scale follow-on projects
- Calculate key metrics that can be used to estimate and sell future projects
- Develop greater skill in performing and presenting WoodCache LCA analyses

As mentioned previously, the WCSP is a pilot project that will provide experience in all aspects of end-to-end TSB methodology execution from project conception through sale and retirement of Carbon Credits. WoodCache envisions a regional hub of facilities that will be operational in the current region of Southern Colorado leveraging similar supply systems, climate, ground conditions, and personnel. This study will inform that expansion.
This study will use an attributional LCA approach to comply with the Puro standard. It is focused on a single product which is carbon storage using woody biomass from local waste wood. The results are intended to augment an application for Puro facility certification and CORC awards. The study may also be used to augment sales initiatives and local environmental agency inquiries. It will be leveraged by WoodCache personnel and partners in other regions and states.

This study covers a very short period of time, the approximately 8 month life-cycle of WCSP operations in 2023.

2.2. Scope of the study

2.2.1. Product-systems considered

The activity boundaries that are included in the LCA to represent terrestrial storage of biomass are defined in Figure 1 as outlined in the TSB methodology. However, certain activities have not been included.

As the WCSP is a single unit storage site. Activities associated with the *Establishment of the storage site* are consolidated with the Construction of the first (and only) storage unit. Our solution has no pre-processing of biomass, so none has been included. It is so noted in the LCA spreadsheet.

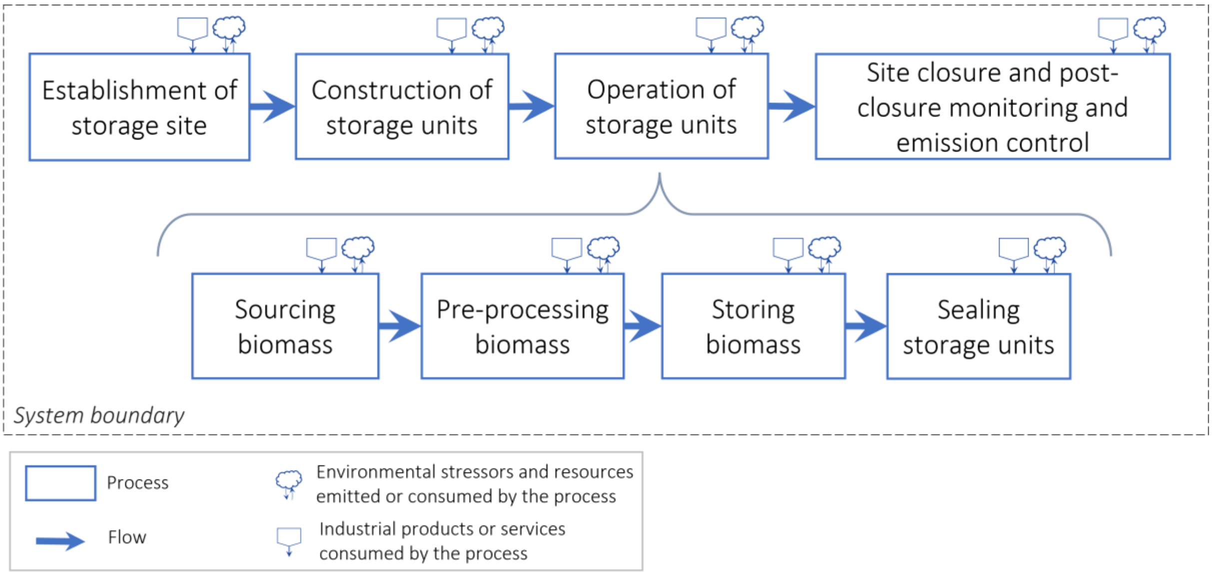

Figure 1. ***Process Flow and System boundaries per Puro TSB methodology***

Functional Units and Flows

The primary goal of this study is to calculate the net carbon equivalent removed through our trial TSB project for Puro CORC application. As prescribed by Puro, for geologically stored carbon CORCs, the FU is 1 tonne of dry mass stored in a compliant storage site.

2.2.2. Impact categories and impact assessment methods

This Study/LCA is the standardized method of calculating the impact of our product on the environment. During this LCA, emission data was gathered from transportation and excavating primarily. A small amount was gathered from harvesting equipment and other small devices. All electrical energy used in our process was solar provided.

During the Life Cycle Impact Assessment (LCIA) of this LCA, we unite these different emissions into one impact category, ‘climate change’. It is expressed in kg CO_2 equivalents (kg CO_2-eq).

We are not including a climate impact because of Direct Land Use Change (DLUC). One feature of our Wood vault is that we return the land we used to its original state and land use. The property is pastureland suitable for grazing and it will be returned to that purpose as authorized by the State. While a small amount of vegetation and trees were disrupted for construction of the pit, they will be allowed to grow back.

Use as pastureland is confirmed with the State in a protective use covenant.

No water is used in the burial process and it's specific design considers that the affected area will support the same run-off quantities and direction without impact or pollution.

2.2.3. System boundaries

System description and Foreground/Background Data

As shown in figure 1, our system process and boundaries are aligned with the Puro Methodology.

Our raw material is wood waste. Our product is putting that wood waste in the ground in an engineered vault. There is no processing of the wood other than selecting wood waste that is at least 1 inch in diameter.

Our wood vault is not manufactured. There are no braces, liners, chemical additives, or other materials. It is dug into the ground. The soils that were removed were placed back in a specific order on top of the now-buried wood waste. No other materials were brought-in from third-party sites other than monitoring equipment and organic fertilizers and seed.

Given this simple process, our foreground data are fuel consumption figures, vehicle upstream costs, and monitoring equipment/infrastructure. Our background data are the emissions according to established metrics.

Time Boundaries

This study provides an LCA for the full 100-year lifetime of a single facility in a specific location. Though a small pilot program, the WCSP will be managed for 100 years. As such, all activities necessary to initiate the program, execute, close and monitor the facility have been addressed.

Cut-off Criteria

We believe the carbon loss from disruption of the soil during construction and closing, as well as DLUC are minimal. To start, the topsoil is poor and shallow, one foot or less. Beyond that it is mostly sand with some finer soils for the next 3 feet or so. Essentially, there is not much carbon

In addition, our excavation process reserved the topsoil separately. When the cap was built, the topsoil was used at the surface to retain any biological material. It was exposed for less than 3 weeks total. About 6 trees were cut down but they will be allowed to grow back in the area.

2.2.4. Multi-functionality and allocation procedures

There were no multifunctionality issues as 100% of the biomass which was used in this program was sourced for this program and stored. All soil excavated was restored in the closing process. All background data was fully allocated to this project.

2.2.5. Assumptions and limitations

We assumed that after year 3, a remote inspector from Pueblo would be enlisted to perform physical inspections. This is a conservative expectation as there are numerous potential outcomes which could include local resources performing the work, drone-based inspections, shared inspections with other facilities, and cancellation of inspections due to minimal findings.

3. Life cycle inventory analysis

3.1. Software, databases, and other data sources

The WCSP is a very simple project that takes a readily available raw material, wood waste, and buries it on the same property using existing soils as the cover material. Nearly 100% of the Climate Change Impact comes from the fuels used to operate the machinery while excavating and covering, as well as transportation to-and-from the site.

The only software used for modeling was Excel spreadsheets for logging biomass weight and fuel consumption. The final calculations were made using the PURO LCA spreadsheet, also Excel. Foreground Data included Biomass weight logging and Fossil Fuel use. Background data included lab testing for inventory calculations and emissions conversion to tCO_2 equivalents.

Embedded software is resident in the Intercomp weighing system that was used. This is operational and proprietary software. The project relied upon the product calibration to ensure software worked as expected and neither modified it nor used it out of specification..

3.1.1. Biomass weight logging

During the staging process, wood from the greater property (70 acres) was stacked and hauled on trailers. Each trailer load was segregated by species, either Cedar or Pine for subsequent testing and tracking. Prior to stacking at the storage site, each trailer load was weighed using the Intercomp PT300 RFX Solar Weighing System (specifications provided elsewhere in the audit data).

This system comes calibrated from the factory and our project was the equipment’s first use. The devices were used according to manufacturer’s recommendations in a 3 or 5 scale network depending on whether the trailer was dual or single axle. The devices communicate wirelessly and provide a composite weight of all contact points.

For a single axle trailer there would be a scale under each wheel and one under the trailer tongue jack. The Master scale aggregated the 3 weights for a single loaded trailer weight. The combined weight of each load, trailer and biomass, was logged and in most cases photographed/video. Photos and videos are provided in supporting data. This combined weight was netted against the trailer's empty mass recorded in similar fashion to provide a net woody biomass weight.

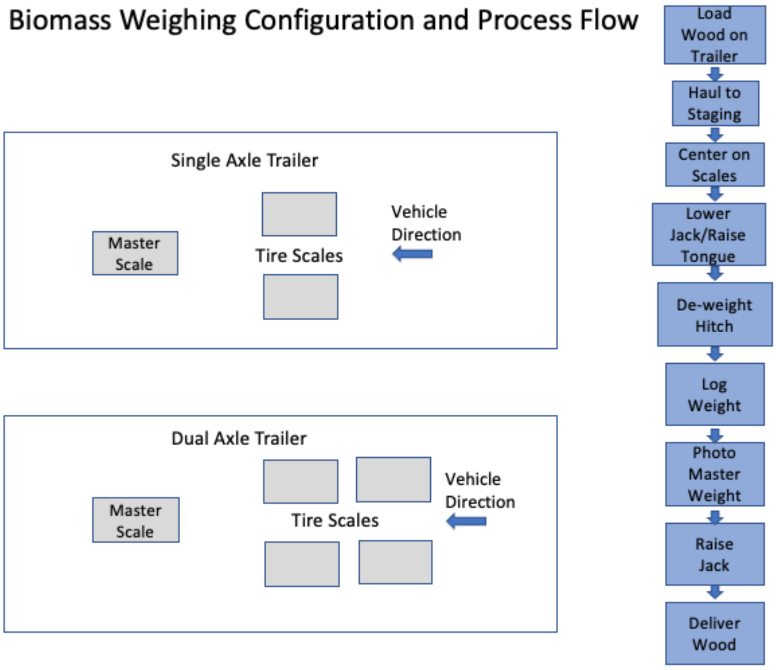

Figure 2 WCSP Scale Configuration and Process Flow used.

The two-axle trailer implementation was the same except that 5 scales were used. 4 under the wheels and 1 under the tongue jack.

3.1.2. Fossil fuel use and logging

Fuel consumption measurements were provided by the equipment users in the following manner:

- Transportation to site – Driver provided:
  - Driver name
  - Date of trips
  - Make and model of vehicle
  - Fuel type
  - Estimated mileage
  - Miles driven

- Operation of Equipment on site – Operator provided:
  - Operator Name
  - Date of Use
  - Type of Fuel
  - Quantity (Gallons)

The above data was logged and aggregated in the Emissions Tracking and Calculation Spreadsheet. An excerpt of the logs is provided Figure 3.

	Who	Activity	Miles	Vehicle	Fuel Type	Total Miles	MPG Est.	Fuel Used
	Excavation & Closure							
ug 7 - 22, 2023	Reed Excavating	Travel, Hauling, Digging and Back-filling		Various	Diesel			700
7-Aug	Ray Bongiovanni	Drive to Site	8	Tacoma Picku	Gas	16	16	1
7-Aug	Andy Jesik	Drive to Site	58	Pickup	Gas	116	18	6.44
8-Aug	Ray Bongiovanni	Drive to Site	8	Tacoma Picku	Gas	16	16	1
9-Aug	Ray Bongiovanni	Drive to Site	8	Tacoma Picku	Gas	16	16	1
10-Aug	Ray Bongiovanni	Drive to Site	8	Tacoma Picku	Gas	16	16	1
14-Aug	Ray Bongiovanni	Drive to Site	8	Tacoma Picku	Gas	16	16	1
15-Aug	Ray Bongiovanni	Drive to Site	8	Tacoma Picku	Gas	16	16	1
16-Aug	Ray Bongiovanni	Drive to Site	8	Tacoma Picku	Gas	16	16	1
17-Aug	Ray Bongiovanni	Drive to Site	8	Tacoma Picku	Gas	16	16	1
21-Aug	Ray Bongiovanni	Drive to Site	8	Tacoma Picku	Gas	16	16	1
7-Aug	Andy Jesik	Drive to Site	58	Pickup	Gas	116	18	6.44
22-Aug	Ray Bongiovanni	Drive to Site	8	Tacoma Picku	Gas	16	16	1
23-Aug	Ray Bongiovanni	Drive to Site	8	Tacoma Picku	Gas	16	16	1
nstallation of Monitoring Equipment & Revegetation								
17-Sep	Jesse	Drive to town from Denver	140	Rental	Gas	280	20	14
17-Sep	Jesse	Drive to Ranch	8	Rental	Gas	16	20	0.8
18-Sep	Jesse	Drive to Facility	15	Rental	Gas	30	18	1.7
17-Sep	Ray Bongiovanni	Drive to Site	7	Tacoma Picku	Gas	14	16	0.9
18-Sep	Wilcox	Drive to Site	7	Diesel Truck	Diesel	14	12	1.2
18-Sep	Wilcox	Skid Steer			Diesel			2.0
18-Sep	Ray Bongiovanni	Drive to Site	7	Tacoma Picku	Gas	14	16	0.9
19-Sep	Ray Bongiovanni	Drive to Site	7	Tacoma Picku	Gas	14	16	0.9
16-Oct	Coleman Glover	Hydroseeding	15	Seeding Truck	Diesel			10
16-Oct	Wilcox	Drive to Site	7	Diesel Truck	Diesel	14	12	1.2
utting & Readying for Transport								
3-Apr	Ray Bongiovanni	Drive to Site	8	Tacoma Picku	Gas	16	16	1
3-Apr	Marc Leduc	Drive to Site	33	Chevy Pickup	Gas	66	19	3.47
3-Apr	Marco Alatore	Drive to Site	12	Tesla Model Y	EV	24		
3-Apr	AJ Palmer	Drive to Site	12	Subaru Forest	Gas	24	21	1.14
4-Apr	Ray Bongiovanni	Drive to Site	8	Tacoma Picku	Gas	16	17	0.94
4-Apr	Serge Bushman	Drive to Site	10	Ford F150	Gas	20	24	0.83
4-Apr	Marc Leduc	Drive to Site	34	Chevy Silverac	Gas	68	19	3.58
5-Apr	Ray Bongiovanni	Drive to Site	8	Tacoma Picku	Gas	16	17	0.94
5-Apr	Serge Bushman	Drive to Site	10	Ford F150	Gas	20	24	0.83
5-Apr	Marc leduc	Drive to Site	34	Chevy Pickup	Gas	68	19	3.58

Figure 3 Excerpt of Emissions Log containing fuel use details and tracking

Lab Testing

As a pre-execution checkpoint and to prove out the process of using a lab to test our raw material, in July 2023, two samples of chipped wood were taken during the harvesting stage. A single sample of each species of wood was taken and tested for moisture content, Volatile Solids, Carbon content and Nitrogen. Figure 4 provides the results of this testing.

Key to this early testing was confirmation of the arid climate and the very dry conditions of the woody biomass targeted by the project. Dead or dying trees were to be removed and stored in the pit. Moisture levels in both samples were under 8% and one was as low as 7%. Carbon/nitrogen ratios were particularly good at over 225.

To characterize the biomass to be stored and support CORC applications, samples of wood were gathered from the stock staged at the storage site. 6 samples were taken to capture the types of stock that was amassed. Mix of types was estimated based on visual inspection.

- Solid Pine – Pinyon Pine larger in diameter, typically >4 inches (~72% of total biomass)

- Solid Cedar – Cedar/Juniper that was larger in diameter, typically >4 inches (~16% of total biomass)
- Pine Aged – Pinyon Pine that had been on the ground and had begun to show some signs of breakdown (~7% of total biomass)
- Cedar Aged – Cedar/that had been on the ground and had begun to show some signs of breakdown (~3.5% of total biomass)
- Pine Twig - Pinyon Pine larger in diameter, typically <4 inches (~1% of total biomass)
- Cedar Twig – Cedar/Juniper larger in diameter, typically <4 inches (~0.5% of total biomass)

Lab ID	Description	Estimated % of Biomass	Sampled	Arrived	Completed	Moisture %	Dry %	Volatile Solids %	Carbon	Total Nitrogen	Carbon/Nitrogen Ratio (target >80)	Weighted Carbon
33944 05	Wood Chips - Cedar		5/30/2023	07/03/2023	07/06/2023	7.6	92.4	90.9	51.29%	0.20%	256.45	
33944 06	Wood Chips - Pine		5/30/2023	07/03/2023	07/06/2023	7.0	93.0	91.9	51.90%	0.23%	225.65	
34133 10	Wood Chips - Cedar Twig	0.50%	8/6/2023	08/10/2023	08/21/2023	52.7	47.3	95.8	51.04%	0.45%	113.42	0.3%
34133 11	Wood Chips - Pine Twig	1%	8/6/2023	08/10/2023	08/21/2023	6.6	93.4	96.7	53.19%	0.51%	104.29	0.5%
34133 12	Wood Chips - Pine Aged	7%	8/6/2023	08/10/2023	08/21/2023	4.6	95.4	93.7	49.79%	0.40%	124.48	3.5%
34133 13	Wood Chips - Cedar Solid	16%	8/6/2023	08/10/2023	08/21/2023	4.7	95.3	94.8	52.02%	0.29%	179.38	8.3%
34133 114	Wood Chips - Cedar Aged	3.50%	8/6/2023	08/10/2023	08/21/2023	5.1	94.9	98.6	54.28%	0.17%	319.29	1.9%
34133 15	Wood Chips - Pine Solid	72%	8/6/2023	08/10/2023	08/21/2023	7.0	93.0	99.4	54.39%	0.12%	453.25	38.3%
												52.7%

Figure 4 Test results from woody biomass samples (6)

Samples were sent to Forage Labs, Cumberland Valley Analytical Services (CVAS). CVAS is an agricultural laboratory focused on providing feed and forage analysis services. Their technologies support animal production, feed manufacturing, agronomy, biofuel production, water quality, and manure management needs in the U.S. and globally.

CVAS has been certified by NFTA yearly since they began participating in the program over 20 years ago. A full list of certifications can be found here:

https://www.foragelab.com/Services/Forage-and-Feed/Certifications

Results were tabulated in a spreadsheet and weighted content calculations were made. Figure 4 summarizes the results. Specific test reports have been provided in the supporting documentation.

Emission Conversions

Background modelling of emissions used the Carbon Dioxide emission coefficients published by the EIA as excerpted in Figure 5. Diesel Fuel and Motor Gasoline by the gallon were the primary measures.

Carbon Dioxide Emissions Coefficients by Fuel

Carbon Dioxide (CO_2) Factors:	Pounds CO_2 Per Unit of Volume or Mass		Kilograms CO_2 Per Unit of Volume or Mass		Pounds CO_2 Per Million Btu	Kilograms CO_2 Per Million Btu
For homes and businesses						
Propane	12.68	gallon	5.751	gallon	138.63	62.88
Diesel and Home Heating Fuel (Distillate Fuel Oil)	22.45	gallon	10.185	gallon	163.45	74.14
Kerosene	21.78	gallon	9.880	gallon	161.35	73.19
Coal (All types)	3,890.78	short ton	1,764.832	short ton	211.47	95.92
Natural Gas	120.96	thousand cubic feet	54.868	thousand cubic feet	116.65	52.91
Finished Motor Gasoline[a]	17.86	gallon	8.103	gallon	148.57	67.39
Motor Gasoline	19.37	gallon	8.785	gallon	155.77	70.66
Residual Heating Fuel (Businesses only)	24.78	gallon	11.241	gallon	165.55	75.09

Figure 5 Source: Carbon factors provided by the U.S. Environmental Protection Agency, Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2021, Tables A19, A-24, A-31, and A-215. Heat content of fuels provided by the U.S. Environmental Protection Agency Greenhouse Gas Emissions Factor Hub, survey Form EIA-923, and Appendix Tables A1-A3 of the EIA Monthly Energy Review

3.2. Missing data disclosure

As a pilot project, record-keeping evolved as needs required. The initial 40% of biomass weight logs were recorded via text or alignment between project personnel with no photographic back-up. The remaining 60% of weight logs included video of both the master device and the trailer load of wood itself. It is strongly felt that the readings are correct and accurate. All other aspects of the process were followed.

3.3. Inventory data

3.3.1. Biomass Cultivation

The WCSP utilized waste wood from an existing unmanaged forest on private land. At some point in the past, much of the land had been cleared for cattle grazing but has significantly grown back as the property came under Landowner Association management. The trees/forest have been left to regrow naturally.

However, the forest is now denser. In the local semi-arid region recently ravaged by wildfires proper wildfire mitigation is necessary and strongly encouraged. The landowner of Lots 30 & 31 of the River Ridge Ranch, decided to remove dead or dying trees to reduce fire susceptibility.

No Cultivation was performed or necessary.

3.3.2. Biomass Harvesting

Tree harvesting was a landowner decision for fire mitigation and not part of the System Boundary.

Though emissions were recorded for the effort for future purposes, they have been fully offset.

	Who	Activity	Miles	Vehicle	Fuel Type	Total	MPG Est.	Fuel Used	Coefficient	Conversion	tCO2
Cutting & Readying for Transport											
3-Apr	Ray Bongiovanni	Drive to Site	8	Tacoma Pickup	Gas	16	16	1	8785.0	8785.0	0.009
3-Apr	Marc Leduc	Drive to Site	33	Chevy Pickup	Gas	66	19	3.47	8785.0	30484.0	0.030
3-Apr	Marco Alatore	Drive to Site	12	Tesla Model Y	EV	24				0.0	0.000
3-Apr	AJ Palmer	Drive to Site	12	Subaru Forester	Gas	24	21	1.14	8785.0	10014.9	0.010
4-Apr	Ray Bongiovanni	Drive to Site	8	Tacoma Pickup	Gas	16	17	0.94	8785.0	8257.9	0.008
4-Apr	Serge Bushman	Drive to Site	10	Ford F150	Gas	20	24	0.83	8785.0	7291.6	0.007
4-Apr	Marc Leduc	Drive to Site	34	Chevy Silverado	Gas	68	19	3.58	8785.0	31450.3	0.031
5-Apr	Ray Bongiovanni	Drive to Site	8	Tacoma Pickup	Gas	16	17	0.94	8785.0	8257.9	0.008
5-Apr	Serge Bushman	Drive to Site	10	Ford F150	Gas	20	24	0.83	8785.0	7291.6	0.007
5-Apr	Marc leduc	Drive to Site	34	Chevy Pickup	Gas	68	19	3.58	8785.0	31450.3	0.031
10-Apr	Marc leduc	Drive to Site	34	04 Dodge	Gas	68	15	4.53	8785.0	39796.1	0.040
	Marc leduc	Drive to Site	34	04 Dodge	Gas	68	15	4.53	8785.0	39796.1	0.040
	Marc leduc	Drive to Site	34	04 Dodge	Gas	68	15	4.53	8785.0	39796.1	0.040
	Marc leduc	Drive to Site	34	04 Dodge	Gas	68	15	4.53	8785.0	39796.1	0.040
	Marc leduc	Drive to Site	34	04 Dodge	Gas	68	15	4.53	8785.0	39796.1	0.040
	Marc leduc	Drive to Site	34	04 Dodge	Gas	68	15	4.53	8785.0	39796.1	0.040
	Marc leduc	Drive to Site	34	04 Dodge	Gas	68	15	4.53	8785.0	39796.1	0.040
	Marc Leduc	Chipper Operation			Gas	0		6	8785.0	52710.0	0.053
	Marc Leduc	chainsaw			Gas	0		2.5	8785.0	21962.5	0.022
	Marc Leduc	Chainsaw Bar Fluid			Oil	0		0.5	8785.0	4392.5	0.004
8-May	Larry Harris	Drive to Site	188	11 Chevy Silverad	Gas	376	18	20.89	8785.0	183518.7	0.184
8-May	Marc Leduc	chainsaw			Gas	0		2.5	8785.0	21962.5	0.022
8-May	Marc Leduc	Chainsaw Bar Fluid			Oil	0		1	8785.0	8785.0	0.009
15-May	Marc Leduc	Drive to Site	34	Chevy Pickup	Gas	68	19	3.58	8785.0	31450.3	0.031
15-May	Marc Leduc	Chipper Operation			Gas	0		2	8785.0	17570.0	0.018
17-May	Marc Leduc	Drive to Site	34	Chevy Pickup	Gas	68	19	3.58	8785.0	31450.3	0.031
17-May	Marc Leduc	Chipper Operation			Gas	0		2	8785.0	17570.0	0.018
23-May	Marc Leduc	Drive to Site	34	Chevy Pickup	Gas	68	19	3.58	8785.0	31450.3	0.031
23-May	Marc Leduc	Chipper Operation			Gas	0		0.5	8785.0	4392.5	0.004
24-May	Marc Leduc	Drive to Site	34	04 Dodge	Gas	68	15	4.53	8785.0	39796.1	0.040
25-May	Marc Leduc	Drive to Site	34	04 Dodge	Gas	68	19	3.58	8785.0	31450.3	0.031
25-May	Marc Leduc	Chipper Operation			Gas	0		1	8785.0	8785.0	0.009
26-May	Marc Leduc	Drive to Site	34	Chevy Pickup	Gas	68	19	3.58	8785.0	31450.3	0.031
30-May	Marc Leduc	Drive to Site	34	Honda Pilot	Gas	68	20	3.4	8785.0	29869.0	0.030
30-May	Marc Leduc	Chipper Operation			Gas	0		3	8785.0	26355.0	0.026
31-May	Marc Leduc	Drive to Site	34	04 Dodge	Gas	68	19	3.58	8785.0	31450.3	0.031
31-May	Marc Leduc	Chipper Operation			Gas	0		3	8785.0	26355.0	0.026
1-Jun	Marc Leduc	Drive to Site	34	11 dodge	Gas	68	15	4.53	8785.0	39796.1	0.040
1-Jun	Marc Leduc	chainsaw			Gas			2.5	8785.0	21962.5	0.022
1-Jun	Marc Leduc	Chipper Operation			Gas	0		3	8785.0	26355.0	0.026
2-Jun	Marc Leduc	Drive to Site	34	11 dodge	Gas	68	15	4.53	8785.0	39796.1	0.040
2-Jun	Marc Leduc	chainsaw			Oil			2.5	8785.0	21962.5	0.022
2-Jun	Marc Leduc	Chipper Operation			Gas	0		3	8785.0	26355.0	0.026
5-Jun	Marc Leduc	Drive to Site	34	Chevy pickup	Gas	68	19	3.58	8785.0	31450.3	0.031
5-Jun	Marc Leduc	Chipper Operation			Gas	0		2	8785.0	17570.0	0.018
6-Jun	Marc Leduc	Drive to Site	34	04 Dodge	Gas	68	19	3.58	8785.0	31450.3	0.031
6-Jun	Marc Leduc	Chipper Operation			Gas	0		2	8785.0	17570.0	0.018
7-Jun	Marc Leduc	Return Chipper I	87	Chevy pickup	Gas	174	19	9.16	8785.0	80470.6	0.080
16-Jun	Marc Leduc	Drive to Site	34	04 Dodge	Gas	68	19	3.58	8785.0	31450.3	0.031
16-Jun	Marc Leduc	chainsaw			Oil			1	8785.0	8785.0	0.009
19-Jun	Marc Leduc	Drive to Site	34	04 Dodge	Gas	68	19	3.58	8785.0	31450.3	0.031
20-Jun	Marc Leduc	Drive to Site	34	04 Dodge	Gas	68	19	3.58	8785.0	31450.3	0.031
20-Jun	Marc Leduc	chainsaw			Oil			1	8785.0	8785.0	0.009
20-Jun	Marc Leduc	chainsaw			Gas			1	8785.0	8785.0	0.009
22-Jun	Marc Leduc	Drive to Site	34	04 Dodge	Gas	68	19	3.58	8785.0	31450.3	0.031
23-Jun	Marc Leduc	Drive to Site	34	04 Dodge	Gas	68	19	3.58	8785.0	31450.3	0.031
26-Jun	Marc Leduc	Drive to Site	34	11 Chevy Silverad	Gas	68	18	3.78	8785.0	33207.3	0.033
27-Jun	Marc Leduc	Drive to Site	34	11 Chevy Silverad	Gas	68	18	3.78	8785.0	33207.3	0.033
28-Jun	Marc Leduc	Drive to Site	34	11 Chevy Silverad	Gas	68	18	3.78	8785.0	33207.3	0.033
29-Jun	Marc Leduc	Drive to Site	34	11 Chevy Silverad	Gas	68	18	3.78	8785.0	33207.3	0.033
29-Jun	Marc Leduc	chainsaw			Oil			1	8785.0	8785.0	0.009
29-Jun	Marc Leduc	chainsaw			Gas			2.5	8785.0	21962.5	0.022
30-Jun	Marc Leduc	Drive to Site	34	11 Chevy Silverad	Gas	68	18	3.78	8785.0	33207.3	0.033
											1.810

Table 1 Harvesting Log Summary and Caclulations

3.3.3. Biomass Supply

Biomass supply in the WCSP included the transport and staging activity to consolidate the biomass at a single point. This is a normal part of fire mitigation and disposal. Therefore, The emissions have been fully offset as a necessary and predictable stage of the baseline process.

On-Site	Who	Activity	Miles	Vehicle	Fuel Type	Total	MPG Est.	Fuel Used	Coefficient	Conversion	tCO2
22-Jun	Serge Bushman	Drive to Site	10	Ford F150	Gas	20	24	0.83	8785.0	7291.6	0.007
23-Jun	Serge Bushman	Drive to Site	10	Ford F150	Gas	20	24	0.83	8785.0	7291.6	0.007
23-Jun	Serge Bushman	Drive to Site	10	Ford F150	Gas	20	24	0.83	8785.0	7291.6	0.007
24-Jun	Serge Bushman	Drive to Site	10	Ford F150	Gas	20	24	0.83	8785.0	7291.6	0.007
24-Jun	Serge Bushman	Drive to Site	10	Ford F150	Gas	20	24	0.83	8785.0	7291.6	0.007
25-Jun	Serge Bushman	Drive to Site	10	Ford F150	Gas	20	24	0.83	8785.0	7291.6	0.007
26-Jun	Serge Bushman	Drive to Site	10	Ford F150	Gas	20	24	0.83	8785.0	7291.6	0.007
26-Jun	Serge Bushman	Drive to Site	10	Ford F150	Gas	20	24	0.83	8785.0	7291.6	0.007
27-Jun	Serge Bushman	Drive to Site	10	Ford F150	Gas	20	24	0.83	8785.0	7291.6	0.007
3-Jul	Serge Bushman	Drive to Site	10	Ford F150	Gas	20	24	0.83	8785.0	7291.6	0.007
4-Jul	Serge Bushman	Drive to Site	10	Ford F150	Gas	20	24	0.83	8785.0	7291.6	0.007
4-Jul	Serge Bushman	Drive to Site	10	Ford F150	Gas	20	24	0.83	8785.0	7291.6	0.007
5-Jul	Serge Bushman	Drive to Site	10	Ford F150	Gas	20	24	0.83	8785.0	7291.6	0.007
5-Jul	Serge Bushman	Drive to Site	10	Ford F150	Gas	20	24	0.83	8785.0	7291.6	0.007
6-Jul	Serge Bushman	Drive to Site	10	Ford F150	Gas	20	24	0.83	8785.0	7291.6	0.007
8-Jul	Ray Bongiovanni	Drive to Site	8	Tacoma Pickup	Gas	16	16	1	8785.0	8785.0	0.009
8-Jul	Ray Bongiovanni	Drive to Site	8	Tacoma Pickup	Gas	16	16	1	8785.0	8785.0	0.009
9-Jul	Ray Bongiovanni	Drive to Site	8	Tacoma Pickup	Gas	16	16	1	8785.0	8785.0	0.009
13-Jul	Ray Bongiovanni	Drive to Site	8	Tacoma Pickup	Gas	16	16	1	8785.0	8785.0	0.009
13-Jul	Whit Childs	Drive to Site	10	Chevy	Gas	20	19	1.05	8785.0	9224.3	0.009
13-Jul	Whit Childs	Pickup Trailer		Chevy	Gas			48.9	8785.0	429586.5	0.430
13-Jul	Wilcox	Drive to Site	8	Pickup	Gas	16	16	1	8785.0	8785.0	0.009
13-Jul	Wilcox	Skid steer			Diesel				10185.0	0.0	0.000
13-Jul	Ray Bongiovanni	Drive to Site	8	Tacoma Pickup	Gas	16	16	1	8785.0	8785.0	0.009
13-Jul	Whit Childs	Drive to Site	10	Chevy	Gas	20	19	1.05	8785.0	9224.3	0.009
14-Jul	Ray Bongiovanni	Drive to Site	8	Tacoma Pickup	Gas	16	16	1	8785.0	8785.0	0.009
14-Jul	Whit Childs	Drive to Site	10	Chevy	Gas	20	19	1.05	8785.0	9224.3	0.009
14-Jul	Wilcox	Drive to Site	8	Pickup	Gas	16	16	1	8785.0	8785.0	0.009
14-Jul	Wilcox	Skid steer			Diesel			5	10185.0	50925.0	0.051
21-Jul	Ray Bongiovanni	Drive to Pueblo	56	Tacoma Pickup	Gas	112	16	7	8785.0	61495.0	0.061
22-Jul	Ray Bongiovanni	Drive to Site	8	Tacoma Pickup	Gas	16	16	1	8785.0	8785.0	0.009
21-Jul	Wilcox	Drive to Site	8	Pickup	Gas	16	16	1	8785.0	8785.0	0.009
22-Jul	Wilcox	Drive to Site	8	Pickup	Gas	16	16	1	8785.0	8785.0	0.009
22-Jul	Wilcox	Skid steer			Diesel			8.5	10185.0	86572.5	0.087
4-Aug	Wilcox	Drive to Site	8	Pickup	Gas	16	16	1	8785.0	8785.0	0.009
5-Aug	Wilcox	Drive to Site	8	Pickup	Gas	16	16	7	8785.0	61495.0	0.061
6-Aug	Wilcox	Skid steer			Diesel			8.5	10185.0	86572.5	0.087
6-Aug	Wilcox	Drive to Site	8	Pickup	Gas	16	16	1	8785.0	8785.0	0.009
6-Aug	Wilcox	Skid steer			Diesel			4	10185.0	40740.0	0.041
											1.069

Table 2 Biomass Supply log and Calculations

3.3.4. Biomass pre-processing

No pre-processing of Biomass was required. All wood waste was used in the condition it was gathered.

3.3.5. Biomass Storage

Emissions for the excavation, burial, and cover of the biomass were logged by the excavation company and visitors/engineers involved in overseeing the effort. Section 3.1.2 Fossil Fuel Use and Logging provides a detailed summary of the methodology used to gather the raw data to calculate the emissions. Miles driven were used to calculate the Scope 3 emissions of the vehicles and equipment used.

	Who	Activity	Miles	Vehicle	Fuel Type	Total	MPG Est.	Fuel Used	Coefficient	Conversion	tCO2
	Excavation & Closure										
Aug 7 - 22, 202	Reed Excavating	Travel, Hauling, Digging and		Various	Diesel			700	10185.0	7129500.0	7.130
7-Aug	Ray Bongiovanni	Drive to Site	8	Tacoma Pickup	Gas	16	16	1	8785.0	8785.0	0.009
7-Aug	Andy Jesik	Drive to Site	58	Pickup	Gas	116	18	6.44	8785.0	56575.4	0.057
8-Aug	Ray Bongiovanni	Drive to Site	8	Tacoma Pickup	Gas	16	16	1	8785.0	8785.0	0.009
9-Aug	Ray Bongiovanni	Drive to Site	8	Tacoma Pickup	Gas	16	16	1	8785.0	8785.0	0.009
10-Aug	Ray Bongiovanni	Drive to Site	8	Tacoma Pickup	Gas	16	16	1	8785.0	8785.0	0.009
14-Aug	Ray Bongiovanni	Drive to Site	8	Tacoma Pickup	Gas	16	16	1	8785.0	8785.0	0.009
15-Aug	Ray Bongiovanni	Drive to Site	8	Tacoma Pickup	Gas	16	16	1	8785.0	8785.0	0.009
16-Aug	Ray Bongiovanni	Drive to Site	8	Tacoma Pickup	Gas	16	16	1	8785.0	8785.0	0.009
17-Aug	Ray Bongiovanni	Drive to Site	8	Tacoma Pickup	Gas	16	16	1	8785.0	8785.0	0.009
21-Aug	Ray Bongiovanni	Drive to Site	8	Tacoma Pickup	Gas	16	16	1	8785.0	8785.0	0.009
7-Aug	Andy Jesik	Drive to Site	58	Pickup	Gas	116	18	6.44	8785.0	56575.4	0.057
22-Aug	Ray Bongiovanni	Drive to Site	8	Tacoma Pickup	Gas	16	16	1	8785.0	8785.0	0.009
23-Aug	Ray Bongiovanni	Drive to Site	8	Tacoma Pickup	Gas	16	16	1	8785.0	8785.0	0.009
										Total	7.339

Table 3 Biomass Storage log and Caclulations

3.3.6. Install Monitoring & Revegetation

Emissions to install the monitoring equipment after the site was capped were logged per previously described processes. During the burial/capping process, large 8-inch tubes were placed vertically within the pit to preserve an access area for the proper positioning of the sensors. These tubes were removed using a skid steer. Electronics were lowered into the pit and covered with soil.

Life-cycle emissions for the equipment installed, the PVC used, the shed, Solar Panels and other related equipment and infrastructure are included in the LCA.

Revegetation seeding and feeding was done utilizing a hydroseeding process. A truck carrying a mixture of seed fertilizer and water sprayed the top of the pit area.

Emissions for the fertilizer and other additives were logged and recorded in the LCA.

Installation of Monitoring Equipment & Revegetation											
17-Sep	Jesse	Drive to town fr	140	Rental	Gas	280	20	14	8785.0	122990.0	0.123
17-Sep	Jesse	Drive to Ranch	8	Rental	Gas	16	20	0.8	8785.0	7028.0	0.007
18-Sep	Jesse	Drive to Facility	15	Rental	Gas	30	18	1.7	8785.0	14641.7	0.015
17-Sep	Ray Bongiovanni	Drive to Site	7	Tacoma Pickup	Gas	14	16	0.9	8785.0	7686.9	0.008
18-Sep	Wilcox	Drive to Site	7	Diesel Truck	Diesel	14	12	1.2	10185.0	11882.5	0.012
18-Sep	Wilcox	Skid Steer			Diesel			2.0	10185.0	20370.0	0.020
18-Sep	Ray Bongiovanni	Drive to Site	7	Tacoma Pickup	Gas	14	16	0.9	8785.0	7686.9	0.008
19-Sep	Ray Bongiovanni	Drive to Site	7	Tacoma Pickup	Gas	14	16	0.9	8785.0	7686.9	0.008
16-Oct	Coleman Glover	Hydroseeding	15	Seeding Truck	Diesel			10	10185.0	101850.0	0.102
16-Oct	Wilcox	Drive to Site	7	Diesel Truck	Diesel	14	12	1.2	10185.0	11882.5	0.012
											0.314

Table 4 Installation of Monitoring Equipment Log and Calculations

3.3.7. Site Monitoring & Management – Long Term

Long-term monitoring and management are the few areas where estimation is required. An assumption of 140 miles per inspection at 20 miles per gallon was assumed. It is further assumed that after year 3, the same inspections would be performed with an EV. Mileage was calculated and a CO2 Equivalent coefficient for EV miles traveled was applied.

Site Monitoring and Management (Long-Term)				
	Years 1-3 Quarterly Inspections and Testing	4 visits per year for 3 years = 12 Inspections 140 miles R/T travel per inspection 20 miles per gallon = 7 gallons per inspection 7 gals * 12 inspections = 84 Gals Gasoline	**0.738**	Prior to closure of site, contractual arrangement with 3rd party will be finalized. Actual details of travel, equipment used, etc… will be documented and updated.
	Years 4-100 Annual Inspections (will be performed using EV's at 120 grams CO2 per mile)	1 visit per year for 97 years = 97 Inspections 140 miles R/T travel per inspection 140miles * 97 inspections = 13,580 miles	**1.630**	Prior to closure of site, contractual arrangement with 3rd party will be finalized. Actual details of travel, equipment used, etc… will be documented and updated.

Table 5 Estimation of future Emissions from Inspection and Management protocols

4. Life cycle impact assessment and interpretation

As we summarize the study, it should be noted how simple and straightforward the WCSP Territorial Storage of Biomass solution is. There is very limited processing. With on-site harvesting, staging, and burial, the carbon cost of operations is minimal. Re-emissions after burial are the only hot-spot and the largest offset to gross carbon removal. The WCSP solution produces virtually no methane and therefore its GWP impact deviates significantly from the Puro default re-emission calculations.

Gross Carbon Storage is 138.6 tonnes CO2 equivalent which equates to 1,804 kg per tonne of Dry Mass stored. Net Supply chain emissions are 20.7 tonnes. Re-emissions are projected to be 13.6 tonnes based on current post-burial testing. However, as a year of test data is required to comply with Puro Methodology, we are including an additional 34.8 tonnes of re-emissions for a total net removal of 69.5 tonnes CO2e or 904 kilograms CO2e per tonne of dry mass stored.

The WCSP Monitoring Reporting and Verification program has reported a minimum mix of CO2-to-combined CO2/CH4 of 98%. This is consistent at any level within the storage pit, flux measurements at the surface, and within the ambient air above the chamber. More specifically, CH4 has not been measured above 2 ppm or more than 2% of the CO2/CH4 mix ratio. The Puro default assumption is a 50/50 mix based on anoxic environments.

As our chamber meets the condition 5 assumptions of Table 3 Flux Dependent Methane Oxidation Rates, we have applied a 35% Oxidation Rate.

Appendix A documents the testing results and calculations in detail.

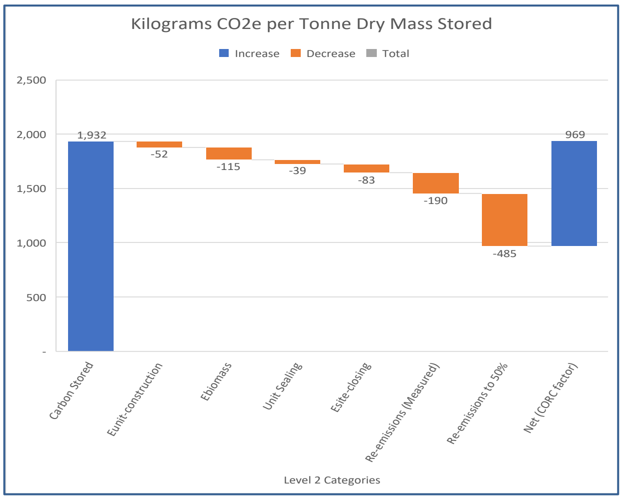

Figure 6 Waterfall of Gross Carbon Removal and resulting Project offsets and Re-emissions

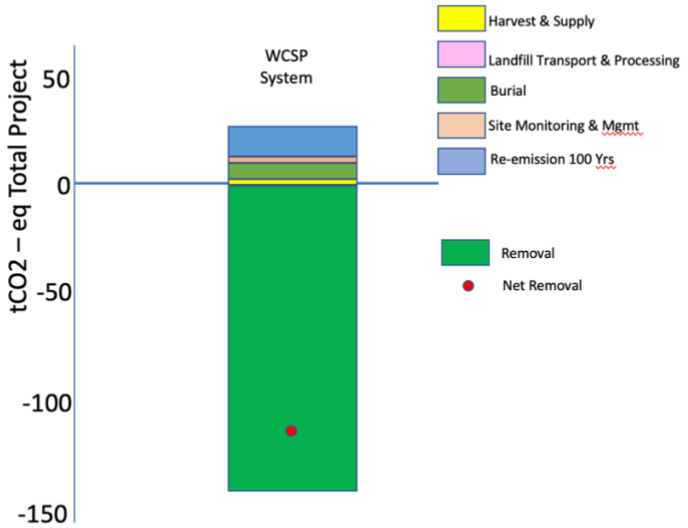

Figure 7. Stacked bar chart presenting the climate change impact of the WCSP System, with explicit contributions of the removal (CO2 stored) and the various life cycle stages and assessment of net-negativity of the removal.

It was stated that there were multiple objectives for this study:

- Calculate the Net Carbon equivalent removed through a trial TBS project for Puro CORC application
- Establish the boundaries of the TSB product system for full-scale follow-on projects
- Calculate key metrics that can be used to estimate and sell future projects
- Develop greater skill in performing and presenting WoodCache LCA analyses

The study's results confirm the completion of the first objective as the Net Carbon equivalent stored has been documented and submitted for CORC awards.

While the system boundary for this project is quite narrowly defined due to its single-site nature, the larger boundaries are understood for future projects. Cultivation will likely never be a consideration. Though some elements of harvesting, staging, and transport may be greatly expanded as facilities move to independent locations and biomass is recovered from distributed sources. Nonetheless, the Supply Chain carbon costs will not be complex to calculate as it will likely only include fuel for transportation and equipment.

Several metrics have been captured that may inform future projects. Establishing a reliable carbon budget is essential to planning a facility and its burial chamber sizes and timing. These become business metrics for investment rationalization.

Metric	**Calculated Value**	**Where it might be Used**
CO2 per tonne Dry Biomass	1.93	We would expect biomass sources from this region to have similar results. May be used in budgeting.
Carbon Cost for Storage/Burial	5%	Can be used for budgeting with similar chamber design (local soils, smaller chamber sizes)
Methane % of Carbon flux	< 2%	Based on measured carbon flux
Re-emission Factor	10%	Can be used for budgeting with similar chamber design (partially oxic, cool, dry)

This study is the first of its kind for WoodCache, PBC. The compilation of data for this submission and its findings will be invaluable going forward to continue to improve and speed the process. WoodCache, PBC has taken the position that the LCA should be an expertise resident within the company, particularly given the simplicity of the solution employed. Subsequent audit and review by third parties will further inform the practice.

5. Discussion, conclusions, and recommendations

The primary audience for this study includes Puro.earth, its auditors, and current and future WoodCache customers. Ideally, the results of this study will leave them with a recognition of how few "moving parts" there are in the WCSP solution. Simplicity leads to lesser outcome variability…leading to greater confidence. It will also be easier to defend in private and public arenas.

When assessing the totality of the LCA for this project and applying it to the region as-a-whole, the efficiency of carbon storage is going to be driven by 4 elements:

- Transportation carbon costs
- Scale
- Burial carbon costs
- Advancing the science of partially oxic, cool & dry storage

Staging waste wood as close to its source as possible will reduce transportation emissions. Scaling up the facilities and equipment will provide huge carbon savings as a percent of total removals. Finding efficient means to bury wood, particularly reducing the amount of excavation, such as through re-use of abandoned mines, will increase savings. And finally, continuing to bring test results and analyses to the table to inform the larger community on the very limited emissions of our solution and its durability will increase its demand and the trust in the solution.

Within this study are gas concentration results which depart significantly from the Puro published methodology for re-emissions. The results are consistent and reliable. They also have the potential to reduce the assumed decay rates of the biomass extending expected storage times by orders of magnitude. Testing and verification will continue with high confidence that compelling arguments can be made to reduce loss forecasts. WoodCache would like to work with Puro to plan out how this can be achieved on a timely basis.

This LCA assumes a revised mix of gas re-emissions based on the above testing which has an out-sized impact on the net carbon retention totals (>40% tCO_2e impact). This is supported with actual project data. (It was surprising to see that at default values, with only 8.8% actual carbon decay, as much as 49% of the Gross Carbon stored would be eliminated from CORC credits.)

As the first of its kind implementation, and with the project completing prior to Puro methodology release, there are clearly learnings to apply going forward. As an example, our evolving rigor in documenting biomass measurement during the project will lead to even greater rigor in the future. Biomass sample testing will be increased to include lignin and cellulose in a broader way.

In conclusion, the WCSP facility's storage solution is simple in design. Its supply chain is easily managed and modeled from an LCA perspective. Net negativity margins are extremely high and will likely grow with scale. As the science progresses, both the carbon removal metrics and the longevity will improve.

6. References

7. Appendix A

Background: Terrestrial Storage of Biomass (TSB) is a carbon removal methodology published by Puro-earth that defines the parameters under which woody materials may be stored for the marketable carbon credits (CORCs). The methodology provides the scientific and mathematical calculations under which a storage site operator may qualify for marketable credits. The baseline calculations are established for an anaerobic environment but provide consideration for modification in dry, partially oxic solutions. At the published default values, re-emission will eliminate 49% of the potential carbon credit claims weighted heavily by the multiplier effect of the Global Warming Potential (GWP) of methane. Methane is assumed to be 50% of the re-emitted carbon mix. Carbon dioxide is the other 50%. This study aims to document the realized test results for the mix of carbon gases emitted from a partially oxic wood storage chamber completed in Southern Colorado in September 2023.

Results: We document the multiple monitoring techniques and protocols that were used to measure the mix of methane and carbon dioxide resident in 1) the storage chamber using regular monitoring, 2) within the chamber/biomass using high precision probes (sub ppm resolution), 3) the flux at the surface, and 4) ambient atmosphere within a few feet of the surface. All measurements indicate a ratio of no-less-than 98% CO2 to CO2/Methane combined.

Conclusions: Our testing of internal gases and surface level flux provides strong evidence that the chamber's design mitigates methane flux to an emission level of less than 2%. We contend that the combination of extremely dry (<.71 water activity) biomass combined with cool temperatures (<15C) and other decay-reducing features, eliminates methanogenesis or immediately oxidizes it to minimal levels that can be sustained. Our testing and analyses do not resolve for the actual decay rate or mix of CO2/CO4 in a partially oxic environment, nor does it resolve the rate of oxidation achieved by the evapotranspirational cover. Both are integral to the Puro re-emission calculations. However, our readings provide strong proof that methane potential re-emission is extremely low and should be recognized in re-emission calculations.

Test Results:

Underground Gas Sensing System: This is a custom system with three distinct gas sensors measuring oxygen, carbon dioxide, and methane. There are four units currently deployed at the Walsenburg Pilot Project site. Each unit has an underground component that contains the gas sensors and an above-ground component containing the power and communication components. The underground components are buried to a depth of 9 – 11 feet and are embedded in the dirt near or above the wood. More information about the sensors is as follows:

- Oxygen
  - Model: CM-42950
  - Full range: 0 – 25% concentration
  - Resolution: 10 ppm
- Carbon dioxide

- Model: GC-0018
- Full range: 0 – 100% concentration
- Resolution: 100 ppm

- Methane
  - Model: Cubic SJH-100
  - Full range: 0 – 100% concentration
  - Resolution: 100 ppm

Data is collected from these sensors every hour, over a five-minute duration, and at a ten-second interval. The data is transmitted from the above-ground component to a cellular gateway via WLAN. Ultimately, the data is stored on an off-site database.

During the six-week period from December 18, 2023, through January 30, 2024, the median daily record of CO2 as a percent of combined CO2/CH4, was never below 98.9% and is currently averaging close to 99.9% with a +/- 100 ppm accuracy. Median methane readings are commonly 0. Figure 1 provides the daily median ratio for each of these sensors.

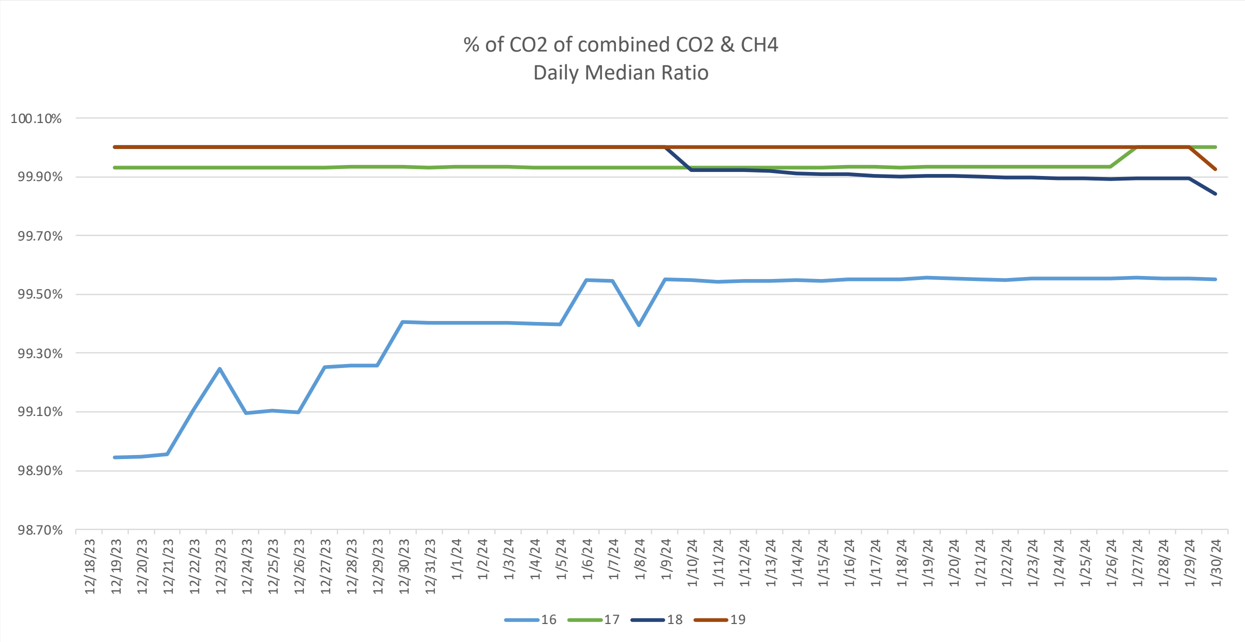

Figure 8 Graph of CO2/CH4 ratios from biomass-level with the storage chamber

Surface flux chamber readings with high precision analyzer: Each quarter we conduct precision monitoring using a handheld analyzer with <1 ppm gas resolution. We conduct three distinct monitoring processes, but they each measure carbon dioxide, methane, and water. One measures the underground conditions. The second measures through-ground gas emissions using a flux chamber. The third, above ground gas concentrations. This data is used for precision validation or contrast to on-going monitoring and is recorded in regular Inspection reports. Locations for each of these is

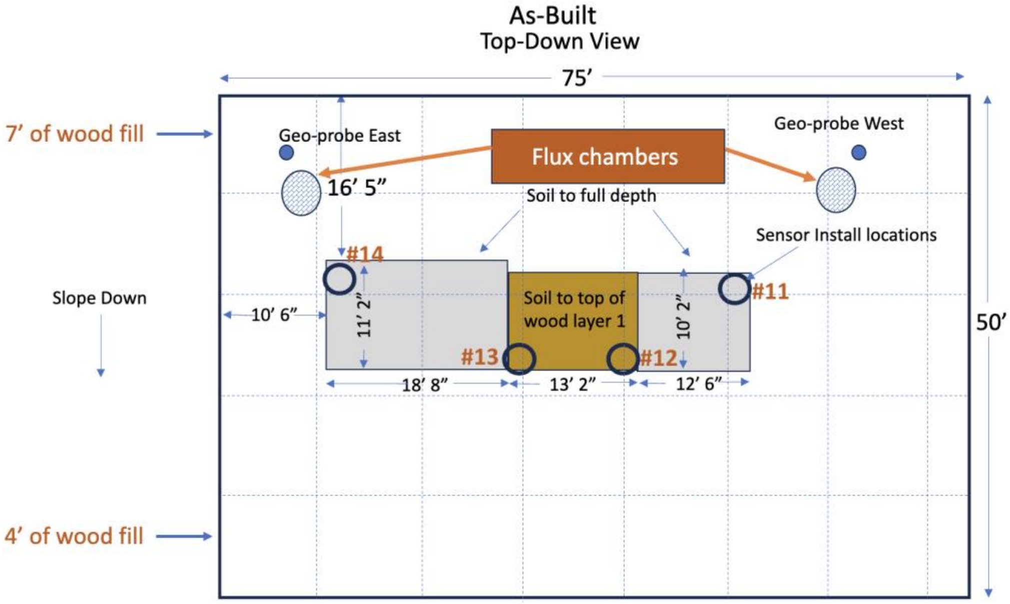

Figure 9 Top-Down location of test sensors, ports, and flux chambers on storage site surface.

Flux chamber testing was performed using a Li-Cor L-7810 analyzer with parts per billion resolution. Each of the 2 Flux chambers was sealed with two ports connected to the analyzer’s input and output ports. Tests were run for 2 hours each. Initial readings were equal to ambient as expected, just under 2 ppm CH4 and 400 ppm CO2. As the flux test was operating, CH4 concentrations reduced while CO2 levels increased indicating lower than 2 ppm CH4 and greater than 400 ppm within the flux.

Ambient mix of CO2/CH4 are typically around 99.7% CO2. As the surface flux began to permeate the chamber, the CO2/CH4 mix rose to >99.85% CO2 and were still rising indicating a higher ratio of CO2 within the flux.

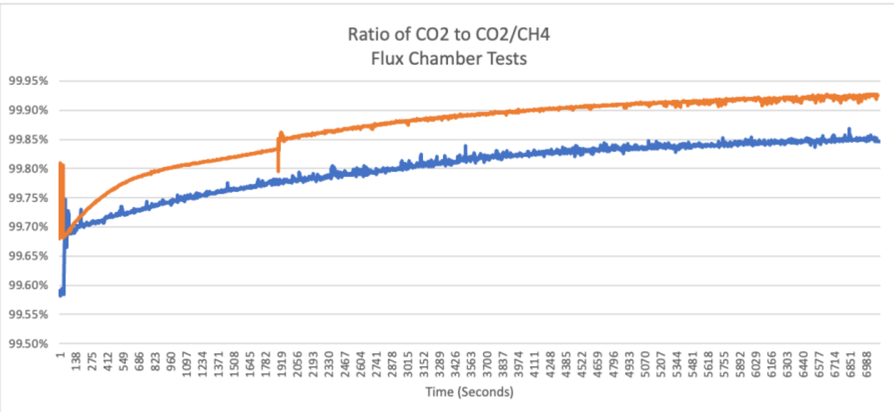

Figure 10 Flux chamber trends of CO2/CH4 ratio over time in seconds

Underground gas probe testing with high precision analyzer: Two geo-probes have been placed within the pit. One is at the top-level of the bio-mass approximately 8.5’ below the surface. The other is within the biomass at approximately 11.5'. During the quarterly inspection, both probes were tested for gas concentrations using the Licor analyzer.

The test set-up included a water trap between the exposed tube and the input to the analyzer. Due to the low pump draw of the device, the water trap had a volume of 5 gallons. Though a stable level was never reached even after several hours of operation the change in gas concentrations provided further evidence of the extremely high levels of CO2 vs CH4 residing at and within the biomass level.

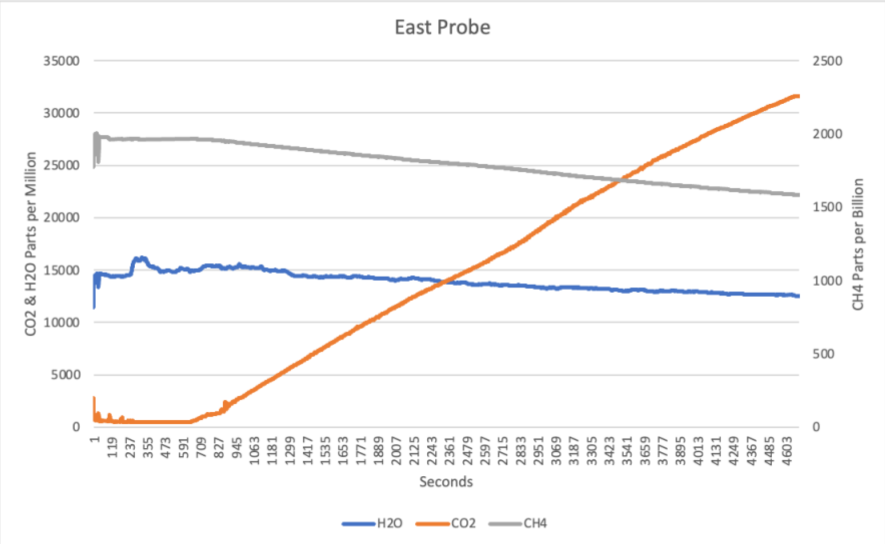

Figure 11 Concentrations of CO2/CH4 and H20 from the east probe located well within the underground biomass

During a 90-minute test, we observed a similar result to what was observed in the flux chamber. As the ambient starting point began to mix with gases drawn from 8-11' below the surface, CO2 concentrations increased while CH4 levels receded. However, in this test, because gases were being drawn out using the analyzer's pump, changes happened much more rapidly.

By the conclusion of the 90-minute test, Co2 concentrations had risen to over 31,635 ppm while CH4 levels had reduced to 1586 ppb/1.586 ppm, a ratio of >99.99%.

Ambient near-to-ground testing with high precision analyzer: In December 2023, consistent with our inspection program, a "walk-around" test was performed using an ABB high precision analyzer (<1 ppm). Protocol was to walk over the entire storage area with an input tube extended away from the body using a solid rod at a level of 2-3' above the ground. Measurements were taken to determine if there was a differential in gas concentrations above the storage chamber vs a controlled area. No differences were noted. Both areas surveyed were >99.9% CO2 to CH4 concentrations indicating no methane flux was impacting the area.

Summary & Conclusions: Though testing will continue and become refined over time, the data collected over the first 4 months since chamber closure indicates with very high confidence that carbon re-emissions are >98% CO_2 and <2% CH_4 as a percent of the combined CO_2/CH_4 mass. Testing has been performed both on an on-going basis and during periodic quarterly inspections within the biomass, within the chamber, and at/above the surface. Results are consistent and summarized in Table 1 below:

Test	CO2 %	Location	Relation to biomass
Puro Methodology Default	50%		
Daily Median Measurement Sensor 16	> 99.5%	11'4" below surface	At level with biomass
Daily Median Measurement Sensor 17	> 99.9%	8'11' below surface	Just above biomass
Daily Median Measurement Sensor 18	> 99.8%	9'5" below surface	Just above biomass
Daily Median Measurement Sensor 19	> 99.9%	12' below surface	At level with biomass
Flux Chamber 1	> 99.8%	At surface	
Flux Chamber 2	> 99.9%	At surface	
Geo-Probe 1	> 99.99%	9'6" below surface	Within the biomass
Geo-Probe 2	TBD		
Geo-Probe 1 (ABB device Dec '23)	> 99.4%	9'6" below surface	Within the biomass
Geo-Probe 2 (ABB device Dec '23)	> 99.7%	8' 0" below surface	On top of the biomass
Ambient above Storage (ABB device Dec '23)	> 99.9%	2-3' above surface	
Ambient above Storage (Feb '24)			

With continuous monitoring within the chamber and periodic high-precision inspections above and below the surface, no measurement has ever been below 98% CO_2-to-CH_4 concentration. Flux levels are above 99.8%. Therefore, a lower-limit value of 98% CO_2 will be used to calculate re-emissions. Because flux at the biomass/cap barrier has not been measured, and there is no source for methanogenesis vs oxidation impact, the re-emission formula will be populated with 98%/2% mix with no oxidation. This provides a more conservative result of 14.4 tCO_2e vs 13.1 tCO_2e. Figures 5 and 6 show these calculations respectively. Figure 7 provides the Example calculation from the TSB methodology.

	Default	WCSP									
M	n/a	76.8	tonnes								
DM	n/a	93.4%									
Corg	48%	52.7%									
Docf	8.80%	8.80%									
Fco2	50%	98%									
Fch4	50%	2%									
Ox	0%	0%									
Estored =	M *	DM*	Corg *	44/12. =	Total						
	76.8	93%	53%	3.66666667	138.61						
	M *	DM*	Corg *	44/12 *	0.5*	0.088. +	0.5*	0.088 *	Ox =	Total	
Eco2 =	76.8	93%	53%	3.66666667	98%	0.088	2%	0.088	0%	12.0	t
	M *	DM*	Corg *	16/12 *	0.5*	0.088 *	27.9 *	(1- Ox) =		Total	
Ech4 =	76.8	93%	53%	1.33333333	2%	0.088	27.9	100%		2.5	t
	Eco2. +	Ech4 =	Total								
Ere-emissions =	12	2	14.4								

Figure 12 Ere-emissions calculation using 98% CO2 mix with no oxidation

		Default	**WCSP**									
	M	n/a	76.8	tonnes								
	DM	n/a	93.4%									
	Corg	48%	52.7%									
	Docf	8.80%	8.80%									
	Fco2	50%	50%									
	Fch4	50%	50%									
	Ox	0%	98%									
	Estored =	**M ***	**DM***	**Corg ***	**44/12. =**	**Total**						
		76.8	93%	53%	3.66666667	138.61						
		M *	**DM***	**Corg ***	**44/12 ***	**0.5***	**0.088. +**	**0.5***	**0.088 ***	**Ox =**	**Total**	
	Eco2 =	76.8	93%	53%	3.66666667	50%	0.088	50%	0.088	98%	12.1	t
		M *	**DM***	**Corg ***	**16/12 ***	**0.5***	**0.088 ***	**27.9 ***	**(1- Ox) =**		**Total**	
	Ech4 =	76.8	93%	53%	1.33333333	50%	0.088	27.9	2%		1.2	t
		Eco2. +	**Ech4 =**	**Total**								
	Ere-emissions =	12	1	13.3								

Figure 13 Ere-emission calculation using 50/50 CO2 mix with 98% oxidation

NUMERICAL EXAMPLE

A CO_2 *Removal Supplier* stores **20.000 metric tonnes** (wet weight) of wood waste over the course of one (1) reporting period. The dry matter content has been determined by on-site measurements to be 61 % of the wet weight, and a laboratory analysis shows that the organic carbon content of the biomass is 48 % of the dry weight. To estimate the re-emissions from the biomass during storage, the default re-emission factor $DOC_f = 8.8\,\%$ is used, as well as the default values $F_{CO_2} = F_{CH_4} = 50\,\%$ for the fraction of re-emitted carbon lost as CO_2 and CH_4. It has furthermore been evidenced by the supplier that 25 % of the re-emitted methane is oxidized in the soil cover above the storage chamber (i.e.$O_x = 25\,\%$)

Now:

$$M = 20\,000\,\text{t} \qquad DM = 61\,\% \qquad C_{org} = 48\,\% \qquad DOC_f = 8.8\,\%$$
$$F_{CO_2} = 50\,\% \qquad F_{CH_4} = 50\,\% \qquad O_x = 25\,\%$$

And therefore:

$$E_{\text{stored}} = 20\,000\,\text{t} \times 0.61 \times 0.48 \times \frac{44}{12} = \underline{21\,472\,\text{t}}$$
$$E_{CO_2} = 20\,000\,\text{t} \times 0.61 \times 0.48 \times \frac{44}{12} \times (0.5 \times 0.088 + 0.5 \times 0.088 \times 0.25) \approx \underline{1181\,\text{t}}$$
$$E_{CH_4} = 20\,000\,\text{t} \times 0.61 \times 0.48 \times \frac{16}{12} \times 0.5 \times 0.088 \times 27.9 \times (1 - 0.25) \approx \underline{7189\,\text{t}}$$
$$E_{\text{re-emissions}} = E_{CO_2} + E_{CH_4} \approx \underline{8370\,\text{t}}$$

Figure 14 Puro Terrestrial Storage of Biomass Example Calculation for E re-emissions

Baseline and Additionality Assessment

The baseline and additionality assessment is a requirement for eligibility under the Puro Standard. The assessment is made by the CO2 Removal Supplier and verified by the independent 3rd party auditor. The assessment made in this document will be publicly available in the Puro Registry.

The Puro Standard only certifies durable carbon removals from the atmosphere that are net-negative and does not certify emissions reductions or avoidance. The CORCs (Carbon dioxide removal certificates), issued therefore represent a net carbon removal (1 tCO2eq. net) from the atmosphere to a durable storage of minimum 100 years, from which are subtracted any supply-chain emissions from the project, any re-emissions over the guaranteed storage time, and any baseline removals taking place in a baseline scenarios.

The CO2 Removal Supplier must in this assessment:

- **Define** and quantify all reasonable **baseline alternatives** to the proposed project activity to remove carbon with carbon financing. A baseline is a scenario that reasonably represents the natural and anthropogenic carbon removals to a permanent storage (storage durability over 100 years) in the absence of the carbon removal activity proposed by the CO2 Removal Supplier. Although anthropogenic emissions may take place in the baseline scenarios, these emissions do not constitute a reference point for the quantification of CORCs (only the baseline removals do).
- Demonstrate **carbon additionality to the baseline**, meaning that the project must convincingly demonstrate that it is resulting to higher volumes of carbon removals than the likely baseline alternatives (question A1.).
- Demonstrate **regulatory additionality,** meaning that the project is not required by existing laws, regulations, or other binding obligations (question A2.).
- Demonstrate **financial additionality**, meaning that the CO2 removals achieved are a result of carbon finance and that the project activity would not be economically viable without the carbon finance. The project activity can have substantial other non-carbon income sources, if the carbon finance through CORCs is significant for the economic viability of the project. To demonstrate financial additionality, CO2 removal Supplier must provide the responses in this form and must be able to provide full project financials for verification.

Reference documents: Puro Standard general Rules v3.0, rule 2.1.3 and Additionality Assessment requirements

Activity name	Activity description	Removals to storage (100+ yr) due to project activity (human activity)	Natural removals to storage (100+ yr), not man-made
Baseline: *Wood Transfer & Disposal*	*Due to recent, significant forest fires in the area, landowners are highly motivated to perform fire mitigation. Typical process is to cut-away excess or dead wood, pile it, then transport it to a local Transfer Station which will chip the material for sale or re-transport to a landfill.*	None	None
Project activity: *Terrestrial Bio-mass Burial*	As in the baseline, wood is cut/collected and staged on-site. However, the wood is buried in permanent (100+ yr) storage chamber built and capped on-site.	140+ tonnes	None
Alternative scenarios			
Do Nothing	*The most likely alternative is to do nothing about the dead or dying trees on one's property. This is common despite posing an increasing fire threat in a drought-ridden, semi-arid region. Either the wood will fully decay or burn. Neither scenario will store any carbon for 100+ yrs.*	None	None
Store and Burn	*An alternate scenario exists whereby the landowner obtains a permit from the County administration to burn the wood. This is common in the area but forbidden by the Landowners' Association by-laws. Therefore, the baseline is the only option considered.*	None	None
Biomass Processing	*There have been plans presented in the local County to gather Landowners' biomass for use in bio-char operations or as bio-fuel. These operations have not been put into production yet and may not for several years while capabilities are developed.*	TBD	None

A1. Does the project lead to higher volumes of carbon removal than the baseline?	Yes / No
The baseline does not remove carbon in any material way.	YES

A2. Is the project required by existing laws, regulations, or other binding obligations ?	Yes / No

There are no laws that require fire mitigation activities. Nor are there laws that require a certain type of disposal. Fire mitigation is encouraged. There are limits on the timing of wood burning which requires a permit.	NO

A3. Is the project first-of-its-kind?	**Yes / No**
This project is the first-of-its-kind in the region.	YES

A4. Is the project dependent on carbon finance?	**Yes / No**
Internal Wood Cache, PBC working capital has been used in anticipation of external carbon financing. It should be noted that full financial coverage (break-even from credit sales, or profitability) may not be realized as this is an initial pilot program from which learnings are worth the investment even if profits do not materialize.	YES

A5. Does the project need a large investment to achieve carbon removal ?	**Yes / No**
Wood Cache, PBC is seeking market pricing for its CORCs.	NO

A6. If investment is needed, is/was carbon finance considered when the investment decision is/was made?	**Yes / No**
The project was initiated and funded solely with the intention of obtaining fair market value for CORCs awarded.	YES

Some projects may demonstrate additionality through simple cost analysis: this is applicable for projects where ex-ante investment analysis is not applicable, because a large investment is not needed. Example of such project could be charcoal producers starting to produce biochar for soil applications using existing equipment with minor adaptations.

Financial Additionality – large investment is not needed (Answer to A5 is "no")	Project response
Please describe adaptations needed and the related cost items and include evidence in attachment.	Please see the document titled Financial Assurance Model and the Wood Cache PBC Financial Assurance Application document for details. Both of these documents were provided formally to the State of Colorado and were accepted. All funds utilized in the to-date performance of the project were provided by WCP. It is understood that this project is not profitable and will not be. However, the intent of the project was to prove feasibility and with scale, we are able to model significant improvements.
Please summarize the simple cost analysis here and provide additional calculation spreadsheet in attachment. All formulas used in the spreadsheet shall be readable to the verifier and all relevant cells shall be viewable and unprotected. Mark confidential when needed.	Pit Open $13,200 Pit Closure $37,700 Post-Closure $95,800 Total $146,700

If large investment is needed, , CO2 Removal Suppliers can be guided by the CDM Methodological Tool 27 of the UNFCCC Clean Development Mechanism "Investment Analysis" to demonstrate financial additionality.

Financial Additionality – large investment is needed (Answer to A5 is "yes")	Project response
Please show your calculations to determine the benchmark rate for either equity IRR or WACC, whichever you are using. Please include documentation of how the rate is suitable for the technology and region.	NA
Please state how CORC revenues change the expected IRR or NPV of the project.	NA
Please conduct a sensitivity analysis in relation to the investment analysis and summarize the results here.	NA
Please provide full calculation spreadsheet file as an attachment. All formulas used in the spreadsheet shall be readable to the verifier and all relevant cells shall be viewable and unprotected. Mark	NA

confidential when needed.	

I hereby declare that all information provided is truthful and precise to the best of my knowledge.

X Serge Bushman

Date, Place:
Representative name, title, organization

Audit Trail

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