Biochar Potential in Minnesota's Forests

An assessment of biochar production and integration opportunities into Minnesota forest management informed by stakeholder perspectives

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Executive Summary

Biochar presents a unique opportunity within forest-based industries, having the potential to consume underutilized woody biomass, serve as an amendment to improve soils, and a strategy to sequester carbon. Biochar is not a new technology, as it was used by ancient civilizations in the Amazon basin to boost soil fertility. Soils containing this black carbon, or Terra preta,[1] allowed those cultures to successfully cultivate the land and remnants of this practice can still be found today. Biochar is now used as a soil amendment, filtration medium or remediation material, and even as animal bedding and a feed additive. However, the biomass industry and related markets are still relatively immature in the U.S. as refinements are being made to optimize processes, biochar characterization, and identify potential and value. The U.S. Biochar Initiative maintains a directory of biochar associated businesses,[2] but consistent supplies are not readily available in all regions for all applications.

The potential benefits and challenges related to biochar are worth exploring within the context of Minnesota's forest and provided the motivation for this project. The goal of the project was to identify and outline the logistical challenges and opportunities of biochar integration in Minnesota's forests, along with presenting the feasibility of various integration strategies, to inform the development of a potential biochar industry in the state. This work is informed by an extensive literature review, in-depth interviews with content experts from across the country, and diverse focus groups with stakeholders throughout the state.[3] Discussions from those focus groups, hosted throughout winter 2020-21, are intertwined throughout this report. Thirty individuals were involved representing land managers, consultants, contractors, and the forest products industry. Despite each session being quite diverse, common themes arose that can inform the development of a biochar industry in Minnesota.

Pathways for biochar production

A variety of pathways for biochar production in Minnesota were explored in this project. Three of which have been identified for Minnesota's forests and are discussed in detail in this report.

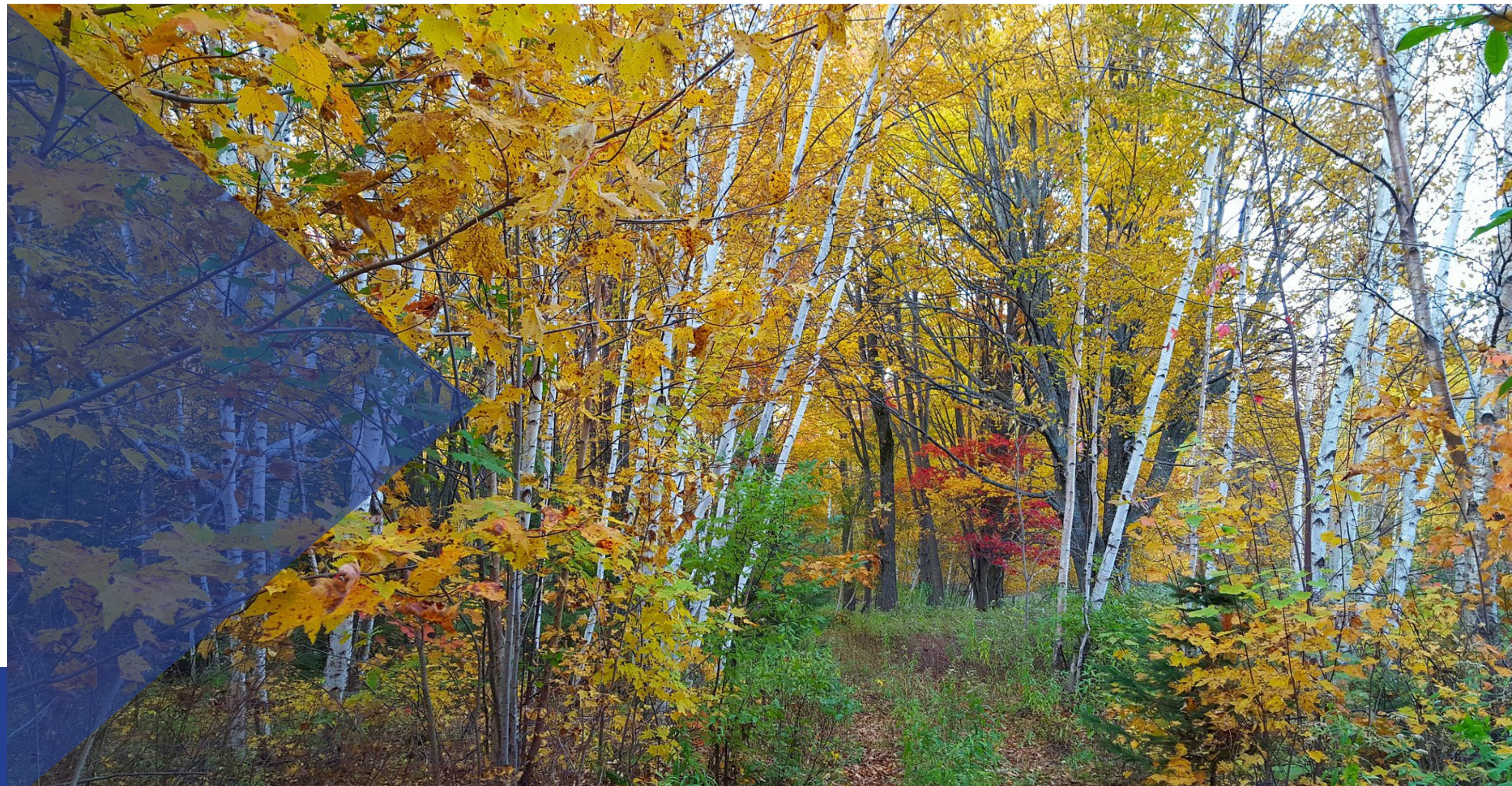
- Pathway 1. Low-tech flame cap kilns leveraging carbon markets to restore forest health
- Pathway 2. Mobilized production units processing slash and residuals for diversified revenue generation
- Pathway 3. Centralized coproduction and colocation leveraging mill residuals

The scale across these applications differs significantly in terms of volume of biomass processed, investment needed for equipment and systems, and the revenue generation potential.

[1] United States Biochar Initiative, n.d. Biochar Then & Now. https://biochar-us.org/biochar-then-now
[2] United States Biochar Initiative, n.d. Directory by State. https://biochar-us.org/directory
[3] Focus group methodology summarized in Appendix B

Main findings from focus groups

- Infrastructure exists to utilize woody biomass and residuals, given a market opportunity for it to "pay itself out of the woods." Biochar could be that opportunity.
- There was limited interest in biochar production for the purposes of a forest soil amendment.
  - Insufficient evidence to support a strong ecological reason to amend forest soil with biochar (solely for improved soil health)
  - Many challenges exist for cost effectively using the biochar in forests.
  - Additional trucking of the biomass from the forest to a biochar production facility and then back onto the site would be needed if offsite char production occurred.
  - The lone opportunity recognized to have potential to utilize biochar back in the woods was regeneration on sandy pine sites (Jack and Red Pine)
- There are plenty of 'undesirables' (forest inventory) out there that could provide an ample supply of biomass without having to tap into slash for biochar production
  - Concern exists around slash utilization – does a low value feedstock result in a low-value biochar product?
- Skepticism exists on of whether biochar markets truly exist and whether their potential could fund a new industry in Minnesota.
- If there was a way to monetize the value of the carbon in biochar (through storage, sequestration), that may significantly open up the opportunities to support biochar production; including mobile efforts to improve forest health across the landscape.



Recommendations to overcome barriers to forest-based biochar applications in Minnesota

The project resulted in several recommendations for overcoming barriers associated with forest-based biochar applications in Minnesota. These recommendations are summarized below and further detailed in the full report.

1. Economic Incentives for Production: including subsidizing and/or incentivizing the cost of biochar production through carbon credits, ecosystem service markets, conservation practices/NRCS incentives, etc. to provide the financial support needed to make the capital investments and bring stability to a rather volatile market.
2. Optimizing Equipment and Operations: including pilots and partnerships for streamlining mobile equipment processes (kiln and applicator), greater opportunity to return biochar back onto forestland, and improving equipment options that are currently limited and costly at the scale needed for efficiency.
3. Understanding of Soil Benefits: increasing understanding of biochar benefits to forest soils is necessary to fully realize a circular biochar industry in Minnesota's forests. Without an established and proven return on investment, capital investment is extremely difficul

The barriers identified through this investigation highlight the need for additional biochar research and development of viable business models. A collaborative approach involving public and private partnerships is necessary to ensure the right questions are being asked and yield applied results that are logistically feasible in the Minnesota context. Amonette et al. (2021)[4] recently published, "Integrated biochar research: A roadmap" in the Journal of Soil and Water Conservation, which outlines a robust strategy that mirrors many of the needs present locally and can inform future research efforts and business development.

Research Needs

This project, the literature review, and focus group discussions highlight research needs to support biochar opportunities in Minnesota, including:

- Need for understanding long-term biochar amendment impacts to forest soils (trials, monitoring sites).
- Replication of nursery research conducted in western states within Upper Midwest systems, specifically focusing on Jack Pine revegetation where the opportunity may be greatest to leverage biochar benefits.
- Need for understanding benefits of charging vs not charging biochar and impacts on forest site applications.
- Characterization analyses of different biochars created from various Minnesota woody biomass feedstocks through varying biochar production processes - identify market opportunities for various outputs.
- Develop enterprise budgets and assess return on investment for various biochar production systems and feedstocks, focusing on the three pathways presented in this report.

[4] Amonette, James E. et al. 2001. Integrated biochar research: A roadmap. Journal of Soil and Water Conservation. Jan 2021, 76 (1) 24A-29A; DOI: 10.2489/jswc.2021.1115A. https://www.jswconline.org/content/76/1/24A

This investigation comes at a time when Minnesota is experiencing shrinking woody biomass utilization pathways and markets, coupled with increased forest pest and disease threats creating forest health issues that exacerbate woody biomass utilization challenges. Land managers and the forest products industry within Minnesota, are poised to lead development of solutions that promote forest health, support economic development, and provide solutions to climate challenges through the production and utilization of biochar. However, that work must be informed by relevant research and investment to prescribe and right-size the solutions. Furthermore, it is critical that when pairing the available biomass supply to meet market demand, a supply chain approach[5] is deployed to ensure sustainability of the benefits sought by these systems are realized. It is critical to understand the five segments of the biochar supply chain: biomass production, feedstock logistics, conversion, distribution logistics, and end use. It is quite easy to focus on the available biomass, but unless it is paired appropriately with the correct system to meet the end use goals and supported by the infrastructure to move the product in and out, the challenges associated with a biomass over-supply will continue.

[5] Anderson, N.M. et al., 2017. A supply chain approach to biochar systems [Chapter 2]. https://www.fs.fed.us/rm/pubs_journals/2017/rmrs_2017_anderson_n001.pdf

Section 1.

Biochar characterization and applications

At the most basic level, biochar is produced when burning organic material (woody biomass, agricultural residues, manure, etc.) in a high-temperature, low-oxygen environment via a process called pyrolysis. Depending on the material used, the temperature reached, and duration at that temperature, the biochar produced can present a variety of attributes. Two attributes most referenced include surface area - alluding to the highly porous structure of biochar, and the carbonized fraction of the material - highlighting its ability to store recalcitrant carbon.

The type of feedstock and production method heavily influences the resulting characteristics of biochar and thus its function and utility. Biochar application in soils has been shown to increase water retention,[6] reduce nutrient leaching[7] and runoff,[8] stimulate soil microbial activity,[9] and generally improve soil fertility.[10] Biochar also has the potential to serve as a natural climate strategy as identified by Griscom, et al. (2017)[11] and Fargione, et al. (2018)[12] through sequestering fixed carbon in the soil, lowering emissions from soil, and by providing potential renewable energy options (e.g., syngas as a byproduct of biochar production). Project Drawdown[13] estimates 2.22-4.39 gigatons of CO2 equivalent could be reduced/sequestered in the period from 2020-2050 if a considerable scaling up of biochar production operations could be realized.

Although biochar has gained quick attraction by the agronomic community as a soil amendment, it has shown specific benefit to forest applications as well.[14] Richard et al. (2018)[15] showed "significant improvements" to the soil by lowering bulk density and increasing water volume and water holding capacity in their field trials located in Wisconsin. This research has been replicated with similar results in other regions in the U.S. and aligns well with the review of data by Omondi, et al. (2016).[16] Biochar application to forest soils is not a one-size-fits-all scenario, and best practices[17] should be followed that are informed by soil type, structure, and site goals. Benefit is likely best realized at sites or locations that are subject to compaction due to forestry operations, skid trails and landings, for example. There is also potential for using biochar as a filtration medium for forest water runoff.[18] Dry sites experiencing reforestation challenges (e.g., Jack Pine stands) may also benefit from biochar, supporting water holding capacity for seedling survival.

Another forest related application for biochar is within the nursery industry, with the potential for biochar to replace or supplement traditional soil mediums and substrates.[19,20,21,22] Various trials have been conducted on biochar as a replacement or amendment in root, plug, and container stock production. Despite seedling productivity results varying significantly, the findings point to biochar's potential as a nursery medium and to its impact on reducing irrigation needs. Similar findings are confirmed in trials of seedlings transplanted with the biochar medium. Replicating trials locally could provide invaluable insight into how this opportunity could be leveraged in the region to support reforestation objectives.

[6]Laird, D.A. et al., 2010. Impact of biochar amendments on the quality of a typical Midwestern agricultural soil. https://core.ac.uk/download/pdf/212810608.pdf

[7]Novak, J. M. et al., 2009. Impact of Biochar Amendment on Fertility of a Southeastern Coastal Plain Soil. https://journals.lww.com/soilsci/fulltext/2009/02000/impact_of_biochar_amendment_on_fertility_of_a.6.aspx?casa_token=Nlo1vpsfKbYAAAAA:0IoPpKdDF6gas4X9Qxdy0R1bBs01W_sVoA3lt0rgJFike0LaOugh0w8lWVmUcPzar6EK5IfI1ZQqiCpBJVu7jlyA

[8]Saarela, T. et al., 2020. Biochar as adsorbent in purification of clear-cut forest runoff water: adsorption rate and adsorption capacity. https://link.springer.com/article/10.1007/s42773-020-00049-z

[9]Steiner, C. et al., 2007. Soil respiration curves as soil fertility indicators in perennial central Amazonian plantations treated with charcoal, and mineral or organic fertilisers. https://onlinelibrary-wiley-com.ezp1.lib.umn.edu/doi/epdf/10.1002/ts.216

[10]Ding, Y. et al., 2016. Biochar to improve soil fertility. A review. https://link.springer.com/content/pdf/10.1007/s13593-016-0372-z.pdf

[11]Griscom, et al., 2017. Natural climate solutions. https://www.pnas.org/content/114/44/11645

[12]Fargione, et al., 2018. Natural climate solutions for the United States. https://advances.sciencemag.org/content/4/11/eaat1869

[13]Project Drawdown, n.d. Biochar Production Technical Summary. https://drawdown.org/solutions/biochar-production/technical-summary

[14]Major, J., 2018. IBI Technical Bulletin #102. https://www.biochar-international.org/wp-content/uploads/2018/04/Technical-Bulletin-Biochar-Tree-Planting.pdf

[15]Richard, R. P. et al., 2019. Biochar and Wood Ash Amendments for Forestry in the Lake States: Field Report and Initial Results. https://www.fs.fed.
us/nrs/pubs/jrnl/2018/nrs_2018_richard_001.pdf

[16]Omondi, M. O. et al., 2016. Quantification of biochar effects on soil hydrological properties using meta-analysis of literature data. https://www.sciencedirect.com/science/article/pii/S0016706116301471?casa_token=GzIHeNqIQO0AAAAA:7cfTVEtPd3y47HaGc3qycMYyA984amZQ6Qvdy6fYHSNo7E0ZWOpGt77ANtDgB7fd3pjcdx1M4bc

[17]Page-Dumroese, D. S. et al., 2015. Water repellency of two forest soils after biochar addition. https://www.fs.fed.us/rm/pubs_journals/2015/rmrs_2015_page_dumroese_d001.pdf

[18]Saarela, T. et al., 2020. Biochar as adsorbent in purification of clear-cut forest runoff water: adsorption rate and adsorption capacity. Biochar. https://doi.org/10.1007/s42773-020-00049-z

[19]Dumroese, R. K. et al., 2011. Pelleted biochar: Chemical and physical properties show potential use as a substrate in container nurseries. https://www.fs.fed.us/rm/pubs_other/rmrs_2011_dumroese_r002.pdf

[20]Dumroese, R. K. et al., 2018. Biochar Can Be a Suitable Replacement for Sphagnum Peat in Nursery Production of Pinus ponderosa Seedlings. https://www.fs.fed.us/rm/pubs_journals/2018/rmrs_2018_dumroese_k002.pdf

[21]Dumroese, R. K. et al., 2020. Biochar Potential To Enhance Forest Resilience, Seedling Quality, and Nursery Efficiency. https://www.fs.fed.us/rm/pubs_journals/2020/rmrs_2020_dumroese_k001.pdf

[22]Matt, C. P. et al., 2018. Biochar effects on the nursery propagation of 4 northern Rocky Mountain native plant species. https://www.fs.fed.us/rm/pubs_journals/2018/rmrs_2018_matt_c001.pdf

Perhaps the greatest forestry-based potential for biochar is in its ability to access emerging carbon market opportunities. If the industry can find a way to monetize the carbon stored in biochar (which is 70-80% carbon), a natural climate solution with negative emission potential,[23,24] revenue generation through the sale of carbon credits can be used to maximize the potential for existing woody biomass and to support projects which improve forest health and mitigate wildfire risk. Despite not yet being accepted into the American Carbon Registry,[25] biochar projects in California have found success in European markets.[26] The International Biochar Initiative continues to refine and support adoption of their methodology and standards[27] for eventual approval and broader adoption.

Given the demonstrated benefits of biochar and the potential opportunit ies to support biochar production or utilize biochar in related forestry industries, the greatest challenge is figuring out the logistics of those integrations.[28]

Connecting Minnesota's forests and mines

Logging and mining have a rich history in Minnesota, and biochar may present a co-benefit opportunity for the industries. Ongoing research is investigating the prospect of producing biochar from woody biomass that could ultimately be used in remediation of mined soils, or in the filtration of leachate from mining operations. Particularly, biochar's innate ability to hold water and build up organic matter in the soil could support revegetation goals on reclaimed sites. A review of what is currently known of this opportunity can be found here: https://www.fs.usda.gov/treesearch/pubs/62095.

[23]Smith, P.,2016. Soil carbon sequestration and biochar as negative emission technologies. https://doi.org/10.1111/gcb.13178

[24]IPCC, 2018. Global warming of 1.5°C. https://www.ipcc.ch/sr15/

[25]American Carbon Registry, n.d. Biochar Projects. https://americancarbonregistry.org/carbon-accounting/standards-methodologies/methodology-for-emissions-reductions-from-biochar-projects

[26] Pacific Biochar, n.d. Carbon Credits. https://pacificbiochar.com/biochar-carbon-credits/

[27]International Biochar Initiative, 2020. Biochar in Carbon Trading Markets. https://biochar-international.org/protocol/

[28] Learn more about how these integrations are happening in several western states through the Forest Utilization Network 2020 Success Stories: https://www.westernforesters.org/sites/default/files/FUN%20Publication%20Revised%20August%2027.pdf

Woody biomass in Minnesota

A report released in 2020 by the Great Plains Institute - Emerging Market Opportunities for Minnesota's Forest Products Industry[29]- indicates a significant reduction in domestic biomass thermal energy production with many facilities going offline in recent years. The lack of markets for residues and the challenge that poses to the growth of the forest products industry in Minnesota is widely recognized, as stated in the report:

> "...stakeholder input makes clear that identifying new markets for wood residues is a critical priority for the state to ensure the continued health of existing forest products industry facilities, especially sawmills. Sawmills are currently facing a challenge as demand for residues from the pulp and paper industry, and biomass electricity production has declined in recent years. As trade-exposed industries competing globally in a commodity market with tight margins, mill operators must maximize revenue from residues and avoid disposal costs to remain viable." (Source: Great Plains Institute - Emerging Market Opportunities for Minnesota's Forest Products Industry)

The decline in markets for wood slash produced by harvest operations and restoration work, along with wood residuals produced at the mills from forest product production, has become a significant challenge for the industry. Although keeping some slash on the forest floor after forest management is customary and necessary for nutrient cycling,[30] contractors have lost the opportunity to capture additional revenue by chipping and transporting material to biomass markets. Some slash is still pile-burned to prepare harvest sites for planting or regeneration and to reduce fuel loading, which produces emissions and can have other impacts on site productivity.

These findings were confirmed through the focus group discussions and interviews with those in the forest product industry who identified the lack of residual markets as a significant limiting factor to the growth of their business. In many of those conversations, forest management contractors and biomass users also felt the infrastructure was still in place to utilize woody biomass and residuals, given a market opportunity for it to "pay itself out of the woods." Biochar could be that opportunity.

Focus Group Perspectives

Biomass management and markets

The focus group discussions highlighted a perception of "a rollercoaster nature of biomass markets in Minnesota" over the past 25 years. It was recognized that "many within the industry have gotten burned over the years" either through investment to tap into markets that were not always there or that quickly dried up. High capital investment into equipment coupled with volatile markets have made many in the industry leery. As one participant explained, "At one time, there was a significant supply of woody biomass pulled from logging operations and taken to fuel energy plants, but those opportunities have all but dried up in the state." However, that does not mean the biomass supply and demand does not still exist. In fact, supplies are growing as various forest disease and pest issues contribute to rising mortality.[31] Many focus group participants also discussed the precarious position we will be in if another significant blowdown event occurs, because the industry is just not capable of handling that significant a volume of material. Furthermore, there are efforts underway to remove buildup of fuel and reduce wildfire risks in some regions of the state, but without a market for the biomass, most of this work has occurred in relatively small areas and landowners and managers bear high treatment costs for this work. Significant volumes of biomass could be made available if stronger markets existed, which would promote improved forest health through increased fuel management. Greater invasive species management could be handled in a similar fashion.

[29]Great Plains Institute, 2020. Emerging Market Opportunities for Minnesota's Forest Products Industry. https://www.betterenergy.org/wp-content/uploads/2020/04/emerging-market-opportunities-for-minnesotas-forest-products-industry-great-plains-institute-april-2020.pdf

[30]Onsite biomass retention rates following harvest are informed by best management practices, including the Site Level Guidelines for Biomass Harvesting developed by the Minnesota Forest Resources Council, https://mn.gov/frc/docs/MFRC_Forest_Mangement_Field_Guides_2014-1_With-Bookmarks.pdf

[31]Minnesota Department of Natural Resources. Forest Health Annual Reports. https://www.dnr.state.mn.us/treecare/forest_health/annualreports.html

Despite many harvesting contracts allowing a biomass utilization option, focus group members reported that biomass is rarely removed anymore as the markets have dried up and that utilization no longer 'pencils out'. Instead, an overwhelming majority of slash is staying in the forest. Land managers and contractors alike stressed that each time material is touched, it complicates the operation and adds costs to the project. Labor is a significant investment, and most are not looking for 'yet another thing to manage'.

Stakeholders in these sessions called for stable, consistent, and secure markets for biomass before they would consider reinvesting in biomass work. They recognized the importance of maximizing benefit from every tree but stressed the important role economics plays in every operation. There is a robust and diverse amount of woody biomass resulting from forest management, and utilization of underutilized, low-value material is welcomed.[32] Biochar production may be a logical fit, but only if that production could bring a financial return to the project.

It is noteworthy that residue management at sawmills and specialty forest product mills is a significant concern that came through clearly during the focus groups. In fact, it was reported that harvests and growth within some forest product industries are already limited by the ability to manage the resulting wood residues. Mills are often managing multiple waste streams for their residuals which takes time and costs money. As markets dry up, shavings, for example, are literally piling up at mills or are taking costly trips to landfills. However, for biochar to be a part of the solution, it must consume a meaningful volume of material to justify the cost and complexities it could present to an operation.

Infrastructure

When presented with a scenario where biochar is a cost-effective solution to process woody biomass in the state, most stakeholders in the focus groups agreed that the infrastructure still exists to handle and transport the biomass as needed. Although some operations have sold off their chippers and trucks, many still exist and the consensus was that "if a money-making opportunity was presented, the industry would take advantage of it." Nonetheless, many of the stakeholders were mindful of how expensive some of these biochar systems can be, and that especially in larger corporate mill operations, that type of investment decision takes time. Adoption can also be challenged by permitting and the seasonality of harvests.

Related to how to build up the infrastructure for a new biomass industry (biochar production), it was repeatedly mentioned how important it was to "centralize equipment" and to "be conscious of matching where the supply and demand was to cut down on transportation costs." Concern was also expressed that centralization could limit potential and that instead a "distributed system of mobile equipment" may be necessary. It was concluded that running the economics of these two pathways was necessary to right-size the model for Minnesota. Finally, it was acknowledged that equipment (chippers, trucks) still exists from previous biomass industries and that they should be leveraged whenever possible.

[32]Focus group members indicated species such as tamarack, balsam and spruce, ash, and some hardwoods are viewed as underutilized and could benefit from additional markets.

Section 2.

Biochar pathways for Minnesota's forests

A variety of pathways for biochar production in Minnesota were explored in this project. Informed by the focus group discussions and interviews, three pathways for biochar integration were identified for Minnesota's forests and are discussed in detail below. They include:

- Pathway 1. Low-tech flame cap kilns leveraging carbon markets to restore forest health
- Pathway 2. Mobilized production units processing slash and residuals for diversified revenue generation
- Pathway 3. Centralized coproduction and colocation leveraging mill residuals

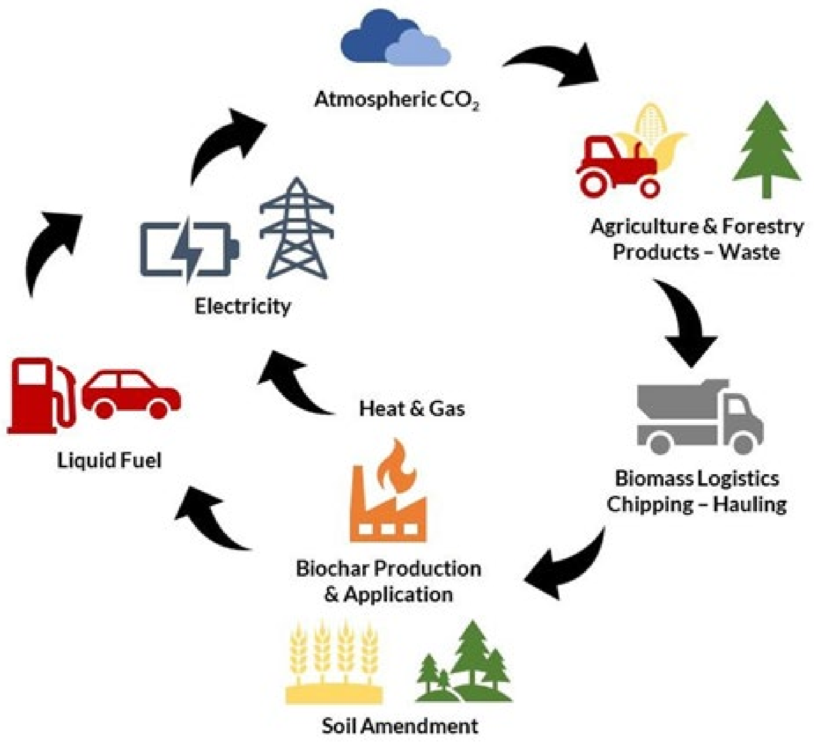
The scale across these applications differs significantly in terms of volume of biomass processed, investment needed for equipment and systems, and the revenue generation potential.[33] Sophisticated equipment is not required to produce biochar; however, to appropriately scale for efficiency, production, and application, systems have been developed to streamline processes to capture the greatest benefit of the feedstock. Although not discussed in great depth here, when assessing these pathways, it is critical to understand the five segments of the biochar supply chain (Figure 1): biomass production, feedstock logistics, conversion, distribution logistics, and end use.[34] It is quite easy to focus on the available biomass, but unless it is paired appropriately with the correct system to meet the end use goals, and supported by the infrastructure to move the product in and out, that biomass supply challenge will continue.

Through our work with stakeholders, it was evident that there was limited interest in biochar production for the purposes of a forest soil amendment, beyond the small-scale restoration focused projects. Land managers and contractors both saw this as an additional, costly step that currently does not show a clear return on investment. Although those circumstances could change, this assessment does not focus on the application of biochar back out into the forest. The following section summarizes the discussion within focus groups around opportunities for biochar production and is followed by a detailed description of each highlighted pathway, which was heavily influenced by those discussions.

[33]It is noteworthy that similar pathways, among others, were identified in the Biomass to Biochar - Maximizing the Carbon Value effort which included input from forty biochar producers, practitioners, scientists, and engineers in the Pacific Northwest. Their work sought to develop a roadmap for necessary research and investment to support a successful biochar industry in their region. A similar effort, built upon this report, could be quite advantageous for the Lake States to take advantage of future funding opportunities (Amonette, J.E. et al., 2021. Biomass to Biochar: Maximizing the Carbon Value. https://csanr.wsu.edu/biomass2biochar/).

[34]Anderson, N.M. et al., 2017. A Supply Chain Approach to Biochar Systems. https://www.fs.fed.us/rm/pubs_journals/2017/rmrs_2017_anderson_n001.pdf

Figure 1. Biochar production and application supply chain (adapted from: Anderson et al. 2017. Chapter 2 in Biochar: A Regional Supply Chain Approach in View of Climate Change Mitigation, Cambridge University Press.)



Focus Group Perspectives

Biomass management and markets

Focus groups participants were encouraged to envision a Minnesota with robust biochar markets utilizing under-valued woody biomass. What would that look like for them? How could we accomplish that? It was particularly interesting to have such diversity of participants from throughout the supply chain within each session which allowed innovation to flow while being aware of each unique perspective that was participating.

Through these conversations, the element that resonated most was little interest by all parts of the supply chain to reapply biochar back onto the forest floor. Landowners and managers, loggers, mill operators, and other stakeholders were consistently lukewarm on the idea of producing biochar and then hauling it to the forest and applying it to soils through mechanized distribution systems. There was insufficient evidence to convince them there was a strong ecological reason to do it (solely for improved soil health), and it certainly became a challenge for most thinking about how it could be done cost effectively. Forest operators and land managers recognized the need to mobilize additional equipment in the field - at minimum chippers, biochar kilns or mobile production units, and equipment to distribute the char, if produced onsite. Additional trucking of the biomass from the site to a biochar facility and then back onto the site would be needed if offsite char production occurred. Participants felt this diminished the ecological rationale for biochar production with the emissions resulting from increased transportation. For these reasons, most of the discussion was focused on how to utilize woody biomass to develop a product that provided revenue generation potential. Through those subsequent discussions, by far, most stakeholders saw the greatest potential in getting that biochar back out to the agricultural industry in the state rather than the forest sector. Some did see opportunities for mobile biochar production in the field (i.e., at the landing site) to replace pile burning, however, so little pile burning is done any more and there was concern that using kilns in the field would significantly slow down operations (time is money!).

Some participants felt that the discussion around potential for low-value woody biomass was "entirely misguided" and that "low value in, meant low value out". In other words, if the emerging biochar industry only focused on utilizing 'waste' material, the value of the resulting biochar would not likely be high enough to support the industry long-term. Those with this perspective felt that roundwood supply should be considered, and that there were plenty of 'undesirables' out there that could provide an ample supply without having to tap into slash and residuals. This type of enterprise would require a higher level of capital investment to ensure the equipment output would match the biochar market it sought to reach (i.e., quality control and product consistency). Furthermore, with this type of equipment cogeneration of byproducts may be possible (biooil, syngas, etc.).

The lone opportunity recognized to have potential to utilize biochar back in the woods was regeneration on sandy pine sites (Jack and Red Pine).[35] Capitalizing on biochar's ability to hold water, biochar could be applied and incorporated with seedlings or distributed during site prep to help build up the organic matter in typically dry, sandy sites. Although ongoing research exists supporting this type of application in other regions of the U.S., additional work is required to determine whether the positive impact is great enough to justify the added expense and to conduct local trials.

Another significant point of discussion was around carbon market opportunities. There was a general sentiment in the focus groups that if there was a way to monetize the value of the carbon in biochar (through storage, sequestration), that may significantly open up the opportunities to support biochar production, even if other markets did not materialize. This market opportunity could also help support greater management of fuels and other forest health issues. Stakeholders hoped that "opportunities may exist to leverage Farm Bill or NRCS programs at the small private landowner scale", or more broadly, "capitalize on motivations from the new federal administration", potentially spurring job creation through the management of this material.

[35] Jack pine (Pinus banksiana) faces a number of management challenges related to successful regeneration, for more information, see: Managing jack pine forests from UMN Extension

Emerging opportunities for biochar

The Natural Resource Conservation Service (NRCS) recently developed a new Conservation Practice Standard (808) – Soil Carbon Amendment, which would provide cost share for "using amendments derived from plant or animal residues to improve the physical, chemical, and biological properties of the soil."

Although this practice standard is still under review, coupled with Conservation Practice Standard (384) – Woody Residue Treatment, it could provide a financial incentive to offset the cost of biochar production and use.

Learn more at: https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/technical/cp/ncps/

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Pathway 1.
Low-tech flame cap kilns leveraging carbon markets to restore forest health

This pathway utilizes flame cap kiln technology[36] that reduces emissions[37] while burning biomass in the field with a low capital investment. This strategy is most effective in applications where contractors are removing woody biomass in the field, for example through invasive species management or fuels reduction projects and would have otherwise 'lopped and scattered' or pile-burned onsite. The biggest challenge to this otherwise low-tech, low-skill operation is funding the additional cost associated with biochar production, including gathering the material, loading, and managing the kiln. This pathway is reliant on accessing additional investment (and labor) that recognizes the benefit to this style of restoration work and/or can tap into emerging forest carbon markets. It is assumed that the biochar produced would not be sold for revenue generation due to the logistical challenges and costs of getting it out of the woods and likely the low volumes (and inconsistency) of char produced.

Flame cap kiln equipment examples:

- **Big box kiln:** [38] Developed by Darren McAvoy from Utah State University Extension, it is a low-tech, low-cost (<$5,000) unit that is portable and can be hauled around on a trailer with a heavy-duty pick-up truck. The design includes air flow control which allows for better flame management. Little technical or mechanical skill is required to work with the big box kiln, but it is recommended to have a mini-excavator or similar equipment available to load the kiln and to dump it. Quenching with water is required to extinguish the fire.
- **Mini/DIY kiln:** [39] Made popular by Wilson Biochar, these small units are portable (can be hauled in the back of a pick-up), easy to manage, and are best deployed at the individual landowner scale due to the smaller volumes of biomass they are intended to handle. Their low cost (<$1,000) makes them attractive to contractors, including use in scenarios where several are needed to process biomass in multiple remote locations.

Application process: After material is quenched (saturated with water to avoid reignition), it can be dumped and scattered onsite, typically by hand or with small-scale machinery, for incorporation into the forest soil. The scale of this type of management effort (i.e., restoration work, fuels management, or invasive species treatment) would typically be much smaller than a traditional harvest operation, making it more feasible to leave the biochar produced onsite.

[36]Hazardous Fuels Reduction Using Flame Cap Biochar Kilns. U.S. Biochar Initiative. https://biochar-us.org/hazardous-fuels-reduction-using-flame-cap-biochar-kilns.

[37]Cornelissen, G.; et al., 2016. Emissions and Char Quality of Flame-Curtain "Kon Tiki" Kilns for Farmer-Scale Charcoal/Biochar Production. https://doi.org/10.1371/journal.pone.0154617.

[38]Utah Biomass Resources Group, 2020. Big Box Biochar. https://ubrg.usu.edu/big-box-biochar/index

[39]Wilson Biochar, LLC. https://wilsonbiochar.com/

Pathway 2.
Mobilized production units processing slash and residuals for diversified revenue generation

This pathway utilizes a mobile unit(s) strategically moved throughout the wood basket to key centralized locations to process slash or other woody biomass produced from forest management activities. The increased investment in this technology results in a more consistent, marketable product, although the feasibility of selling the char will need to be evaluated for each project and is reliant on a maturing and stabilization of the biochar markets. This strategy

can be right sized to larger operations requiring mobility. Puettmann, et al. (2019)[40] explored three mobile systems processing forest slash in a cradle-to-gate life cycle assessment and found that all three systems lowered greenhouse gas emissions, compared to pile burning of the same material. Those benefits increased the closer the production system was to the source feedstock, supporting mobile systems that can be deployed effectively onsite. This is further supported by Coleman, et al. (2010)[41] and McElligott, et al. (2011)[42] that identified multiple benefits to onsite production and application

Mobile production equipment examples:

- **CharBoss (Air Burners, Inc.):**[43] At an estimated equipment cost of $100,000, this air curtain burner processes material quickly and at a higher temperature and features a walking floor that dumps char into a pan with water for immediate quenching to reduce reignition risk (1-10T/hr depending on unit).
- **Carbonator 6050 (Tigercat):**[44] This unit requires larger investment with greater throughput efficiency, reducing debris volume by 90% with an integrated quenching system (20T/hr).

Application process: Quenched material can be applied on site or loaded for transport.

Pathway 3.

Centralized coproduction and colocation leveraging mill residuals

This pathway requires significantly greater investment than the previous two alternatives and would capitalize on the available residues at a mill operation as the primary feedstock. Although there would be an opportunity to process slash hauled in from logging operations, this type of sophisticated equipment is best maximized when fed a consistent material, which allows it to produce a highly consistent product that is much more marketable. In addition to enhanced revenue generation potential in this model through more market-ready biochar, many of the more sophisticated kilns also provide opportunities for coproducts, including bio-oil and syngas, not to mention the heat generated from the operation that could be fed back into the mill. Campbell, et al. (2018) assessed various biomass to bioenergy alternatives and found that integration of biochar production, and specifically dialing in equipment for that goal, would provide financial benefits (in their case of utilizing beetle-killed trees in the Western U.S.).

Centralized equipment example:

- **Rotary kiln (e.g. FEECO International, Inc.):** Offering the ability to control multiple variables (temperature, air flow, etc.), with the ability to produce byproducts (bio-oil, syngas, etc.), this unit has a much more significant investment, but has the capacity to process a consistent product at higher volumes, typically located at a centralized facility that requires biomass transport and delivery.

Application process: The premise for this pathway is not to apply the biochar produced back into the forest, although that option does exist. Instead, it is more likely the biochar product would be packaged for sale. Larger-scale biochar applications in the forest can benefit from more sophisticated spreaders, one of which was designed by the U.S. Forest Service, and is discussed below.

Additional biochar production equipment

The equipment highlighted above is not meant to be an exhaustive list of equipment suitable for pyrolysis and thus biochar production, but highlights many of the options that are readily available and currently deployed. There are additional research and development opportunities to continue to refine systems for biochar production, in addition to retrofitting opportunities that leverage existing equipment.[46]

[40]Puettmann, et al., 2020. Life cycle assessment of biochar produced from forest residues using portable systems. https://doi.org/10.1016/j.jclepro.2019.119564.

[41]Coleman, M. et al., 2010. Can portable pyrolysis units make biomass utilization affordable while using bio-char to enhance soil productivity and sequester carbon? https://www.fs.usda.gov/treesearch/pubs/37322

[42]McElligott, K. et al., 2011. Bioenergy production systems and biochar application in forests: potential for renewable energy, soil enhancement, and carbon sequestration. https://www.fs.usda.gov/treesearch/pubs/39454

[43]United States Forest Service, 2020. Introducing CharBoss: New mobile biochar production machine.

https://www.fs.usda.gov/inside-fs/delivering-mission/apply/introducing-charboss-new-mobile-biochar-production-machine

[44]Tiger Cat, 2020. 6050 Carbonater. https://www.tigercat.com/product/6050-carbonator/

[45]Campbell, R. M., 2018. Technoeconomic and policy drivers of project performance for bioenergy alternatives using biomass from beetle-killed trees. https://www.mdpi.com/1996-1073/11/2/293/htm

[46]You can learn more about the equipment above, along with other equipment systems here: https://docs.google.com/document/d/1o7dwvxrk90RAY107A9CaRoh7ouUcjkp_vnpplkTo_h0/edit. Several equipment options are also summarized in this publication: https://www.fs.fed.us/rm/pubs_journals/2017/rmrs_2017_page_dumroese_d001.pdf

Biochar application equipment

As with production systems, the type of biochar application system is dependent on the scale of the project and available equipment. It is also important to note that the volume and weight of material fed into the system will be greatly decreased (potentially by 90%) as a finished biochar product. Furthermore, depending on the type of feedstock used and pyrolysis conditions, the resulting material may vary widely, greatly impacting the application needs, primarily due to the sizing and consistency of that product. Finally, incorporation into the soil is recommended to minimize wind and rain erosion risk. In all systems, the resulting char needs to be quenched and cooled before application to prevent reignition and fire hazards. Quenching will also assist in mitigating dust associated with biochar. When applying, be mindful of application rates and the need to 'charge'[47] the material based on the goals of the product use.

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In systems utilizing pile burning or small to mid-scale kilns to produce biochar, it is likely hand applying or raking is appropriate. Hand tools, buckets, wheel barrels, etc. can be used to distribute biochar across the site. In larger scale operations, specifically looking to reapply biochar to forests, there is the potential to retrofit a lime or manure spreader, depending on the biochar product and site conditions and operability.[48] The U.S. Forest Service commissioned the Missoula Technology and Development Center in Missoula, MT to design a commercial-scale spreader[49] specifically for biochar applications[50] by retrofitting a salt/sand spreader mounted on forest harvest equipment (e.g., forwarder) and that works with bulk or pelletized biochar (as seen above).

Reimagining slash piles

Slash piles, composed of waste woody biomass material from forest operations, are common practice in Minnesota's forests. Traditionally, these piles are burned in times of low-fire risk to mitigate their potential as a fuel in the future, and to clean-up the operation site making way for revegetation. The impact of those fires, however, can be damaging to the soil below due to the intensity and duration of the fire and releases emissions. An alternative strategy to traditional pile burning is to build the piles in a way that encourages air flow and soil protection. This methodology will result in biochar production that can then be incorporated into the soil on-site.

Best practices for slash pile biochar production:

- Create a base layer of large woody debris (logs, etc.) to elevate the slash pile of the ground—depending on scale, can be done by hand, bulldozer, grappler, or log loader.
- Ignite pile from top where smaller debris is located encouraging a top to bottom burn of the pile.
- Consider quenching (watering) the pile once biochar is achieved to stop the fire from turning the residue into ash.

[47]Biochar has the natural tendency to absorb nutrients, potentially tying those nutrients up for soil and plant use. It is recommended to amend biochar with compost, in a process called charging. You can learn more about this practice here: https://biochar-us.org/learning-topic/charging-biochar.

Section 3.

Economic Feasibility

A significant challenge exists in determining the economic feasibility of these biochar pathways for Minnesota's forests given the immense variability within these systems. Thinking back on the supply chain of biochar; recognizing unique factors within the biomass production, feedstock logistics, conversion, distribution logistics, and end use, it is difficult to build an enterprise budget or determine feasibility for any scenario that has broad applicability. As Keske et al. (2019) states, "In general, biochar field studies show site-specific sensitivity, which creates general uncertainty throughout the literature about the transferability of results." Furthermore, this challenge is exasperated by stakeholder perceptions of a volatile biochar market lacking price stability and a relatively shallow long-term understanding of the benefits of biochar when matched with comparable products (other soil amendments, filtration mediums, etc.).

The economic hurdles faced by the biochar industry were outlined by Dan McCollum and Nate Anderson from the U.S. Forest Service Rocky Mountain Research Station in their presentation, The Economics of Biochar,[53] a part of the U.S. Forest Service Biochar Webinar Series (2020). They reiterated the need to examine opportunities individually and confirmed that broadscale conclusions are difficult to make. They identified three major challenges that face the biochar industry:

1. **High cost of production.** The costs of biochar production are often exceeding achievable market price, which could be due to inefficient process, high-cost feedstock, or too much supply chain variability.
2. **Insufficient market price.** The market price of biochar often does not include all costs and benefits associated with biochar, which could mean external factors are not truly based in biochar prices or substitutes which could result in under-valued biochar typically due to a lack of information on the product's true value and benefits. This relates to the need to understand the value of the public goods and benefits associated with biochar.
3. **Business and investment uncertainty.** Low demand, spotty markets, and market volatility are resulting in lack of cost competitiveness, products not meeting market needs, or insufficient production capacity.

It was recognized that there are likely external factors contributing to an unfair market situation for biochar, exacerbated by disinformation and a lagging policy framework to support growth.

[48]Major, J., 2010. Guidelines on Practical Aspects of Biochar Application to Field Soil in Various Soil Management Systems. https://www.biochar-international.org/wp-content/uploads/2018/04/IBI_Biochar_Application.pdf

[49]Page-Dumroese, D. S. et al., 2016. Development and use of a commercial-scale biochar spreader. (https://www.fs.fed.us/rm/pubs/rmrs_gtr354.pdf)

[50]United States Forest Service, 2016. Development of a Biochar Spreader. https://www.fs.usda.gov/rmrs/science-spotlights/development-forest-biochar-spreader

[51] Keske et al. (2019) Economic feasibility of biochar and agriculture coproduction from Canadian black spruce forest. https://doi.org/10.1002/fes3.188.

[52]Although their study explored the economic feasibility of biochar production from black spruce in Canadian forests for potato and beet production, a study that certainly has applicability to our Minnesota context, we cannot simply assume those results would apply locally.

[53] McCollum, D. and Anderson, N. 2020. The Economics of Biochar. U.S. Forest Service Biochar Webinar Series. http://forestrywebinars.net/webinars/economics-of-biochar/?searchterm=biochar.

In response to these challenges, the following solutions were presented by McCollum and Anderson:

1. **Feedstock Optimization.** Gains can be made in reducing costs in both feedstock procurement and in production. It is also vital to work at an appropriate scale that matches the feedstock, process, and market. De-risk investment when possible through external support.
2. **Value Creation.** Increase the value of your product by realizing full market potential which may mean tapping into emerging markets, or opportunities where non-market value could be realized (carbon sequestration, mitigating fire risk). Co-benefits and products should also be explored.
3. **Market Development.** Expand markets by stealing market share from other products or finding new uses. Potential exists within remediation, restoration, agricultural, and material development industries. Education is necessary for the full benefit of biochar to be captured and understood.

To fully realize these solutions, McCollum and Anderson recognized a collaborative approach involving industry to serve as an economic driver and entrepreneur of innovation; universities to lead in education and outreach; and government to support research and market development, potentially be a source of biomass feedstocks and consumer of biochar, and help build out incentives and policy to support the industry.

Homagain et al. (2016)[54] sought to assess some of the non-market values and co-production benefits through their life cycle cost and economic assessment of biochar-based bioenergy production and biochar land application in Northwestern Ontario, Canada. They assessed four scenarios addressing feedstock availability and land application. Their work concluded that a "Biochar-based bioenergy system is economically viable when life cycle costs and environmental assumptions are accounted for." However, the study recognized the limitations in the scope of analysis and identified opportunities to scale-up the study for further investigation. This points to opportunities for biochar integration, also supported in the following research findings:

- Importance of aligning your supply chain to your landscape: "Biochar offers the greatest opportunity where dryland food crops, limited water availability, existing energy transmission infrastructure, and high-fire hazard forests share the same landscape." Study conducted in Oregon assessing feasibility of forest to farm biochar operation. [55]
- Additional price support may be needed to enhance profitability, and price uncertainty makes economic assessment difficult: "Biochar-only production offers a potentially profitable venture. Biofuel-biochar co-production requires RINs to achieve financial success." [56]
- Research often spurs need for further investigation and innovation to maximize benefit of systems: "Given the promising results for the Biofuel Scenario, further research into the production process and business landscape for liquid biofuel and biochar production is warranted. In particular, given the strong influence of biochar price and weak influence of biofuel price on NPV outcomes, and the potential for price volatility in the future as markets for biochar mature, the impact of market conditions on the decision space for producers of biofuel and biochar offers an intriguing topic for more detailed analysis." AND "Given the much stronger effect of biochar price than capital costs on NPV for the Biofuel Scenario, additional processing of biochar to create product differentiation that could allow biochar to be sold at a premium price would provide financial benefits. Because the NPV of biofuel and biochar production is much more sensitive to the conversion rate of biochar than the conversion rate of biofuel, optimizing the system to maximize biochar production by operating at lower temperatures, at the expense of lower biofuel production, may be a viable tradeoff depending on market conditions." [57]

[54]Homagain et al., 2016. Life cycle cost and economic assessment of biochar-based bioenergy production and biochar land application in Northwestern Ontario, Canada. https://forestecosyst.springeropen.com/articles/10.1186/s40663-016-0081-8

[55]Sessions, J. et al.,2019. Can biochar link forest restoration with commercial agriculture? https://www.forestry.oregonstate.edu/sites/default/files/BiocharForest-to-Farm2019.pdf

[56]Campbell, R. M., 2018. Financial viability of biofuel and biochar production from forest biomass in the face of market price volatility and uncertainty.

https://www.sciencedirect.com/science/article/abs/pii/S0306261918312558

[57]Campbell, R. M., 2018. Technoeconomic and policy drivers of project performance for bioenergy alternatives using biomass from beetle-killed trees. https://www.mdpi.com/1996-1073/11/2/293/htm

It is important to note that there are specific aspects of Minnesota's forests[58] and our associated forest products industry to consider when assessing the economic feasibility of these potential ventures. Compared to some other regions, Minnesota has a shorter growing season and therefore more slow-growing forests, which impacts productivity and competitiveness. Also, local wood markets in the Lake States tend to be well developed for pulpwood with generally less reliable demand for other products that a landowner might wish to manage for, which impacts our ability to conduct management and makes some treatments cost prohibitive. Adding the complexity of biochar production into these systems may provide an economic benefit, but the cost associated with that addition must be offset by revenue generation, especially in situations where the profit margins of our forestry operations are already tight. Any cost vs. benefit considerations should also include a discussion of risk; however, this level of assessment was beyond the scope of this project.

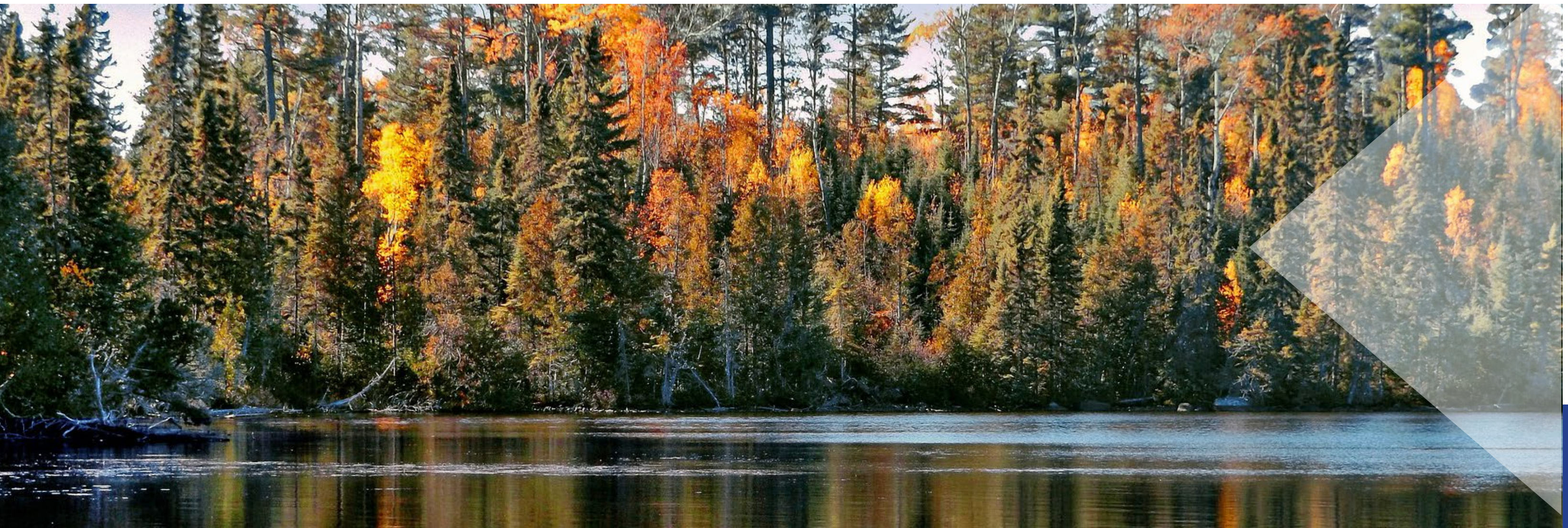
Focus Group Perspectives

Economics

Generally, participants in the focus groups were skeptical of whether biochar markets truly existed and whether their potential could fund a new industry in Minnesota. Thorough return on investment studies were requested for each potential utilization and production strategy to better understand the financials of the opportunity. Development of enterprise budgets that would outline feedstocks, systems, and markets would be extremely helpful in determining potential and supporting discussions on future capital investments. Again, it was stressed that perspectives may need to change in terms of where opportunity exists, and that it may require a steady roundwood supply to fuel a profitable biochar industry. Nonetheless, it was reiterated that "if the demand is there, the supply side will work itself out" and that "if there is money to be made, the industry will adapt."

Despite a healthy amount of skepticism, the focus group conclusions demonstrated that the prospect of a new market to utilize woody biomass excited most participants. In fact, it was eye-opening to hear how many of them had already researched biochar and had looked into purchasing equipment or had explored markets. Although most did not see a pathway for biochar back into the forest, many were interested in what potential may exist around carbon market opportunities that could support a mobile and dispersed effort to improve forest health across the landscape. The wisdom gained from this experience was invaluable and greatly informed the recommendations in this report. Much is yet to be learned, however, with regards to investments needed and markets available to make the right judgement calls on what biochar models are best suited for Minnesota's forests.

[58] Additional context for this discussion can be found in the report published by the Minnesota Forest Resources Council (2014), Report on the Competitiveness of Minnesota's Primary Forest Products Industry: https://mn.gov/frc/documents/council/Forest_Industry_Competitiveness_Report.pdf



Section 4.

Recommendations

There is no denying opportunities exist to leverage existing woody biomass sources in Minnesota to fuel a budding biochar industry, but significant unknowns in market potential limit the capital investment necessary to launch production. Three potential pathways for biomass production in Minnesota were explored in this project, informed by knowledge gleaned from literature, interviews, and stakeholder focus groups. Through these explorations the investigation found that these paths are not entirely clear, and barriers exist to successful execution.

Main findings from focus groups

- Infrastructure exists to utilize woody biomass and residuals, given a market opportunity for it to "pay itself out of the woods." Biochar could be that opportunity.
- There was limited interest in biochar production for the purposes of a forest soil amendment.
    - Insufficient evidence to support a strong ecological reason to amend forest soil with biochar (solely for improved soil health)
    - Many challenges exist for cost effectively using the biochar in forests.
    - Additional trucking of the biomass from the forest to a biochar production facility and then back onto the site would be needed if offsite char production occurred.
    - The lone opportunity recognized to have potential to utilize biochar back in the woods was regeneration on sandy pine sites (Jack and Red Pine)
- There are plenty of 'undesirables' (forest inventory) out there that could provide an ample supply of biomass without having to tap into slash for biochar production
    - Concern exists around slash utilization – does a low value feedstock result in a low-value biochar product?
- Skepticism exists on of whether biochar markets truly exist and whether their potential could fund a new industry in Minnesota.
- If there was a way to monetize the value of the carbon in biochar (through storage, sequestration), that may significantly open up the opportunities to support biochar production; including mobile efforts to improve forest health across the landscape.

Recommendations for overcoming the barriers associated with forest-based biochar applications include:

1. Subsidizing the cost of production through carbon credits, ecosystem service markets, conservation practices/NRCS incentives, etc. may provide the financial support needed to make the capital investments for any of the three pathways and bring stability to a rather volatile market.
2. By streamlining mobile equipment processes (kiln and applicator), greater opportunity may exist to utilize biochar back onto forestland, but currently, equipment options are limited and costly at the scale needed to maintain efficient, mobile operations.
3. An increased understanding of biochar benefits to forest soil is necessary to fully realize a circular biochar industry in Minnesota's forests. Without an established and proven return on investment, capital investment is extremely difficult.

These barriers highlight the need for additional biochar research. A collaborative approach involving public and private partnerships is necessary to ensure the right questions are being asked yielding applied results that are logistically feasible in the Minnesota context. Amonette et al. (2021)[59] recently published, “Integrated biochar research: A roadmap” in the Journal of Soil and Water Conservation, which outlines a robust strategy that mirrors many of the needs present locally and can indeed serve as a roadmap for future research efforts.

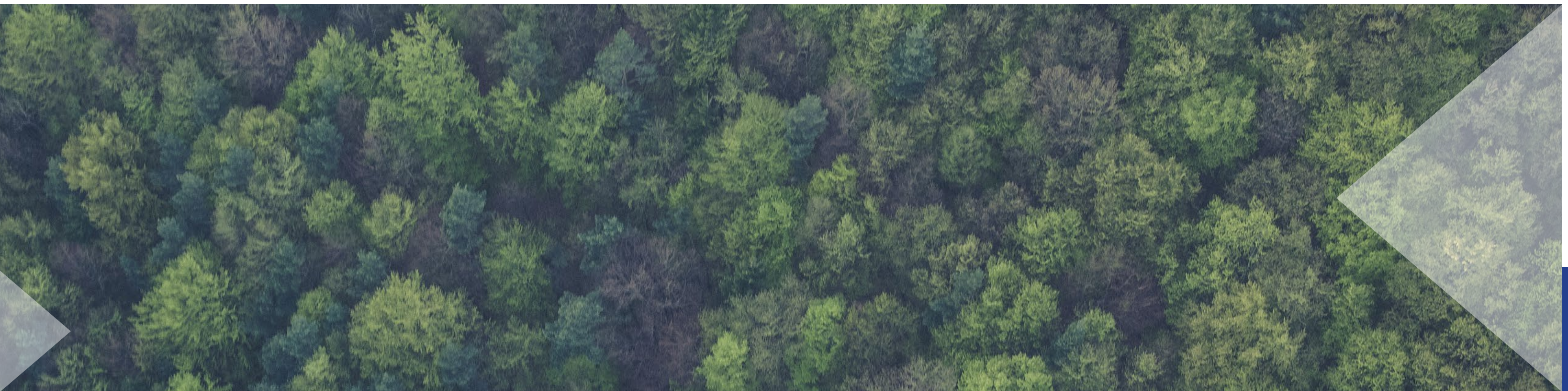
Specific research needs highlighted through this work include:

- Need for understanding on long-term biochar amendment impacts to forest soils (trials, monitoring sites).
- Replication of nursery research conducted in western states within Upper Midwest systems, specifically focusing on Jack Pine revegetation where the opportunity may be greatest to leverage biochar benefits.
- Need for understanding on benefits of charging vs not charging biochar and impacts on forest site applications.
- Run characterization analyses of different biochars created from various Minnesota woody biomass feedstocks through varying biochar production processes - identify market opportunities for various outputs.
- Develop enterprise budgets and assess return on investment for various biochar production systems and feedstocks, focusing on the three pathways presented in this report.

This investigation comes at a time when Minnesota is experiencing shrinking woody biomass utilization pathways and markets, coupled with increased forest pest and disease threats creating forest health issues that exacerbate woody biomass utilization challenges. Land managers and the forest products industry within Minnesota, are poised to lead development of solutions that promote forest health, support economic development, and provide solutions to climate challenges through the production and utilization of biochar. However, that work must be informed by relevant research and investment to prescribe and right-size the solutions. Furthermore, it is critical that when pairing the available biomass supply to meet market demand, a supply chain approach is deployed to ensure sustainability of the benefits sought by these systems are realized. It is critical to understand the five segments of the biochar supply chain: biomass production, feedstock logistics, conversion, distribution logistics, and end use. It is quite easy to focus on the available biomass, but unless it is paired appropriately with the correct system to meet the end use goals and supported by the infrastructure to move the product in and out, that biomass supply challenge will continue.

Exponential interest in biochar throughout the world impresses the importance of the timeliness of this work. Despite the unknowns and volatility in this emerging industry, if the Minnesota forest industry wants to become a leader in biochar production and utilization, investment will be necessary very soon to broaden understanding and to tackle the barriers that impede growth.

[59] Amonette, James E. et al. 2001. Integrated biochar research: A roadmap. Journal of Soil and Water Conservation. Jan 2021, 76 (1) 24A-29A; DOI: 10.2489/jswc.2021.1115A. https://www.jswconline.org/content/76/1/24A



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Appendix A.

Additional Resources

Dovetail Partners' collection of biochar reports:

- Biochar's Role in Climate Mitigation: https://www.dovetailinc.org/portfoliodetail.php?id=5f3c24debc853
- Survey and Analysis of the U.S. Biochar Industry: https://www.dovetailinc.org/portfoliodetail.p?id=5f3c24debc853
- Biochar as an Innovative Wood Product: A Look at Barriers to Realization of its Full Potential: https://www.dovetailinc.org/portfoliodetail.php?id=5e2622ce74378
- Biochar 101: An Introduction to an Ancient Product Offering Modern Opportunities: https://www.dovetailinc.org/ portfoliodetail.php?id=5e28c20e735a8

Forestry and Natural Resources Webinar Portal (keyword: biochar): http://forestrywebinars.net/search?SearchableText=biochar

U.S. Biochar Initiative, U.S. Biochar Week YouTube playlist: https://www.youtube.com/playlist?list=PL1S3D7L3NZpWDcLbCqstsNKe0-0dWPkcx

International Biochar Initiative: https://biochar-international.org/

Recent Biochar Research Publication Summary, U.S. Forest Service: https://docs.google.com/document/d/1E4SLBPNNt3Beh3eH7Sh2tNpGVlJAKZdJ/edit#heading=h.gjdgxs

Appendix B.

Focus group methodology

Focus group sessions were held remotely (via Zoom) due to limitations on in-person events through the COVID-19 pandemic. A list of 50+ potential stakeholders was generated with input and recommendations from the project partners, and invitations were sent to individuals to register for a session. Each session (5 total) was approximately 90 minutes and were held in December 2020-January 2021. Focus group make-up was random, based on availability, which offered a diverse co-mingling of expertise and interest. Some one-on-one interviews were conducted when a stakeholder had interest in participating but was unable to make one of the scheduled focus groups. In total, 30 individuals participated representing forest management agencies, logging contractors, scientists/researchers, consultants, and land managers (Figure B.1).

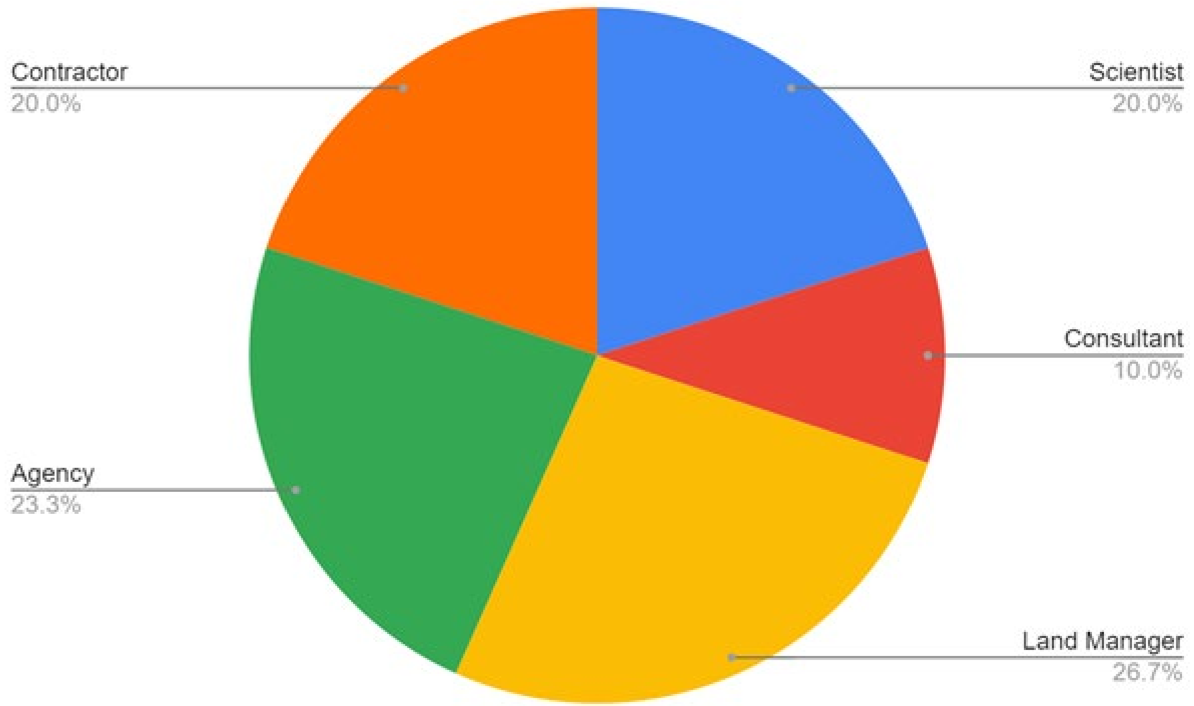

Figure B.1. Focus group participant affiliations (n=30).

Participating scientists consisted of university and agency professionals from within Minnesota and the U.S. Consultants all focused primarily on biochar. Land managers consisted of those managing county lands (n=3), tribal lands (n=1) and private industrial forestland (n=4). Agency professionals included MN DNR and SWCD participants. Contractors all actively worked in the woods at various scales and specialty and/or within the timber products industry.

Prior to each focus group, the following resources were shared so that attendees could familiarize themselves with biochar and the project.

- Project overview flyer: https://drive.google.com/file/d/1Lr0im-KPysj-V82usuxmGdcrnePES1mw/view?usp=sharing
- Production and application system fact sheet: https://drive.google.com/file/d/1FL9qty8_7dRaq4848dudEkjo7qi2CYAO/view?usp=sharing

During the focus group sessions, a brief presentation was shared to explore what opportunities exist with biochar, focusing on production systems, application methods, and market opportunities. Both on-site and centralized systems were discussed. The following two videos were also viewed so that participants could get a better understanding of how the equipment and systems work.

- https://youtu.be/Ro5wgtoXUUs
- https://vimeo.com/469838020/37de5454a7 (viewed 5:32-6:21 & 6:42)

Below is an outline of the questions asked during each focus group session, and in the case of some of the interactions, one-on-one interviews. Although each session followed this general line of inquiry, when appropriate, conversation took us to other topics, and we remained flexible to allow for free-flowing thought and discussion.

General focus group questions

1. 1Begin with introductions around the room - have participants share how their operation and/or program engages with forest management
2. How are you currently handling (how are your contracts currently addressing) slash/woody biomass on jobs/logging sites, and what challenges/bottlenecks exist?
    - Is there significant seasonal variance?
    - Is there significant species variance?
    - Is there significant geographical variance?
3. Do you feel biochar production and/or application can be slotted into your existing forest operations (contracts)?
    - Would you want them to be?
    - What would be your preferred systems (from those presented)
4. Is there willingness to invest in additional equipment to meet these needs?
    - If so, how much?
5. What limitations do you foresee?
6. Are the potential biochar markets attractive opportunities? Alternatively, can we justify biochar production without markets, given other benefits (minimize slash burning, fuels reduction benefits, carbon markets, etc.)?
7. A perfect system certainly does not exist yet. As a land manager/timber professional, do you have thoughts on how biochar production/application could be integrated into timber operations (equipment mix, timing of application, etc.)? Please be creative.

Additional, specific questions used when appropriate based on participants

1. Land managers – Describe your timber program (management strategies, sales, scale, markets, etc.)
2. Operators – Describe your business (types of jobs you take on, scale of jobs, employees, equipment, etc.)
3. Scientists
    - Provide some context for your background working with biochar
    - What do you perceive to be some of the greatest opportunities with biochar within a forestry application?
    - What do you perceive to be some of the greatest challenges with biochar within a forestry application?
    - How localized/regionalized are those opportunities and challenges?
    - How do we 'sell' biochar?
    - Do you feel there is a future in biochar, specific to forestry applications?
    - What inspires you to continue working with biochar, despite the slow industry start?
    - Can you share 3-4 publications you feel need to be included in a comprehensive literature review of biochar in forestry applications?

Each focus group session had a moderator and note-taker, and in the case when the session only had 2-3 participants, one person handled both tasks. After all of the focus groups and additional interviews were concluded, the notes were summarized into one document and were then sorted based on general theme – biomass management and markets, infrastructure, opportunities, economics, other. Each of those themes became the basis for the 'focus group perspectives' sections in the above report. Greater emphasis was placed and reported on ideas that came up frequently throughout the discussions.

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