Biochar-Urban Forestry Strategy

FOR THE CITY OF BOULDER, COLORADO

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Table of Contents

Introduction

This strategy document aims to estimate the potential for utilizing urban forest biomass as a feedstock for biochar production and application within and around the City of Boulder, Colorado. This analysis is one of four municipal case studies completed in coordination with Nature-Based Climate Solutions (NCS) and supported by the Carbon Neutral Cities Alliance (CNCA). Peer assessments from the cities of Helsinki, Minneapolis, and Stockholm were developed in conjunction with this project.

The following analysis aims to create a framework for assessing a full life cycle management strategy from tree biomass to biochar. Based on interviews and local data, the report considers the total feedstock availability of wood waste generated by tree care and removal activities. Subsequently, the scale of biochar production and use cases for local application are examined, as well as associated potential for environmental impact. Finally, a summary of recommendations toward development of an urban forest-derived biochar system are provided.

Why Biochar?

Biochar is a carbon-rich solid obtained from pyrolysis of organic matter in a low-oxygen environment. Classified as a negative emissions technology by the IPCC, biochar's long-term carbon sequestration potential has yielded growing awareness as a natural climate solution, with production further incentivized by a burgeoning carbon offsets market. The application of biochar in soil poses several benefits to vegetative growth[1] and plant health, including increased water holding capacity[2] and disease resistance.[3] Additionally, biochar has shown proven efficacy in contaminant remediation and water management.

Critically, biochar presents an opportunity to derive a high-value and environmentally beneficial product from low-value or traditionally wasted material. Biochar can be produced from a variety of feedstocks, including green/yard waste, food scraps, sewage sludge, and wood. Feedstock, along with pyrolysis conditions, plays an important role in determining the quality, pore structure, nutrient content, and characteristics of resulting biochar.

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[1] Scharenbroch, B.C. et al. 2013. Journal of Environmental Quality 42 1372-1385 "Biochar and Biosolids Increase Tree Growth and Improve Soil Quality for Urban Landscapes"

[2] Omondi, M et al. 2016. Geoderma 274 28-34 "Quantification of biochar effects on soil hydrological properties using meta-analysis of literature data"

[3] Zwart, D.C. and Kim, S-H. 2012. Hort Science 47 1736-40 "Biochar Amendment Increases Resistance to Stem Lesions Caused by Phytophthora spp. in Tree Seedlings"

Supply: Total Feedstock Availability

The goal of this analysis is to understand the scale of potential production and application of biochar within the City of Boulder's urban forest system; as a result, urban forest biomass was chosen as our feedstock of focus. Urban forest biomass – or fresh cut wood residues resulting from tree removal and maintenance work – presents an exciting opportunity for biochar production, given both proximity to centralized infrastructure (relative to traditional harvested wood), and the current cost burden tree care companies face to dispose of their waste stream. A demand for this material by biochar producers could help **1.) cut disposal costs**, **2.) reduce waste**, and 3.) **sequester tree carbon** in a semi-permanent product, rather than release greenhouse gasses into the atmosphere.

In order to size the potential volume of wood debris resulting from tree work, two methods were used to estimate annual availability: a top-down and bottom-up approach.

Top Down: Approximating Yield from Total Canopy Loss

Tree inventory data served as a basis for quantifying total biomass resulting from forest management activity within the City of Boulder. A 2019 study by Nowak et al[4] estimated that a 2 to 7% annual mortality rate would be typical of urban forests in the United States. Using this range as a foundation, we assume a total 5% urban forest biomass availability from combined tree removal, pruning, and hazard management activity. The City's Tree Inventory data[5] (Table 1) was used to summarize the demographics of Boulder's public trees, including most prevalent species, average size, and total biomass.[6]

Table 1. Summary of City of Boulder Public Tree Inventory

Species	Count	Average DBH	% Total	Dry weight above ground biomass (kg/tree)	Total Biomass (MT)
Maple	5,835	10.6	11.7%	361	2106.4
Pine	4,860	9.1	9.7%	66.1	321.3
Elm	4,645	10.4	9.3%	655.0	3,042.5
Ash	4,130	12.0	8.3%	650.0	2,684.5

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[4] Nowak, David J.; Greenfield, Eric J.; Ash, Ryan M. 2019. Annual biomass loss and potential value of urban tree waste in the United States. Urban Forestry & Urban Greening. https://doi.org/10.1016/j.ufug.2019.126469.

[5] https://open-data.bouldercolorado.gov/datasets/dbbae8bdb0a44d17934243b88e85ef2b_0/explore

[6] Biomass calculations were derived using the USDA Forest Service's CUFR Tree Carbon Calculator. https://www.fs.usda.gov/ccrc/tool/cufr-tree-carbon-calculator-ctcc

Species	Count	Average DBH	% Total	Dry weight above ground biomass (kg/tree)	Total Biomass (MT)
Honeylocust	3,652	10.0	7.3%	416.0	1,519.2
Cottonwood	3,453	15.5	6.9%	712.5	2,460.3
Oak	3,434	6.7	6.9%	122.0	419.0
Crabapple	3,029	7.2	6.1%	93.8	284.1
Spruce	2,133	10.2	4.3%	218.8	466.7
Linden	1,816	8.5	3.6%	156.0	283.3
Other	12,901	6.4	25.9%	88.0	1,135.3
Total/Average	**49,888**	**9.7**	**100%**	**321.7**	**14,723.0**
% city canopy on public land					**10%**
Estimated total city biomass (public & private)					**147,230**
Estimated annual biomass loss %					**5%**
Total annual biomass loss (MT)					**7,362**

The City of Boulder's public tree inventory contains an estimated 14,723 metric tons of wood biomass; however, it is believed that this inventory represents only 10% of the City's total canopy, with 90% of trees situated on privately managed lands. As a result, it is estimated that there are more than 147,000 tons of biomass in the city's urban forest. With an annual biomass loss of 5%, this would result in approximately **7,362** metric tons of biomass availability across public and private landscapes.

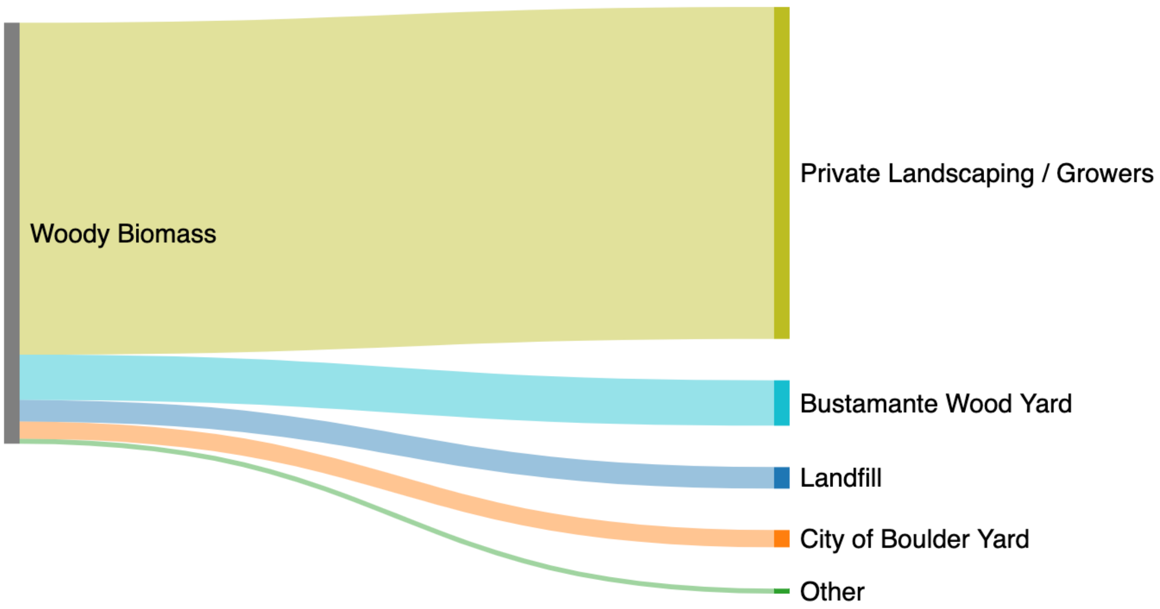
It should additionally be noted that severe weather events, targeted forest health management campaigns (such as preventative tree removals aimed at mitigating spread of Emerald Ash Borer), and large urban development initiatives could all significantly increase the volume of urban biomass availability in a given year.

Bottom-Up: Aggregating Arborist Sample Data

A second approach was used to approximate urban forest biomass loss from the perspective of the tree care industry responsible for this activity. Eight of Boulder's largest tree care companies provided estimates of their annual wood waste generation, as well as the typical disposal pathways for resulting material

(Figure 1). The companies averaged roughly 1,005 tons of annual wood waste generation each, a total of **8,039 tons** of biomass. At present, the majority of this debris is chipped and dropped at soil, landscaping, and nursery operations. Excess chips and whole logs – which can prove difficult to dispose of – are often sent to secondary disposal outlets, including landfill.

Figure 1: Typical Disposal Pathways for Woody Biomass in Boulder, CO



Assuming that the 8 companies surveyed represent 75% of all tree work in the City of Boulder, it can be estimated that a total of **10,719** tons of urban forest biomass would be generated annually. Several arborists surveyed and interviewed during the course of this project noted that they would be happy to divert wood waste from their operations toward a municipal biochar production facility. Yet key drivers to incentivize participation include:

- Low or no cost for disposal of wood waste
- Proximity: a location within the city of reasonable driving distance, to minimize transportation costs.
- Allowing for wood waste from the adjacent communities (beyond the City of Boulder), as many tree care companies have crews working throughout the region, and separating waste streams would present an extra logistical hurdle.

Biochar Processing

Averaging the top-down and bottom-up projections, a total **9,041 tons of urban forest biomass** could be fed annually into a local biochar production system. An important next step in converting this biomass to biochar will be selecting and scaling processing infrastructure.

The City of Boulder is currently piloting a community-scale bioenergy-biochar unit by TrollWorks that can process roughly 200 tons of biomass into 30 tons of biochar annually (15% yield), with an additional 200,000 Btu of heat cogenerated hourly.[7] Using this technology, as many as 45 units could be powered annually by the city's tree waste, resulting in roughly 1,356 tons of biochar from the city's urban forest residues.

Alternative scales of production could include a containerized pyrolysis reactor by ARTi Biochar: a unit currently under review by the City of Minneapolis can process 16 tons of green wood into 4 tons of biochar across 2 lines daily (25% yield). Total processing potential for the unit is estimated at 3,200 tons of green biomass annually, a scale sufficient for a single system to handle ⅓ of the City of Boulder's wood waste.

Biochar Now, a large-scale commercial biochar producer located in Berthoud, CO, noted a near infinite capacity to feed the city's wood waste into its production process, so long as material was dried or shredded prior to drop-off. The company currently pays a rate of $60/ton for dried and shredded wood provided by the US Forest Service, and likely could offer a similar rate for Boulder's wood waste. If this price were paid for all 9,041 tons of available biomass, the City of Boulder could capture more than $500,000 annually from its wood waste stream, though transportation costs and emissions would also have to be considered.

In evaluating various biochar production systems, additional selection criteria should include:

- Carbon impact and efficiency. Pyrolysis systems can vary dramatically in carbon efficiency, heat capture, and biochar yield from biomass. As a result the carbon payback period can be an important metric in considering how long it takes for a process to become carbon negative – this can vary by an order of magnitude across different technologies.
- Transportation distance. In order to maximize the carbon benefit of wood utilization, colocation of biochar processing to feedstock sources will play a role in the net carbon impact of the system. While zoning and permitting may constrain siting, locating infrastructure in as close proximity to the urban forest as possible and utilizing low-carbon vehicles for hauling biomass will help increase total carbon benefit.
- Community justice & equity. In order to combat a legacy of siting industrial activity in minority and low-income communities, it is critical that decisions regarding the selection and placement of biochar production infrastructure consider social and environmental impacts to the

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[7] Annual figures are calculated based on an operating schedule of 8 hours/day, and 240 days/year.

surrounding community, including the potential air quality impacts of both ongoing pyrolysis system operations as well as the associated trucking of wood in and out of the site.

Demand: Application Areas

The following section explores potential avenues for utilizing biochar within the City of Boulder. Estimates were derived according to current best practices established by subject matter experts, peer city pilots, and academic research. A summary of highlighted biochar application areas is outlined in Table 2.

Table 2. Biochar Application Potential in the City of Boulder

User	Application Area	Use Estimates	Biochar potential	Estimated Carbon Sink
Urban Forestry	Public tree planting	600-1,000 trees planted annually by the City of Boulder. Assumes 10-15% inclusion rate in soil/biochar/compost mix, roughly ~2lbs biochar per tree.	1 ton	2-2.5 tons CO$_2$e annual
Urban Forestry	Community tree planting	2,000 trees planted annually by community members. Assumes 10-15% inclusion rate in soil/biochar/compost mix, roughly ~2lbs biochar per tree.	2 tons	4 – 5 tons CO$_2$e annual
Parks & Recreation	Parks & turf management	1,918 acres of property maintained by Parks and Recreation. Estimate assumes biochar is applied at a rate of 0.41 lbs per square foot at 4in depth to between 1% - 5% total acreage	155 – 776 tons	311 – 1940 tons CO$_2$e annual
Urban Agriculture	Public giveaway (community gardens/ resident use)	100 cubic yards	18 tons	36 – 45 tons CO$_2$e annual
Public Works	Roadside management (filtration of runoff)	300 miles of city-managed roadway. Assumes 5% annual maintenance & 10% of projects including biochar as ⅙ of soil blend	24 tons	48–60 tons CO$_2$e annual
		Totals:	**200 - 821 tons biochar**	**400 - 2,053 tons CO$_2$e annual**

Because of the region's arid climate and water stress, landscape application within the city's parks and green turf areas presents not only the highest volume potential use, but also a promising opportunity to leverage biochar's water-holding capacity as a tool in reducing water demand.

Assuming that sequestration per ton of biochar typically ranges from 2-2.5 tons CO_2, the total carbon sequestration potential of biochar use as outlined above ranges from 400 to 2,053 tons of carbon dioxide equivalent annually. This wide range stems predominantly from the significant range of potential use in turf applications. Given that urban forest biomass from tree maintenance activities within Boulder could provide sufficient feedstock to produce somewhere between 1,300 and 2,300 tons of biochar annually, offtake channels would need to expand significantly to effectively utilize all of this volume each year. That said, the initial 30 tons of biochar produced by the pilot TrollWorks reactor can be utilized to test various application strategies to assess carbon and non-carbon environmental impacts before scaling further.

Impact Quantification

A major driver of implementation of a city-scale biochar production and application system is the opportunity to create value and impact through up-cycling a waste stream. In considering the benefits of investment into such a system, a few categories of possible impact are discussed below:

Carbon Impact[8]

In order to estimate biochar's potential to mitigate greenhouse gas emissions, a simplified calculation method based on hydrogen to organic carbon ratio (H/C_{org}). Table 3 is drawn from the International Biochar Initiative (IBI) estimation of biochar BC_{+100}, which represents the amount of biochar carbon expected to remain stable after 100 years, relative to H/C_{org}.[9] It should be noted that IBI's chosen value of stable carbon is conservatively selected to be estimated below the lower limit of a 95% confidence interval.

Table 3. Biochar Stability Based on Biochar H/Corg at 95% confidence (Budai, et. al, 2013)

	BC_{+100} (%)			
H/C_{org}	Mean	Lower limit	Upper limit	Chosen value
0.4	**80.5**	**72.6**	**88.2**	**70**
0.5	73.1	67.1	78.9	50
0.6	65.6	60.5	70.6	50
0.7	**58.2**	**52.5**	**63.8**	**50**

Based on the BC_{+100} index, a simple calculation of a biochar's carbon sequestration potential can be estimated using the following formula:

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[8] Adapted from: EcoTopic, "Carbon Sinks in Urban Public Green Areas: Calculations of Potential Carbon Storage in the City of Stockholm." April 6, 2022. See also: IPCC, 2019

[9] Budai, A. et. al (2013). Biochar Carbon Stability Test Method: An Assessment of Methods to Determine Biochar Carbon Stability. International Biochar Initiative.

$$\text{CO}_2 \text{ sequestration (at 100 years)} = \% C * BC_{+100} * 3.67$$

The present carbon content of the biochar (% C) is multiplied by BC_{+100} to reflect how much carbon will be present in the biochar after 100 years. Because a single atom of carbon binds with two heavier oxygen atoms to create a molecule of CO_2, the resulting carbon dioxide weighs 3.67 times the amount of its carbon content. As a result, to calculate CO_2 sequestered by biochar after 100 years, a multiple of 3.67 must be used.

For example, one ton of biochar with 85% carbon content and an H/C_{org} ratio of 0.4 would be calculated as follows: 85% C * 70% * 3.67 tons of carbon dioxide equivalents = 2.18 tons CO_2 equivalent remaining after 100 years. This formula is offered as a baseline estimate for carbon impact calculation, until a more complete life-cycle assessment can be performed and certified.

Economic Impact

Given the upfront costs of financing a pyrolysis system, it is important to consider opportunities for value capture from this circular economy model of reuse. Biochar produced via pyrolysis of wood waste could have two significant sources of revenue generation: sale of finished product, and sale of carbon credits per ton of associated emissions reductions.

According to a 2014 IBI report, the average wholesale price among 56 pure biochar products was $4.54 per pound ($2.06/kg).[10] Retail prices were even higher, at $6.78 per pound ($3.08/kg). At this wholesale rate, the 30 tons of biochar produced by a single TrollWorks unit could generate more than $300,000 worth of biochar annually, assuming sufficient quality and local demand. Because demand is so critical to enabling both public and private processing infrastructure, the City of Boulder has an opportunity to play an early role in creating the foundations for biochar markets by procuring biochar for use in urban forestry, agriculture, and green infrastructure.

Additionally, the emergence of robust carbon markets has provided another financial incentive to support biochar production. A selection of projects traded on the puro.earth marketplace in April 2022 included 6 biochar carbon removal projects based in the United States, trading at an average $206 per ton of emissions reductions.[11] At this average price per metric ton of carbon removal, emissions reductions from the biochar application opportunities highlighted in Table 2 could generate an estimated $82,400 - $422,918 from the sale of carbon credits annually.

Alternatively, a final method of capturing value from urban forest biomass within a biochar production system would be the sale of wood as a feedstock to a private sector producer. As mentioned previously, Biochar Now could pay a rate of $60/ton for supply of dried/shredded wood biomass, presenting an

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[10] International Biochar Initiative. "State of the Biochar Industry 2014." https://biochar-international.org/state-of-the-biochar-industry-2014/

[11] https://puro.earth/CORC-co2-removal-certificate/

opportunity for the City of Boulder to feed its urban forest residues into local biochar production, without investment into direct ownership or operation of a pyrolysis system.

Tree Growth & Health

One potential benefit of biochar application is the increased vitality and resilience of trees grown in a biochar-containing soil medium. A meta-analysis of published work on forest restoration and biochar applications found an average 41% increase in tree biomass from biochar additions.[12] While impacts may vary significantly based on environment, tree species, and growth context (eg. nursery propagation vs. forest plantings), biochar additions up to 20% of soil volume have shown consistent efficacy. Additions of biochar can help increase the pH of acidic soils and help stimulate tree growth and biomass yield[13]. Some adverse results may occur at inclusion rates greater than 20%, due to heightened levels of soil pH.

A 2014 study analyzed tree growth of two species – sugar maple (Acer saccharum) and Honey locust (Gleditsia triacanthos) – in three typical urban soils: sand, silt and compacted clay. Biochar was included as a top-dressing to soil surfaces at a rate of of 25 Mg per hectare per year (~.51 lbs per square foot). Across species and soil types, samples treated with a pine-based biochar saw a 44% increase in tree biomass, compared to control samples.[14] Additionally, research has shown that biochar can be a source of natural disease resistance. Biochar additions in potting mixes aided resistance to stem cankers caused by water mold in red oak and red maple.[15]

Stormwater Management

A final driver of biochar utilization may be the potential to increase water holding capacity and reduce irrigation demands in drought-prone environments. Numerous studies have shown that biochar can increase water-holding capacity and reduce soil compaction. As a result, significant yield increases have been found where medium and coarse textured soils have seen biochar added, likely to be due to improved water holding capacity.

In one study, biochar derived from maize cobs via slow pyrolysis was added to soils growing corn and soybeans. Results showed that for every 1% addition of biochar, available water and soil aggregate stability increased by 3%, while soil bulk density reduced by 3-5%.[16] These impacts could make a significant impact on agricultural viability and soil ecosystem health in regions with low or erratic rainfall.

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[12] Thomas, S.C. and Gale, N. 2015. New Forests 46 931-946 "Biochar and forest restoration: a review and meta-analysis of tree growth responses"

[13] Dai, Z., Zhang, X., Tang, C., Muhammad, N., Wu, J., Brookes, P.C., et al., 2017. Potential role of biochars in decreasing soil acidification - a critical review. Sci. Total Environ. 581–582, 601–611.

[14] Scharenbroch, B. C., Meza, E. N., Catania, M., & Fite, K. (2014). Biochar and Biosolids Increase Tree Growth and Improve Soil Quality for Urban Landscapes. Journal of Environmental Quality, 42(5), 1372–1385.

[15] Zwart, D.C. and Kim, S-H. 2012. Hort Science 47 1736-40 "Biochar Amendment Increases Resistance to Stem Lesions Caused by Phytophthora spp. in Tree Seedlings"

[16] Obia, A. et al. 2016. Soil and Tillage Research 155 35-44. "In situ effects of biochar on aggregation, water retention and porosity in light-textured tropical soils."

A model developed by researchers from Rice University predicted that biochar application in soil could **reduce need for irrigated water use by 37%** in one studied site in Nebraska.[17] Given increasing water scarcity and associated cost considerations, the water conservation impacts – rather than carbon impact potential or soil health considerations – may be the most critical driver in increasing municipal biochar use in the City of Boulder.

Recommendations

Based on our analysis, the following recommendations are provided to the City of Boulder as next steps in considering development of a city-scale biochar production system utilizing urban forest residues:

Support wood waste capture by centralizing collection and incentivizing tree care companies.

The current material flow of wood waste in Boulder is poorly tracked and highly disaggregated. The city's tree care companies largely send wood waste to be shredded into chips and mulch, yet several companies expressed a desire for more proximate, low-cost disposal outlets for logs and brush generated by urban forest management activities. By establishing a central collection yard for clean wood waste, the City of Boulder could feasibly capture thousands of tons of biomass from local arborists to feed into a biochar production system. Additionally, due to seasonal fluctuations in tree work and the associated material flow of biomass, this type of storage capacity will be important to smooth month-to-month variations in feedstock availability.

Additionally, policy incentives and requirements could help increase reporting on wood waste disposal and secondary utilization of wood biomass moving forward. At present there are no reporting requirements for licensed arborists to share how much wood waste they haul and where they dispose of material. As suggested by City Forester Kathleen Alexander, standards for reporting and disposal of wood waste could be developed as a component of future licensing requirements, or be incentivized by making wood waste disposal a consideration in contract awards. Similarly, companies with government contracts for public tree work could be mandated to dispose of wood waste at a specific station, such as a biochar production facility.

Catalyze local demand for biochar.

Sustainability of a biomass to biochar production system hinges on the development of ongoing application pathways for utilizing biochar within and around the City of Boulder. As a result, fostering demand for biochar within city application channels – such as stormwater management, urban

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[17] J.E. Kroeger, G Pourhashem, K.B Medlock, C.A Masiello. Water Cost Savings from Soil Biochar Amendment: A Spatial Analysis. GCB Bioenergy, 2020.

agriculture, and tree planting projects – will be an important first step in establishing consistent demand. In addition to driving procurement as a purchaser of biochar, the City of Boulder could help develop carbon projects using a biochar production methodology.

Pilot and evaluate new use cases for local biochar application.

Furthermore, because biochar's climate impact potential is subject to variables including selection of specific technology, further research is needed to quantify the efficiency of carbon and waste heat capture within a specific pyrolysis system. Transportation distances between source feedstock, processing, and application, will also play a role in determining the net carbon impact of a biochar production system. Finally, as non-carbon impacts such as increased water availability and pollutant remediation are variable according to local context and application practices, onsite evaluation will be necessary to validate and quantify environmental impact prior to large-scale program implementation.