Biochar-Urban Forestry Strategy

FOR THE CITY OF MINNEAPOLIS, MINNESOTA

June 2022

Prepared by:

Cambium Carbon

With support from:

Carbon Neutral Cities Alliance

Nature-Based Climate Solutions

Table of Contents

Introduction

Minneapolis faces a mounting wall of wood waste – logs and tree limbs coming out of the city and its surrounding urban forest, driven largely by the Emerald Ash Borer (EAB) and its decimation of local ash populations. As Hennepin County looks for solutions to its growing wood problem, biochar has emerged as a potential solution to utilize urban forest biomass in a regenerative system with economic and environmental impact.

This project aims to explore the potential for using urban forest biomass as a feedstock for biochar production within and around the City of Minneapolis. 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 Boulder, Helsinki, and Stockholm will also be available at the culmination of the project.

The following analysis aims to create a framework for assessing a full life cycle management strategy from urban forest biomass generation to biochar production and application. 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

---

[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"

conditions, plays an important role in determining the quality, pore structure, nutrient content, and characteristics of resulting biochar.

Supply: Regional Wood Feedstock Availability

The goal of this analysis is to understand the scale of potential production and application of biochar within the City of Minneapolis and the surrounding region. Given the number of upcoming tree removals and overwhelming volume of corresponding wood waste, urban (and peri-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 charcoal, rather than release greenhouse gasses into the atmosphere.

In order to size the potential volume of wood debris available for biochar feedstock, two sources were considered: material from public trees managed within the City of Minneapolis's urban forest, and biomass generated from tree removals in Hennepin County.

Minneapolis Tree Data

Within the City, the Minneapolis Park & Recreation Board manages all public planting, maintenance, and removal of street and park trees. Since 2014, a targeted Emerald Ash Borer management campaign resulted in a near doubling of annual tree removals, with roughly 40,000 ash trees removed over an 8-year period.[4] 2021 marked the last year of this campaign, with removals beginning to trend toward pre-2014 levels. In total **5,924 trees** were removed from the city landscape, containing an estimated **4,481 metric tons** of woody biomass. [5] Data from 2021 tree removals is summarized in Table 1.

Table 1. 2021 Public Tree Removal Data for the City of Minneapolis

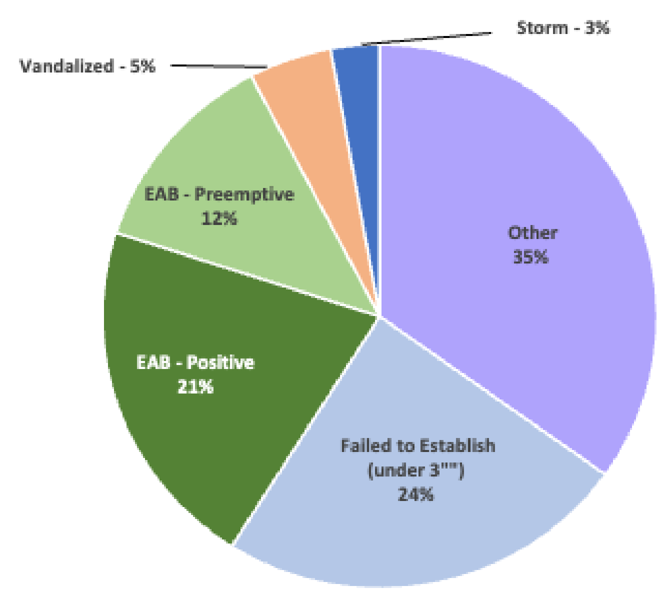
Species	Total Count	Average DBH	% Total Inventory	Above Ground Biomass (kg/tree)	Biomass Total (MT)
Green Ash	1695	18.6	28.6%	1729.3	2931.1
Norway Maple	300	13.9	5.1%	596.4	178.9
Tamarack	193	2.6	3.3%	2.4	0.5

[4] Tree removal data and estimates provided by Philip Potyondy & Ralph Sievert of the Minneapolis Park & Recreation Board, and Dustin Ellis, Community Forester for Hennepin County.
[5] 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	Total Count	Average DBH	% Total Inventory	Above Ground Biomass (kg/tree)	Biomass Total (MT)
Sugar Maple	191	14.8	3.2%	859.2	164.1
Ash	169	15.6	2.9%	780.9	132.0
Littleleaf Linden	149	17.3	2.5%	669.5	99.8
'Espresso' Kentucky Coffee Tree	145	2.8	2.4%	6.8	1.0
American Linden (Basswood)	142	19.9	2.4%	926.0	131.5
American Elm	120	25.0	2.0%	2118.4	254.2
Swamp White Oak	99	6.2	1.7%	79.1	7.8
Other	2721	7.69	46.0%	213.0	579.7
Total / Average	5,924	13.1	100%	536	4,481

Figure 1 illustrates the major causes of 2021 public tree removals in Minneapolis. Although EAB-related removals account for roughly one-third of all tree loss, it should be noted that other driving causes of tree removal include failure to establish, vandalism, and storm; consequently, biomass will continue to be removed from the city's urban forest upon conclusion of the EAB management campaign.

Figure 1. Major Causes of Tree Removals (2021)

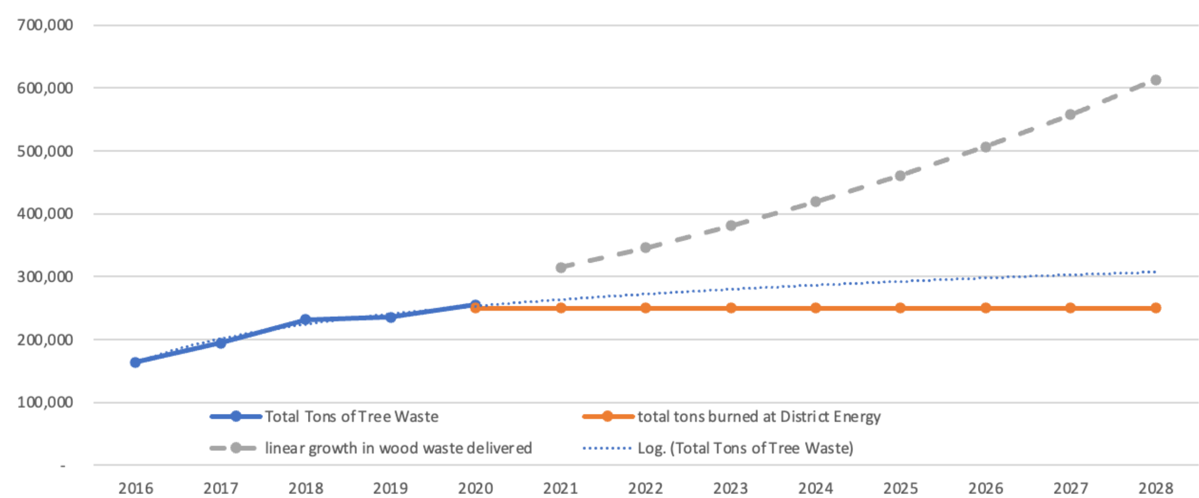


At present most wood debris generated through maintenance and removal activity is sent to a wood processing site leased by an external company (Precision Landscape & Tree) that processes the material into biofuel or wood chips for landscape application. A portion of material is sold to Wood from the Hood to be milled into lumber products. Site constraints are a concern, as there is little room in the current system for additional wood storage or processing.

Hennepin County Biomass

In addition to public and private tree work within the City of Minneapolis, Hennepin County and the surrounding region present a huge source of potential biomass feedstock for biochar production. While the City's EAB campaign has concluded, the County faces management of nearly 1 million ash trees situated on public and private landscapes. From 2016 to 2020, an average **56,148 tons of tree waste** were recorded annually in Hennepin County.[6] Figure 2 summarizes the state-wide volumes and projected growth of tree waste in Minnesota, driven largely by EAB management activities.

Figure 2. Wood Waste Projections (State of Minnesota)



Courtesy of Anne Jackson, Minnesota Pollution Control Agency

While Ever-Green Energy's District Energy St. Paul facility serves as the largest wood biomass processor in the region, the company has no current plans to scale production to meet the estimated increases in regional wood waste. And although transportation costs may ultimately limit the geographic scope of unified wood waste capture across the region, development of biochar systems in and around the City of

[6] Data from state-wide Minnesota Pollution Control Agency data.

Minneapolis may help manage a portion of the growing volumes of wood waste, while capturing economic and environmental value.

Biochar Processing

A pilot ARTi biochar unit being reviewed by the City of Minneapolis can process 16 tons of green wood into 4 tons of biochar across 2 lines daily. Total processing potential for the unit is estimated at 3,200 tons of green biomass annually, but will vary depending on run time.[7] Under this scenario, two 2-line units would be required to manage biomass from Park Board tree removals, generating an estimated **1,120 tons of biochar annually** from the Park Board's 4,481 metric tons of wood biomass. These totals exclude biomass generated by private tree care activities.

In order to process all of Hennepin County's 56,148 tons of tree waste annually, it would take more than 17 two-line ARTi pyrolysis systems. One alternative approach to increasing the number of small-scale biomass processing units would be to incentivize Ever-Green Energy to invest in large-scale biochar production systems. Given that the company already maintains infrastructure to collect and process wood biomass at scale, expanding this public-private partnership model of waste management.

In evaluating various biochar production systems, additional selection criteria to be considered by the City of Minneapolis 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 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.

[7] Based on manual operation and 200 days run time/year (per ARTi website, https://www.arti.com/reactors/)

Demand: Application Areas

The following section explores potential avenues for utilizing biochar within the City of Minneapolis. Estimates were derived according to current best practices established by subject matter experts, peer city pilots, and academic research.

Within the City of Minneapolis, pilot projects utilizing biochar in roadside green infrastructure have shown promise in managing road runoff in meridian zones by absorbing and removing contaminants as water filters into the ground (see *Case Study: Hiawatha Avenue*). As a result, the city's Public Works department would likely be the largest end users of biochar produced in the region. Table 2 provides a summary of target end users for city-generated biochar, and the estimated scale of annual use per category.

Table 2. Biochar Application Potential in the City of Minneapolis

User	Application Area	Use Estimates	Biochar potential	Estimated Carbon Sink
Public Works	Roadside management (filtration of runoff)	1000+ miles of roadway. If 5% are rehabbed annually with 10% of projects including biochar as ⅙ of soil blend	80 tons	160-200 tons CO_2e annual
Urban Agriculture	Public giveaway (community gardens, & resident use)	100 cubic yards	18 tons	36-45 tons CO_2e annual
Park Board & Urban Forestry	Tree planting	10,000 trees planted annually, 10-15% inclusion rate in soil/biochar/compost mix. Roughly ~2lbs biochar per tree	9 tons	18-23 tons CO_2e annual
Park Board & Urban Forestry	Green space / park land management	200 cubic yards	36 tons	72-90 tons CO_2e annual
		Totals:	**143 tons biochar**	**286 - 358 tons CO_2e annual**

Given that sequestration per ton of biochar typically ranges from 2-2.5 tons CO_2, the total carbon impact of biochar application in the categories identified in Table 2 is estimated to be between 286-358 tons annually. In the preceding section it is estimated that the City of Minneapolis could generate as much as 1,120 tons of biochar annually from its urban forest residues; that said, additional offtake channels would be needed to utilize the full potential of this supply. Beyond initial City pilots, large-scale biochar users (including the statewide Minnesota Department of Transportation) will play a critical role in scaling regional biochar use and achieving a carbon sequestration potential of more than 2,000 tons CO_2 equivalent annually.

Case Study: Hiawatha Avenue

A joint effort between Hennepin County and the City of Minneapolis, this stormwater infrastructure project took place in the fall of 2019 along State Highway 55 (Hiawatha Avenue). The four-lane divided highway connects downtown Minneapolis to the Minneapolis/St. Paul International Airport. The corridor is maintained by Hennepin County under an agreement with the Minnesota Department of Transportation (MNDOT).

Over time, the soil in Hiawatha Avenue's grass median had become compacted and overrun by weeds. The County received a grant to restore vegetation with a pollinator lawn mix, and replace dead trees along a four block stretch of the roadway.

Rather than rebuild the existing system, Hennepin County teamed up with the City of Minneapolis to construct a swale to improve rainwater infiltration. Medians often present a harsh environment for vegetation, given their high exposure to road salt. To increase infiltration, reduce maintenance, and increase vegetative growth, the project team replaced the existing crowned, compacted soil with a compost/biochar mix.

Compost from the Shakopee Mdewakanton Sioux Community (SMSC) Organics Recycling Facility (ORF) was mixed with biochar supplied by the City of Minneapolis. A hardwood biochar (prepared by slow pyrolysis at 650° C) was mixed at a ratio of 1-part biochar to 9-parts compost. A total of 15 cubic yards of biochar were used.

The City of Minneapolis Public Works removed soil from the median and shaped the swale. Biochar and compost were then mixed into the upper 6-inches of soil. County staff planted a pollinator mix and covered it with burlap. Hennepin County replaced 40 trees with a variety of bare-root stock, backfilled with a mix of soil and a 50-50 biochar/compost mix. The project aims to reduce mortality and increase vitality of the replacement trees.

Next steps will include measurement and evaluation of pollinator populations by the University of Minnesota. For now, the mix is well established and has successfully weathered two winter seasons.

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/C_{org} 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:

$$CO_2 \text{ sequestration (at 100 years)} = \% C * BC_{+100} * 3.67$$

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.

[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.

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 1,120 tons of biochar produced annually by an ARTi system could generate more than $11 million worth of biochar annually, although identifying sufficient regional demand to capture that full value would present a challenge. Because market development is so critical to enabling both public and private sector biochar production infrastructure, the City of Minneapolis and State of Minnesota will likely need to play an early role in establishing incentives through high-volume procurement of biochar for use in urban forestry, agriculture, and green infrastructure.

Another source of financial incentive for biochar production has been the growth of carbon markets and the procurement of carbon credits to offset emissions by governments, companies, and other organizations. 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 $58,916 - $73,748 from the sale of carbon credits annually.

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).

[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/

[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.

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 improve groundwater infiltration (see *Case Study: Hiawatha Avenue)*, 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.

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] That said, in addition to carbon storage potential and soil health considerations – water benefits for agriculture and turf management may be additional drivers in increasing biochar use by the City of Minneapolis, local residents, and businesses.

Recommendations

Grow biochar demand within the transportation sector

Market acceptance will be a critical step in catalyzing a system of large-scale biochar production from tree biomass waste. It is clear from early market analysis that incorporation of a biochar-compost mix in stormwater management projects can provide a huge source of material offtake impact potential. In

[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."

[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.

order to drive large-scale biochar usage by the Minnesota Department of Transportation (MNDOT), the department needs better standards and guidelines for biochar application and use.

While this project has established a guidance document for biochar procurement and application, next steps include development of a design manual to outline and provide visuals for staff on how to incorporate biochar into roadside green infrastructure projects. By providing a handbook as a framework for statewide use as well as an approved vendor list, the City of Minneapolis could help enable MNDOT to become the single largest driver of biochar markets in the region.

Leverage local research & resources

Minneapolis has proven a leader among US cities in advancing biochar research and pilot demonstration projects. The region is home to many leading academic organizations with expertise in biochar analysis, including the Natural Resource Research Institute (NRRI) and University of Minnesota. As a result, there is a significant opportunity to engage these institutions in support of biochar system development.

By developing case studies to demonstrate biochar efficacy in soil health improvement, stormwater management, and treatment of both establishing and mature trees, local researchers can address knowledge gaps and strengthen interest in biochar procurement among the tree care and agriculture industries, as well as within local government. Additionally, the City of Minneapolis can play a role in facilitating a connection between research teams and prospective biochar users in order to relay documentation of biochar benefits and provide the guidance necessary for effective application.

Collaborate with private sector partners

While this report focuses on opportunities to utilize biochar within public projects, the private sector will play an important role in developing and sustaining a circular economy model for biochar production and use. As a dominant force in the capture and utilization of local wood waste, Ever-Green Energy's District Energy facility will be a critical private-sector partner in increasing the scale of processing infrastructure to match projected needs.

At present, the City of Minneapolis is unequipped to handle Hennepin County's influx of wood waste from tree removals and maintenance work. However, a contract with District Energy to offtake wood waste and pyrolyze a portion into biochar could provide sufficient incentive to catalyze private-sector infrastructure and ultimately scale biochar production and availability, without requiring direct ownership or operation of units by the City.