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Life cycle focused assessment of carbon dioxide removal (CDR) potential of the RocketChar 301 pyrolizer use at Yellow Barn Farm

Report prepared by Biosystems Engineering, PLLC

Report prepared for High Plains Biochar

Lead Author and LCA Practitioner:
Gudmundur Johannesson

Lead GHG Analyst:
Stephen Boles

Editor:
Link Shumaker

Biosystems Engineering, PLLC

101 Westview Dr

Carrboro, NC 27510-1501

High Plains Biochar LLC

108 Howe Rd Laramie, WY 82070

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Contents

List of Figures

List of Tables

1 Process Description

1.1 Overview

This report is based on a proof-of-concept for the potential use of an existing pyrolizer, the RocketChar 301[1] for production of biochar. The pyrolizer will be stationed at the Yellow Barn Farm[2] in Boulder County, Colorado, an operation dedicated to the practices of regenerative farming. The feedstock for this project would be sourced from a source adjacent to the Yellow Barn Farm, and the generated biochar would be applied to on-site soils in alignment with the farm's regenerative vision of soil enrichment.

1.1 Baseline system

In absence of the Yellow Barn Farm biochar project, a forest fire clean-up project carried out by Boulder County results in variable amounts of slash biomass. This biomass would be hauled away from the harvest site to a composting facility, located about 20 miles away in a neighboring county, where the biomass would be processed.

1.2 Project System

The biomass for this project will be sourced from Boulder County, Colorado, and consists of approximately 100 cubic yards of pine wood chips from local forest fire clean-up projects. The stock of available biomass, approximately 500 cubic yards, is already chipped and located ½ mile from Yellow Barn Farm (see appendix A - 3 aerial photo, location label '2'). It should be noted that the three carbon dioxide removal (CDR) protocols assessed in this report do not allow use of avoided emissions in calculation of the project's CDR potential. Therefore, the reduced transportation of biomass feedstock in the project (where the 20-mile transport distance to the composting facility is eliminated) is not considered as an avoidance of GHG emissions.

The chips would be hauled the 0.5 mile distance to Yellow Barn Farm with a dump trailer using a front loader-equipped tractor to load the chips and another for pulling the trailer. Approximately 20 gallons of fuel would be used hauling 10 loads of 10 cubic yard volume each of chips the 0.5 mile to the greenhouse at Yellow Barn Farm where the RocketChar 301 would be located.

The wood chips will be stored in piles at Yellow Barn Farm where conditions are dry, and a tarp can be used to protect chips from snow/ice buildup in the winter months. Likely, the chips would be brought in during the summer (June/July/August) so they can be used starting in September or October. These wood chips will have some oversize pieces mixed in which will require running the material through a hammermill. This will be done using a chipper shredder with a medium screen. A tractor will be used to operate the chipper shredder (hammermill) and another tractor with a bucket will be used to load the chips into the chipper shredder.

[1] https://www.hpbiochar.com/rocketchar
[2] https://www.yellowbarn.farm/

Equipment used to process biomass:

- Small Tractor with bucket to load chips - 30 HP tractor used to load chips
- Small tractor to operate chipper shredder - 30 HP tractor used to operate chipper
- Bearcat Chipper Shredder -
- Medium Screen for chipper shredder
- Blower for chipper shredder

The equipment to be used for the biochar project belongs to the Yellow Barn Farm and is used for all regular farm operations. It is assumed that the embodied GHG emission from the manufacturing of the equipment is negligible, given the low contribution of the machinery usage for the biochar project (maximum ten hours per year) relative to the usage of the machinery for all other farm operations. Estimated fuel use for the biomass processing is 30 gallons of diesel fuel to run the tractor and loader.

The pyrolysis technology for the project is a RocketChar 301 which is fabricated in Charlotte NC (Fabrication Associates) and assembled in Laramie WY (High Plains Biochar). The RocketChar 301 is a fast pyrolysis system which takes about 10 minutes to produce biochar at approximately 750°C. The unit is comprised of approximately 1000 pounds of steel. Annual electricity consumption for the machine is 414 kWh at 115V AC (assumed run time of 2,400 hours per year). The RocketChar 301 has undergone emission testing, resulting in lower than quantifiable amounts of methane emissions (see appendix A - 4 for summary table of emission tests).

The generated biochar does not require further processing. It is steam quenched as it comes through the reactor tube and then falls into a steel 55-gallon drum which is filled every 2 days of operation. Quenching is done with a small pump which uses approximately 4 gallons of water per day.

Most of the biochar will be used in the main farm bed which is adjacent to the Yellow Barn Farm greenhouse and the rest will be used in the greenhouse grow media. The amount of biochar produced is approximately 25 cubic yards, equivalent to 6.1 metric tons.

As a co-product approximately 100k BTU/hr of heat will be captured with a liquid heat exchanger and plumbed into a 1,500-gallon underground storage tank where the heat can be stored and then used to heat the greenhouse and adjacent building via a hydronic system where the piping is run in the soil and ground used as a heat sink. The RochetChar 301 machine will be located in the greenhouse so any heat that radiates will also be captured.

A summary of all data parameters and values used in the calculation of the carbon dioxide removal potential of the project is presented in Table 1. A process flow diagram of the project is presented in Figure 1.

***Table 1**. Data parameters and values used in the calculation of project carbon dioxide removal potential. Values presented are for one year of operation.*

Parameter	Description	Value	Unit	Data source/info
Feedstock	Chipped pine from fire cleanup project	22.7	Metric ton (dry weight)	100 cubic yards was reported by High Plains Biochar. Volume was converted to dry weight using a 500 lbs/cubic yard factor obtained from US EPA[3] and the lab-derived moisture content.
Feedstock	Moisture content	6.28	%	Laboratory analysis.
Fuel for feedstock transport	Gasoline consumption from chip pile to RocketChar 301 using pickup truck	76	Liters	Estimate provided by High Plains Biochar
Fuel for feedstock processing	Diesel consumption for bucket loader and tractor-mounted chipper/hammermill	114	Liters	Estimate provided by High Plains Biochar
Composition of Rocket Char 301	Assumed to be steel	0.45	Metric ton	Estimate of 1,000 lbs weight of RocketChar 301 unit provided by High Plains Biochar
Transport distance of Rocket Char 301	Transport distance from the manufacturing location to the Yellow Barn Farm	2,850	Km	RocketChar 301 was manufactured in Charlotte NC and assembled in Laramie WY prior to its transport to Yellow Barn Farm
Operating temperature	Predicted operating temperature of pyrolysis system	750	Celsius	Estimate provided by High Plains Biochar
Electricity consumption	Grid-supplied electricity consumption of the RocketChar 301	414	kWh	Estimate provided by High Plains Biochar based on the following: - usage is 1.5 amps of electricity at 115V AC. - Machine will be run 2,400 hours per year
Biochar	Amount of biochar produced	6.1	Metric ton (dry weight)	Estimate of 25 cubic yards was reported by High Plains Biochar. Volume was converted to dry weight using a factor obtained from US EPA[3] and the lab-derived moisture content.
Biochar	Moisture content	11.54	%	Laboratory analysis.
Biochar	Carbon content	85.84	%	Laboratory analysis.
Biochar	Hydrogen:organic carbon ratio	0.09	Molar weight	Laboratory analysis

[3] https://www.epa.gov/sites/default/files/2016-03/documents/conversions.pdf

Biochar	Energy content	11,650	BTU/lbs	Laboratory analysis
Soil Temperature	Average soil temperature at Yellow Barn Farm of lands where biochar is applied	15	Celsius	Global average soil temperature applied.
Co-product (heat)	Amount of heat generated, captured, and used from the RocketChar 301 system	240	MMBtu	Estimate of 100,000 BTU/hour was reported by High Plains Biochar. Converted to annual total of MMBtu using assumed operating time of 2,400 hours.
Energy-based allocation rate for biochar	Amount of emissions allocated to biochar production using an energy-based allocation approach	0.40	Fraction	Heat energy = 240 MMBtu / year Biochar production = 13,450 lbs (6.1 metric ton) Biochar energy content = 11,650 BTU/lbs Biochar energy = 13,450 lbs x 11,650 BTU/lb = 157 MMBtu/year

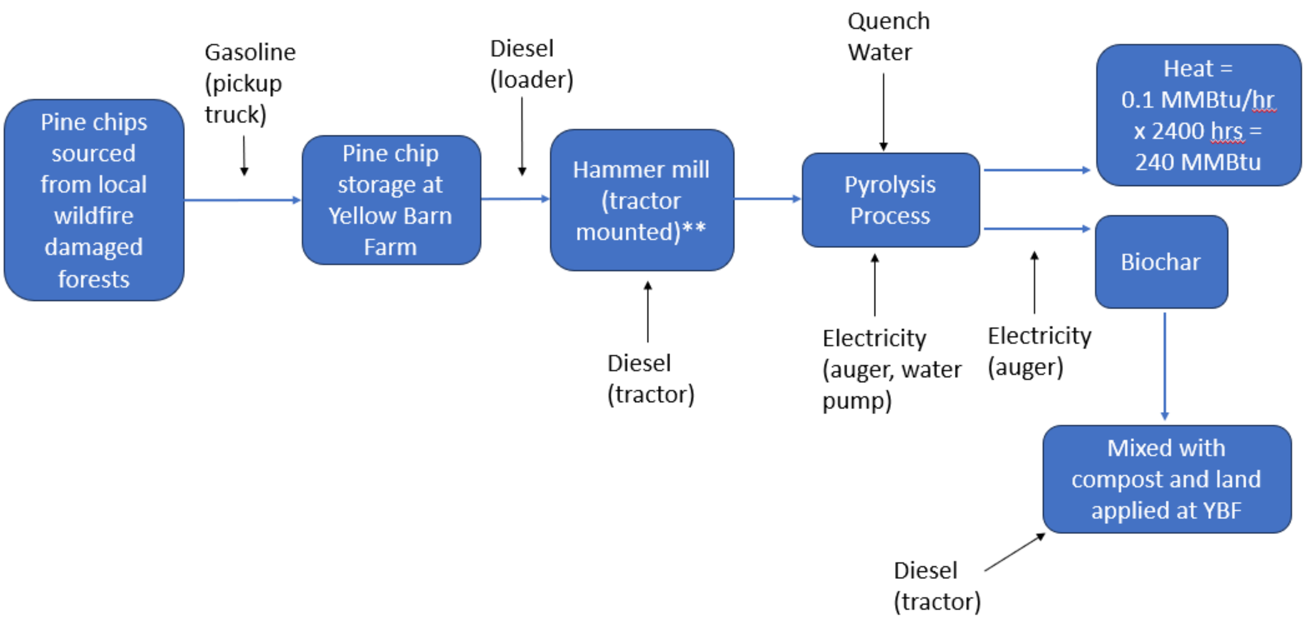

Figure 1. Process flow chart of the RocketChar 301 pyrolysis system at Yellow Barn Farm.

2 Summary Calculation Results

Table 2 presents the gross carbon dioxide removal for the Yellow Barn Farm RocketChar 301 project before all sources of greenhouse gases emitted from the project operations have been deducted. Note that the gross carbon dioxide removal for the project varies between the three biochar certification pathways that have been selected for analysis (Puro.earth[4], EBC C-Sink[5], Verra[6]).

***Table 2**. Gross carbon dioxide removal for the Yellow Barn Farm project.*

	Puro.earth	EBC C-Sink	Verra
A. Biochar Production (metric tons – dry)	6.1	6.1	6.1
B. Carbon Content (wt% - dry)	85.84	85.84	85.84
C. Permanence factor	0.99 Dynamic value (impacted by H/C_{org} and end-use soil temp.)	0.86 Static value	0.89 Dynamic value (impacted by reactor operating temp.)
D. Convert C to CO_2e	44/12	44/12	44/12
A * B/100 * C * D = Gross Project Carbon Dioxide Removal (metric ton CO_2e)	**19.10**	**16.50**	**17.09**

Table 3 presents the various sources of greenhouse gases emitted from the Yellow Barn Farm biochar project operations. These sources of greenhouse gas emissions are deducted from the gross carbon dioxide removals (Table 2) to arrive at the net carbon dioxide removals that are eligible for certification (Table 4). Note that the sources of greenhouse gas emissions for the project vary between the three biochar certification pathways that have been selected for analysis. The Puro.earth methodology has significantly lower GHG emissions for some GHG sources as this program allows the emissions to be allocated (on an energy basis) between multiple co-products of the system. Since the biochar to be generated at Yellow Barn Farm will represent approximately 40% of the project's total potential energy (with the remaining being captured heat), 40% of the greenhouse gas emissions are allocated to the biochar production with the Puro.earth methodology.

[4] https://carbon.puro.earth/biochar
[5] https://www.european-biochar.org/en/c-sink
[6] https://verra.org/methodologies/methodology-for-biochar-utilization-in-soil-and-non-soil-applications/

***Table 3**. Sources of greenhouse gas emissions for the Yellow Barn Farm project (values shown are metric tons of carbon-dioxide equivalent).*

	Puro.earth	EBC C-Sink	Verra
A. Chipping of Feedstock	0.13	0.31	0.31
B. Transportation of feedstock to farm	0.08	0.02	0
C. Manufacturing of pyrolysis equipment	0.07	0	0
D. Biochar facility electricity consumption	0.04	0.11	0.11
E. Application of biochar to agricultural fields	0.06	0.06	0
A + B + C + D + E = Total Project GHG Emissions	**0.38**	**0.50**	**0.42**

***Table 4**. Net carbon dioxide removal for the Yellow Barn Farm project (values shown are metric tons of carbon-dioxide equivalent).*

	Puro.earth	EBC C-Sink	Verra
A. Gross Project Carbon Sink	19.10	16.50	17.09
B. Project GHG Emissions	0.38	0.50	0.42
C. Margin of Security	0	0.05	0
A – B – C = Net Project Carbon Sink	**18.72**	**15.95**	**16.68**
CO_2e content per metric ton of biochar	**3.07**	**2.62**	**2.73**
Estimated revenues from sale of certified carbon dioxide removals[7] (assuming sale price of $100 per metric ton CO_2e)	**$1,872**	**$1,595**	**$1,668**

[7] Estimated revenue is based on sale value of certified carbon dioxide removals using assumed tonnage price – actual revenues must consider costs associated with certification of carbon dioxide removals such as project listing fees, registry fees, third-party audit fees, and brokerage fees.

3 Conclusions

This report is a study of forest fire clean-up biomass used as feedstock for a gasifier, generating biochar, that subsequently was used for land application. Prior to the gasifier system installation, the biomass was used as an input to compost production. This project enables the Yellow Barn Farm to utilize biomass waste feedstock resulting from a forest fire clean-up efforts with the added environmental benefits of producing biochar that is potentially eligible for Carbon Dioxide Removal (CDR) credits. These CDRs are considered additional from the baseline operation of the Yellow Barn Farm, as the biochar production and application to soil creates a permanent carbon sink that previously did not exist, neither at the farm nor through the previous use of the feedstock. Data collection and project calculation estimates are based on a year period, that although conceptual in presentation, represent operations at the Yellow Barn Farm, and factual operational parameters of the RocketChar 301 machine. Data collection and CDR calculation estimates were carried out by Biosystems Engineering PLLC personnel, with support of Rowdy Yeatts on behalf of the project proponent, High Plains Biochar LLC.

Calculations presented in Section 2 represent the potential of the High Plains Biochar gasifier system to create high quality biochar carbon sink through each of the biochar CDR protocols represented; puro.earth[8], EBC C-Sink[9], and Verra[10]. Biochar production, along with the soil application activity, has the potential to create high quality CDRs in the form of marketable credits. It has been estimated that this project conceptually can generate 2.62 to 3.07 MT CO_2e of CDR certificates per tonne DMB of biochar, through the production process, and subsequent land application to soil at Yellow Barn Farm.

Through this report, full compliance with requirements with the three CDR protocols has been adhered to, following the full life cycle of the CDR units (tonne CO_2e/tonne biochar) from feedstock to final use.

No significant issues have been identified that limit the findings of the report, and the findings are based on science and material basis and developed through a rigorous process of best industry practices.

[8] https://puro.earth/methodologies/
[9] https://www.european-biochar.org/en/c-sink
[10] https://verra.org/methodologies/vm0044-methodology-for-biochar-utilization-in-soil-and-non-soil-applications/

A - 1. Project practitioner credentials

Gudmundur Johannesson, MSc, PhD is an environmental expert with 6+ year experience in ISO 14040/44 compliant Life Cycle Assessment (LCA) projects that, among others, include conventional and renewable energy, biofuels, and industrial systems. Clients include governments and private organizations in Canada, USA, and Europe. Further, Gudmundur has 20+ year experience in applied research that includes greenhouse gas emission measurements (GHG) using agrometeorological approach and emission modeling according to IPCC protocols. Other research and development work includes soil science, agronomy, organic waste, and agriculture water quality, both in the field and a laboratory setting using variety of instrumentation, protocols, and data analysis. Gudmundur's extensive work experiences include private consulting, academia, and government, while his PhD in Atmospheric Science and MSc in Soil Science are obtained from the University of Guelph, Ontario Canada.

Stephen (Steve) Boles, MSc, EP (sustainability) has been active in the climate change community as a scientist and consultant for over 20 years. He received his Master of Science degree from the University of Alaska Fairbanks in 1998 and spent the next eight years working as a scientist at one of the world's leading climate change research centers at the University of New Hampshire. As a consultant, Stephen has led GHG quantification, verification, or reduction projects for clients in a range of industry sectors including oil and gas, automotive manufacturing, insurance, government (federal, provincial, municipal), food processing, energy utilities, retail finance, and real estate. Stephen is active in the development of GHG policies in North America. He served as an expert stakeholder on the working groups commissioned by the Climate Action Reserve to develop waste- related and agriculture-related carbon offset protocols for Ontario's former cap and trade program. He also served as an expert stakeholder on the working group to develop a forestry carbon offset protocol in the Province of Alberta.

Link Shumaker, MSc, PE is a practicing engineer with 15 years of experience in industrial biofuels and bioenergy process scale-up and operations. He owns Biosystems Engineering, PLLC which is active in regenerative technology deployment for carbon-sensible 21st century systems at the nexus of food, energy, and water. Link is an accredited lead auditor under International Sustainability and Carbon Certification (ISCC), lead verifier under California's Low Carbon Fuel Standard (LCFS), certified Manager of Environmental Safety and Health (MESH) and certified Lean Six Sigma Black Belt. Link holds a Master of Science in Biosystems and Agricultural Engineering and a Bachelor of Science in Chemical Engineering from the University of Kentucky. He is licensed to practice engineering in North Carolina, Tennessee and Missouri. His passions include creating order from chaos and exploring the world with youngsters.

A - 2. Biochar characteristics

Lab results for two samples of biochar, generated by the RocketChar 301 pyrolizer. Analysis were carried out at KMT labs, Newton IA in March, 2023.

Parameter	Sample 1	Sample 2	Unit	Method
Results as received				
Moisture	6.28	11.54	% wt	ASTM D7582
Ash	0.58	6.38	% wt	ASTM D7582
Volatile Matter	77.52	8.73	% wt	ASTM D7582
Fixed Carbon	15.62	73.35	% wt	ASTM D7582
Sulfur	<0.01	0.02	% wt	ASTM D4239
Carbon	47.90	75.93	% wt	ASTM D5291
Hydrogen	6.46	1.87	% wt	ASTM D5291
Nitrogen	<0.20	<0.20	% wt	ASTM D5291
Oxygen by Difference	44.94	15.62	% wt	ASTM D5291
Low Heat Value	7409	11470	BTU/lb	ASTM E711
High Heat Value	8008	11650	BTU/lb	ASTM E711
Results Dry Weight Corrected				
Ash	0.62	7.21	% wt	ASTM D7582
Volatile Matter	82.72	9.87	% wt	ASTM D7582
Fixed Carbon	16.67	82.92	% wt	ASTM D7582
Sulfur	0.02	0.02	% wt	ASTM D4239
Carbon	51.11	85.84	% wt	ASTM D5291
Hydrogen	6.14	0.65	% wt	ASTM D5291
Nitrogen	<0.20	<0.20	% wt	ASTM D5291
Oxygen by Difference	42.00	6.07	% wt	ASTM D5291
Low Heat Value	7906	12970	BTU/lb	ASTM E711

***Table 5**. Laboratory report on properties of biochar generated by RocketChar 301.*

A - 3. Production Site Information

Production Site: Yellow Barn Farm, 9417 N Foothills Hwy, Longmont, CO 80503

Coordinates (GPS): 40.145570, -105.282310

Google Earth image, see below (LINK TO GOOGLE MAP)

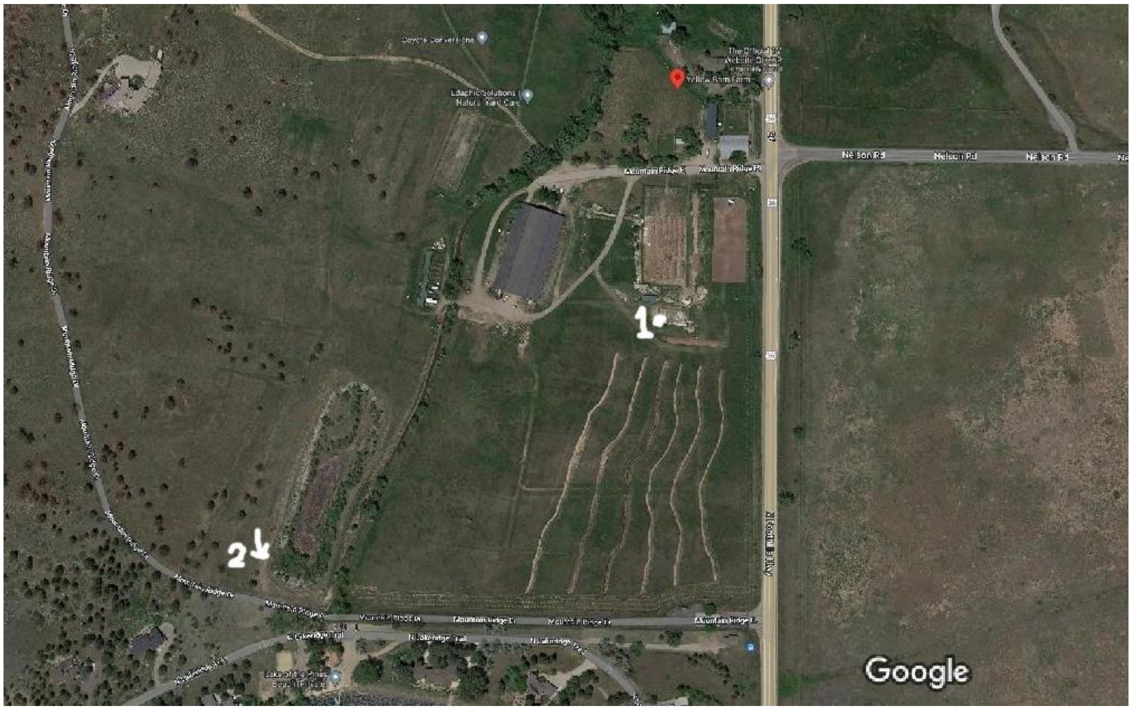

***Figure 2**. Google Maps screenshot of project site at Yellow Barn Farm. Locations labeled '1' and '2'respectively indicate where biochar generated in this project will be incorporated into soil growing marketable plants using silvopasture farming methods, and where biomass feedstock used for the project is located.*

A - 4. Gasifier Emission Test documentation

Selected results of emission testing report on the RocketChar 301 pyrolizer. The emission test was carried out by Mountain Air Engineering, Cottage Grove OR, on February 16 and 17 2023.

		Test 1			Test 2			
metric	units	detection limit			detection limit			metric description
$EF_{NO2,fuel}$	g/kg_{fuel}	ND	<	0.134	ND	<	0.219	NO_2 emission factor: grams per kg raw fuel loaded
$EF_{SO2,fuel}$	g/kg_{fuel}	ND	<	0.187	ND	<	0.305	SO_2 emission factor: grams per kg raw fuel loaded
$EF_{HC,fuel}$	g/kg_{fuel}	ND	<	14.6	ND	<	23.8	HC emission factor: grams per kg raw fuel loaded
$EF_{NMHC,fuel}$	g/kg_{fuel}	ND	<	0.654	ND	<	1.070	NMHC emission factor: grams per kg raw fuel loaded
$EF_{CH4,fuel}$	g/kg_{fuel}	ND	<	7.3	ND	<	11.9	CH_4 emission factor: grams per kg raw fuel loaded
$EF_{NO2,dry fuel}$	$g/kg_{dry fuel}$	ND	<	0.167	ND	<	0.274	NO_2 emission factor: grams per kg dry fuel
$EF_{SO2,dry fuel}$	$g/kg_{dry fuel}$	ND	<	0.233	ND	<	0.381	SO_2 emission factor: grams per kg dry fuel
$EF_{HC,dry fuel}$	$g/kg_{dry fuel}$	ND	<	18.2	ND	<	29.8	HC emission factor: grams per kg dry fuel
$EF_{NMHC,dry fuel}$	$g/kg_{dry fuel}$	ND	<	0.815	ND	<	1.340	NMHC emission factor: grams per kg dry fuel
$EF_{CH4,dry fuel}$	$g/kg_{dry fuel}$	ND	<	9.1	ND	<	14.9	CH_4 emission factor: grams per kg dry fuel
$EF_{NO2,char}$	g/kg_{char}	ND	<	0.83	ND	<	1.63	NO_2 emission factor: grams per kg char produced
$EF_{SO2,char}$	g/kg_{char}	ND	<	1.16	ND	<	2.26	SO_2 emission factor: grams per kg char produced
$EF_{HC,char}$	g/kg_{char}	ND	<	90	ND	<	177	HC emission factor: grams per kg char produced
$EF_{NMHC,char}$	g/kg_{char}	ND	<	4.1	ND	<	7.9	NMHC emission factor: grams per kg char produced
$EF_{CH4,char}$	g/kg_{char}	ND	<	45	ND	<	89	CH_4 emission factor: grams per kg char produced
$EF_{NO2,energy}$	g/MJ	ND	<	0.014	ND	<	0.021	NO_2 emission factor: grams per MJ
$EF_{SO2,energy}$	g/MJ	ND	<	0.020	ND	<	0.030	SO_2 emission factor: grams per MJ
$EF_{HC,energy}$	g/MJ	ND	<	1.540	ND	<	2.320	HC emission factor: grams per MJ
$EF_{NMHC,energy}$	g/MJ	ND	<	0.069	ND	<	0.104	NMHC emission factor: grams per MJ
$EF_{CH4,energy}$	g/MJ	ND	<	0.770	ND	<	1.160	CH_4 emission factor: grams per MJ
ER_{NO2}	g/hr	ND	<	0.97	ND	<	1.70	NO_2 emission rate: g per hour
ER_{SO2}	g/hr	ND	<	1.36	ND	<	2.37	SO_2 emission rate: g per hour
ER_{HC}	g/hr	ND	<	106	ND	<	185	HC emission rate: g per hour
ER_{NMHC}	g/hr	ND	<	0.82	ND	<	1.34	NMHC emission rate: g per hour
ER_{CH4}	g/hr	ND	<	53	ND	<	93	CH_4 emission rate: g per hour

Table 6. *Emission estimate for the RocketChar 301, importantly indicating non-detectable levels of methane (CH_4).*

A - 5. Photos of biochar system at the Yellow Barn Farm site

Below are photos depicting the biochar system in relation to the aerial photo in Appendix A - 3, showing a water cistern for storage and transfer of thermal energy generated by the pyrolysis operation (see section 1.2), the greenhouses where the generated biochar will be applied to soil (and thermal energy used), and example of the feedstock used for the project. The RocketChar 301 will be housed in greenhouses to capture any heat radiating from the process.