Forestry and Agriculture Circular Economy Research

Feasibility Assessment and Business Case Development

FORESIGHT

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Acknowledgements

With gratitude and respect, we acknowledge that the lands on which Foresight operates are the traditional, ancestral, and unceded territories of the First Nations, Inuit, and Métis peoples. This project centred on the Creston Valley, located on the current, traditional, unceded ʔamakʔis of the yaqan nuʔkiy (Lower Kootenay Band) of the Ktunaxa Nation. We honour their past, present and future stewardship of these lands and waters.

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About Foresight

Foresight Canada helps the world do more with less, sustainably. As Canada's largest cleantech innovation and adoption accelerator, we de-risk and simplify public and private sector adoption of the world's best clean technologies to improve productivity, profitability, and economic competitiveness, all while addressing urgent climate challenges.

About Wildsight and Creston Community Forest

Wildsight's vision is to inspire a shared community desire to protect our natural world for future generations. Wildsight works locally, regionally and globally to protect biodiversity and encourage sustainable communities in Canada's Columbia and Rocky Mountain regions. Wildsight's Youth Climate Corps, a program that provides training and workplace experience for young people in climate action, was involved in this project. Nestled between the Purcell and Selkirk Mountains, Creston Community Forest is a not-for-profit forest corporation. Creston Community Forest's focus is forest management, education, recreation and community resiliency for future generations.

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Table of Contents

Glossary

Term	Definition
Air Curtain Burner (ACBs)	A technology or device designed to burn wood waste in a controlled manner to minimize emissions and particulate matter. Some ACBs can also produce biochar.
Adsorb	Where a solid holds molecules (of a gas or liquid or solute) as a thin film on the outside surface or on internal surfaces within the material.
Biochar	A carbon-rich, charcoal-like, solid product created by heating biomass in a controlled environment by pyrolysis.
Biochar Kiln	A device or thermally insulated container used to produce biochar. Traditional kiln technology has been used to produce charcoal since ancient times.
Biomass	Organic matter that comes from plants and animals. In this report biomass generally refers to woody debris as a result of forestry operations.
Carbonization	A specific type of pyrolysis process where the goal is to maximize the carbon solid product and carbon-rich residue.
Compound Annual Growth Rate (CAGR)	The average rate of growth experienced by an investment over a multi-year period.
Ecosystem Services	The various benefits that humans derive from ecosystems, such as provisioning services, regulating services, cultural and supporting services. [1]
Flame-cap Kiln	A type of portable, metal-enclosed kiln used for creating biochar. Biomass is burned in a controlled, limited-oxygen environment that prevents excessive smoke and complete combustion.
Pyrolysis	A process of heating organic materials (e.g., woody biomass) in the absence of oxygen to yield a series of bioproducts, biochar, bio-oil, and syngas.
Pyrolyzer	A general term for a technology that facilitates pyrolysis to produce charcoal or biochar.
Mobile Pyrolyzer	A portable pyrolysis system.
Wildland Urban Interface (WIU)	The area where human development meets or mixes with wildland vegetation.

Executive Summary

Foresight is working with Creston Community Forest and Wildsight to undertake feasibility assessment and business case development to identify opportunities for using wood biomass, namely by producing biochar, with a focus on agricultural applications.

As the effects of climate change increase, wildfire mitigation remains a key regional priority; however, the financial cost of this work is significant, and there are avoidable environmental impacts. In current wildfire mitigation processes, accumulated fuels and woody debris are often burned, contributing to more greenhouse gases (GHG) and air quality impacts. Although these emissions are significantly less than those created from a large, uncontrolled wildfire in the area, there are alternative solutions that can better utilize forest fibre and reduce GHG emissions from wildfire risk reduction work. This research investigates viable methods and end products that could help offset the financial cost of the work, namely: biochar, woodchips, and compost, focusing predominantly on biochar as a soil amendment either in the agricultural sector or the forestry sector.

Biochar is produced by heating biomass at high temperatures in a low-oxygen environment in a process called pyrolysis. It is a charcoal-like substance that offers a wide range of potential benefits and ecosystem services, including carbon sequestration, improved soil health and structure (through enhanced water retention, nutrient availability, and microbial activity), soil erosion control, bioremediation, and water quality improvement. The generation of end-products that could contribute to offsetting some financial costs associated with wildfire mitigation work is beneficial to Creston Community Forest and could have wider benefits for industry partners in the region facing similar challenges.

The assessment evaluates the current use of mobile pyrolyzers in a forestry context and includes consideration of simpler kiln technologies and newer technology options. The report outlines necessary adaptations and considerations in the use of pyrolysis technologies, including access and land availability, biochar production rates, labour inputs, air quality permitting, feedstock preprocessing requirements, and community considerations and benefits.

Several pathways exist for using biochar, including selling it to local farms and landowners as a soil amendment or combining it with compost. Alternative and less widely used applications for biochar include material enhancement in construction, supporting the remediation of abandoned mines, and other industrial applications.

Biochar can also be used in situ in forests, with potential benefits including supporting the reforestation of roads and logged areas, encouraging native plant species to grow, and improving water quality. In the future, Creston Community Forest and Wildsight can also consider obtaining and selling carbon credits, which can further support the financial viability of investing in pyrolysis technologies.

Although there are various market opportunities for biochar within the region, there are barriers to its use on a commercial scale and as a viable saleable product —it is a relatively new product, and the market is

not fully developed. In particular, there are varying results in terms of biochar benefits as a soil amendment depending on its quality and the nature of the end-use application.

Despite these challenges, there are exciting opportunities for Creston Community Forest and similar entities across British Columbia (BC) to pursue biochar production (and/or other products) from underutilized wood biomass. There is a range of biochar production technology options at varying capital costs. While existing regional demand for woodchips could offer an interim solution, further research and financial analysis, alongside a small-scale pilot project with robust data collection, are needed to strengthen the business case and clearly communicate the benefits of biochar production.

Introduction

Located in the Kootenay region of southeastern BC, Creston Community Forest encompasses over 21,000 hectares of land near the town of Creston, between the Purcell and Selkirk Mountains. Creston Community Forest works to maintain healthy forests that have social, ecological, and economic benefits to the local community. The forest and its stewards play an important role within the region by maintaining hiking trails, managing five community watersheds, and working to minimize fire risks across the land and along recreation trails. As part of forestry operations and wildfire risk reduction activities, Creston Community Forest is responsible for managing accumulated woody debris and is looking to improve fibre utilization by identifying circular and more sustainable uses.

Biochar is a form of charcoal that is produced through the process of pyrolysis, in which biomass such as wood debris, woodchips, or agricultural wastes are heated at high temperatures with a limited oxygen supply. This produces a solid material with a high carbon content, which can be used to store carbon for long periods of time or as a soil amendment. Research into biochar demonstrates that in specific applications, biochar can have multiple benefits, including carbon sequestration, improved soil structure, and improved nutrient and water retention in soils. However, demonstrating and quantifying biochar's benefits is difficult because of the diverse characteristics of biochar, its production process, the soil it is used on, and other influencing factors.

In addition to managing wood biomass from forestry operations, wildfire mitigation and risk management is a core function for Creston Community Forest. Preventative measures such as vegetation management can significantly reduce the risk of wildfire damage to homes and communities, and are becoming increasingly important with the effects of climate change. Severe wildfires, which lack restorative benefits and damage ecosystems, can be mitigated through vegetation management. However, this work is expensive (around $10,000 per hectare), highlighting the need for end-use products or revenue streams to offset costs and generate further benefits. The financial cost and GHG emissions associated with wildfire risk reduction activities is a challenge across the forestry sector, particularly with traditional pile burning. Biochar production technologies could support Wildsight and Creston Community Forest and other partners in the region to offset these costs and drive down carbon emissions.

This report summarizes the outcomes of the feasibility study and business case development, with the goal of identifying potential opportunities for using wood biomass for agricultural applications, either in the form of biochar or wood chips. The research evaluates the current use of mobile pyrolyzers in a forestry context and considers the necessary adaptations and economic considerations for implementing a biochar production system within Creston Community Forest's operations. The assessment highlights potential applications and markets for biochar and identifies potential revenue streams, including the sale of biochar for agricultural applications, the sale of biochar mixed with compost, other biochar application opportunities outside of agriculture and carbon credit production. This work will help Creston Community Forest and Wildsight pursue circular economy solutions in the region and develop a stronger business case for a potential pilot project.

As part of the research, a comprehensive literature review was undertaken and supplemented by 11 interviews with key industry partners and specialists in the biochar and forestry sectors. Additionally, Wildsight conducted 6 interviews with agricultural industry partners and 11 interviews with local farmers. This data has been incorporated into the research anonymously.

Location and Background

The Kootenays and Local Area

Creston Community Forest is located in the Kootenay region of southeast BC, featuring high mountain slopes and wide, fertile valleys. Agriculture and farming play a large role in the Kootenays. The region's goods-producing sector accounts for 31% of its workforce, dominated by beef cattle ranching, hay farming, and small-scale growing of fruits and vegetables. [2]

The region's large size encompasses diverse climatic zones, all experiencing the impacts of climate change. Climate projections show there is likely to be an increase in drier summer conditions, more frequent and intense wildfires, and increased rainfall in spring and fall, along with drier winters and a reduced snowpack. The Creston Valley is already experiencing the effects of a changing climate. The Pacific Climate Impacts Consortium anticipates an annual increase in average temperatures of between 1.9°C to 4.4°C by 2050. Additionally, they project a 12% increase in average spring precipitation and a 12% decrease in average summer precipitation by 2050. [3]

As the region experiences lower than normal precipitation in summer months and decreased snowpack in the winter, supply watersheds in the area are expected to experience decreased water supply. Ensuring stability in the agricultural sector is important for the Kootenays in terms of economic growth and community development. [4] Agricultural areas that rely primarily on surface water for crops and livestock may be impacted by a decreased water supply. As such, sustainable water management is a growing priority area for producers to maintain productivity and allow water sources to recharge for future use. For 3 of the last 5 years, the region faced moderate to severe drought conditions (levels 3-5) in the summer and/or fall. Adaptation and sustainable water management practices to conserve available and remaining water supplies are key. [4]

In addition, climate variability and extreme weather events increase the importance of appropriate soil management practices for agricultural resilience. Soil properties that are key to sustaining crop production include porosity for air circulation and water infiltration, and retention. Organic matter also supports biological and chemical processes that convert nutrients into plant-available forms.

Nutrient management is essential in maintaining soil function and optimizing crop yield and quality. Nutrient management practices involve applying nutrient sources such as manure, fertilizer, or compost. The quantity, timing, and type of application are key considerations for specific crops. [4] In particular, nitrogen and phosphorus are essential elements for crop growth.

Overuse of certain fertilizers can result in runoff from agricultural lands to water bodies, which can lead to negative environmental impacts, including eutrophication. Eutrophication is the process in which a water body receives excessive nutrients—this can lead to algal blooms, reduced oxygen, and negative impacts to aquatic ecosystems. Organizations such as Kootenay Boundary Farm Advisors are supporting local farmers in the region to promote good soil health. [5] Biochar could play an important role in these efforts, as it can enhance soil water retention due to its high porosity and surface area, and support nutrient retention, in some soils, particularly in coarse-textured soils. [6] Studies also suggest that the application of biochar can support the slower release of nutrients, which could reduce the economic and environmental burden of excessive use of conventional fertilizers. [7]

Biochar's effects and the resulting outcomes in Creston's varied soils are contingent on the specific biochar and soil types. For example, Biochar's ability to improve water retention is greater in coarse-textured, sandy soil but less pronounced in loamy and clay soils. Biochar can also have greater benefits in nutrient-poor and acidic soils. [8,9] However, most soils will benefit from biochar additions. [10]

The main areas surrounding Creston include the Kootenay River Flats, Lister-Canyon, and Erikson/Wynndel. The Kootenay River Flats are low-lying floodplains that are highly fertile due to repeated alluvial deposits from the Kootenay River. The area is characterized by deep and nutrient-rich soil that retains moisture and is ideal for forage crops and livestock production. Medium silt to coarse sand deposits formed natural levees adjacent to the river, while finer sediments were carried across the levee. The benchlands adjacent to the Kootenay River Flats are composed of lacustrine soil parent materials. Further details and information can be found in the Government of Canada’s Soil Survey of the Creston Area. [11]

The Creston Series is a soil type that occurs immediately to the east of the Kootenay River, in Creston south towards Rykerts, and in small pockets in the Wynndel area. The parent material consists of freshwater deposited lacustrine sediments with silty clay loam to clay textures. This soil is well drained. Due to the rich quality of this soil, biochar may be less likely to have a significant benefit. [11]

Lister-Canyon is characterized by gently rolling to moderately sloping landscapes with well-drained soils suitable for tree fruit, vineyards, and livestock feed crops. The soil is of a loamy texture and has good aeration. Lister Series soil is highly dominant in this area and formed from glacial till with loam to silt loam textures; it is well drained with moderate fertility. [11]

In Erickson/Wynndel, the soil is characterized by moderately sloped benchlands and alluvial and glacial deposits. This region is a premier fruit-growing region with orchards, market gardens, and vineyards. The Benny Series can be found along the banks of the Kootenay River and is fine sandy loam grading to silt-loam. The soils are imperfectly drained, and most are being cultivated. [11] Studies suggest that in sandier soils, biochar can lead to more positive benefits, such as improvements in soil structure, water retention, and nutrient retention; however, additional research and site-specific trials are required. [12] Benefits have also been noted in other types of soils.

Interviews with local farmers highlighted that challenges in soils include water retention and temperature regulation in lighter sandy loam. However, the majority of tree fruit farming is done in Erickson soil, which is a heavier loam or clay loam soil. In this case, water retention is less of an issue, but Creston's limited water resources and increasing droughts have resulted in water availability becoming a greater concern. In tree fruit farming, perennial in nature, mulches and compost are used to help with weed suppression and to support the build up of organic matter in the root zone. There is increased interest in the orchard community and across other farming in soil health and soil biology.

Creston Community Forest

Creston Community Forest includes 21,000 hectares of land located in the Kootenay Lake Timber Supply Area. The majority of the management area is in close proximity to the town of Creston, directly north of the town, including Goat (Arrow) Mountain and Arrow Creek. The remaining management area is located east of Creston, encompassing Skimmerhorn Range, Thompson Creek, Russell Creek, Birch Creek, Carroll Creek, Kitchener Mountain and Found Creek. [13]

Creston Community Forest's management area contains five Community Watersheds. This includes Arrow Creek—the main source of water for the Town of Creston—as well as Sullivan Creek, Camp Run Creek, Floyd Creek, and Russell Creek. In addition, 7 domestic watersheds are contained within the management area.[13]

The Biogeoclimatic Ecosystem Classification (BEC) zones in the management area include: the Interior Cedar-Hemlock (ICH) and Engelmann Spruce-Subalpine Fir (ESSF) zones. The ICH zone is characterized by long, warm summers and cool, damp winters, creating a typically warm, moist climate. The ICH has the greatest diversity of tree species over any other zone in the province and includes the growth of western red-cedar, western hemlock, lodgepole pine, Douglas-fir, ponderosa pine, western white pine, western larch, paper birch, trembling aspen, subalpine fir, and spruce. The moist conditions and long growing seasons provide the most productive sites in the interior of BC, as well as create an ideal habitat for wildlife. [13]

The presence of long, cold winters and deep snowpacks are characteristic of the ESSF zone. Tree species in this zone include: Engelmann spruce, subalpine fir, western white pine, western larch, western hemlock, and lodgepole pine. Historically, the growing season in the ESSF has been short, with snow covering the landscape 5 to 7 months of the year. [13]

Changing climates are impacting ecosystems across BC and will continue to change in the coming years. As mentioned, the Kootenays are expected to experience decreased precipitation and rising temperatures. There is also a greater risk of fire events and droughts. Wildfire risk reduction projects are undertaken within the Wildland Urban Interface (WUI) at a 2 km buffer around communities or structures that need protection.

The Creston Community Forest site has a timber harvesting land base (THLB) of approximately 11,000 hectares that meets the annual cut control of 25,000 cubic metres. With such a large area, the varying topography within Creston Community Forest would be an important consideration for any potential new pyrolyzer machinery. Machinery would need to navigate steep slopes and switchbacks. During the timber harvesting process, landings can be built to provide a stable worksite for pyrolyzer machinery; however, the use of existing roads is preferred.

Creston Community Forest is also responsible for managing on-site lakes, hiking trails, community engagement, and education. This presents further opportunities for in-situ biochar application, including water management, education, and forest or trail restoration. The Biochar Application and Market Research section discusses this further.

Biochar Production

Pyrolysis is a process where organic materials are heated to temperatures between approximately 300-1000°C in the absence of oxygen. [14] This process chemically decomposes the material into soild, liquid, and gas products. Biochar and syngas or wood vinegar can be obtained through this process, depending on factors such as heating rate, temperature, and residence time. [15,16] The biochar produced is a high-carbon, porous material that has many emerging and existing uses as a value-added product. [10]

Various pyrolysis technologies are available, ranging from simpler, more traditional methods to more advanced options. Traditional biochar production methods involve piling up biomass, covering it with a thin layer of soil, igniting the biomass at the seal, or heating the biomass in a biochar kiln so that it is burned and pyrolysis takes place in an environment depleted of oxygen to form biochar. [17] This method has its challenges, including long cycles, unreliable production, and environmental pollution.

Newer and larger-scale technologies have been developed to control this process and improve production output. Large-scale pyrolysis technologies are traditionally not designed to be mobile or for use in remote areas such as forests. Industrial pyrolyzers generally need electricity, feedstock drying and pre-processing, which necessitates large open areas. [10] Technology companies are increasingly developing mobile pyrolyzer units that address these challenges and can be used in remote locations. Mobile pyrolyzers offer quick setup and are ideal for temporary or space-limited locations.

In the case of Creston Community Forest, a portable pyrolysis unit is key to enable use in various locations across a large area, without having to transport feedstock and without the need for additional pre-processing or chipping. Increasingly, self-contained systems with integrated diesel or electric blowers are being developed for use in remote operations. There are some concept models with waste-to-energy capabilities using syngas and biodiesel in a closed system, which would be preferable in terms of cost and carbon emissions, but this technology is limited in availability. [18]

Air curtain burners (ACBs) were designed principally as a pollution control device for open burning, to reduce the particulate matter (PM) or smoke which results from burning clean, woody biomass. Many air curtain burners now also have the ability to produce biochar, whilst simultaneously reducing emissions associated with burning. In some cases, the ash and coals produced need to be quenched with water to prevent further combustion. [19,20] This report considers ACBs that produce biochar and biochar kilns.

Assessment of Available Technologies

Landing size and accessibility are key considerations—some technologies require flat, accessible areas with adequate space for operation and feedstock storage. Depending on the pre-processing requirements of the feedstock, there may be a need for additional machinery or piling of feedstock via excavators to support loading. Some technology options also require water to enable quenching of the biochar, so accessibility and availability of water supply via pumps or tankers could be required on the site. The feedstock from Creston Community Forest will include clean wood biomass and debris, stumps, trees, and slash. There may be additional considerations if contaminated wood biomass or waste were to be used.

Table 1 below summarizes key information on various pyrolysis technologies, including lower technology options (biochar kilns) and more technologically advanced options. It focuses on mobile units that can be used in forestry operations. [10]

Additional technologies are available from companies such as ARTi, BluSky and Takachar; however, comparative data is not publicly available for these portable units. Many organizations offer multiple units and can tailor them to the needs of the client. They also offer services, including maintenance and carbon credit support. The figures in the table below are based on an eight hour shift for producing biochar.

Table 1. Relevant available technologies adapted from Wilson et al. (2024) [10] and TWER (2022) [21]

Name and Description	Est. Cost (CAD)	Size	Feedstock Processed per Shift (Tonnes)	Biochar Produced	Fuel Use (L/Hr)	Loading Method and Feedstock Requirements	Water Req. per Shift (L)	Labour Req.
Air Curtain Burners								

BurnBoss Trailer can produce biochar if hot coals are unloaded and quenched with water. Batch system.	Approx $76,000 Operating costs $2 per hour for fuel plus labour.	6 m x 2.4 m 4,526 kg Landing size is the machine plus one day's feedstock pile.	11	5 m^3 per 8 hour shift	1.3	Max size: 3 m x 30 cm Moisture: 50% but optimal is <25% Machine loading via mini excavator or skid steer loader. Ensure an area of 15 m is cleared and monitored for embers downwind.	1,900	One hand crew, one machine operator
Charboss Self-contained, continuous ACB.	Approx $215,000	7 m x 2.4 m 17,500 kg	4	5 m^3 per 8 hour shift	3.4	Max size: 3 m x 30 cm Moisture: 50% but optimal is <25% Machine loading via mini excavator or skid steer loader. Ensure an area of 15m is cleared and monitored for embers downwind.	1,100	One super-visor, one machine operator, one hand crew
Tigercat 6050 Carbonizer Large ACB designed for continuous biochar production.	Approx $700,000+ [22]	12 m x 3.6 m 41,723 kg	51	12 m^3 per 8 hour shift	19	Max size: 6 m x 46 cm Moisture content: Up to 50%, optimal <25% Machine loading via large excavator or log loader. Ensure an area of 15 m is cleared and monitored for embers downwind.	11,300	Two machine operators, two hand crew
FireBox S220 Various sizes available. The 200 is the mid-sized ACB in the range.	Approx $142,00 to $241,000 Operating costs $9 per hour for fuel plus labour	9.2 m x 2.6 m 16,620 kg	50	2% of input weight to ash or biochar	60.8	No pre-sorting or grinding required.	Info un-availabe	Info un-availabe

Trackboss [23] Track driven self-propelled unit that is remote controlled.	Approx. $139,000	5.2 m x 2.6 m 6963 kg	7.2	2% of input weight to ash or biochar	4.2	No pre-sorting or grinding required. The machine should not be located within 31 m of any stored combustible materials.	Info un-available	One person to operate the remote controlled machine, one person to operate the excavator
Biochar Kilns								
Ring of Fire Kiln Metal container panel kiln that can be easily transported and adjusted in size.	Approx. $1,400 per kiln	2.5 m diameter 150 kg	7	9 m^3 per 8 hour shift	N/A Ignited by drip torch or propane torch.	Max size: 1.8 m x 10 cm Moisture content: <25% Sorting is required from small to large. Loading by hand or mini-excavator.	2,300	One supervisor, four hand crew to operate four kilns
Oregon Kiln Small flame-cap bin kiln that can be used on uneven or steep terrain.	Info un-available	1.5 m x 1.5 m 91 kg	7	9 m^3 per 8 hour shift	N/A Ignited by drip torch or propane torch.	Max size: 1.8 m x 10 cm Moisture content: <25% Sorting is required from small to large. Loading by hand.	2,300	One supervisor, four hand crew to operate six kilns
Big Box BB-12 Kiln Large double-walled flame-cap bin kiln that can be loaded with machinery.	Info un-available	3.6 m x 1.8 m 907 kg	10	12 m^3 per 8 hour shift	N/A Ignited by drip torch or propane torch.	Max size: 1.8 m x 10 cm Moisture content: <25% Sorting is required from small to large. Machine loading by small excavator or log loader.	2,300	One machine operator and one hand crew per kiln.

Airburners completed a comparison of costs to remove 100 tonnes of wood waste using the FireBox compared to grinding and landfill disposal. The disposal cost for 100 tonnes using the FireBox was $267 USD compared to $5780 USD for grinding and landfill. The greatest cost savings are seen in the hauling of residual to landfill and the tipping fees which would both be $0 for implementing a biochar production technology. [24]

Key Considerations and Case Studies of Biochar Production

Access and Land Availability

In Canada, pyrolyzers are increasingly used in forestry for converting forest residues into biochar, bio-oils, and other products with high value in carbon capture and soil amendment applications. Examples include Lil'Wat Forestry Ventures who is working with Skytech Enterprises to use the TigerCat Carbonator, a mobile ACB, across the Sea to Sky region. [25] Similarly, BC Biocarbon, based in Robson Valley, BC has a proprietary biorefinery facility where they produce and sell biochar for use as a natural soil enhancement and other by-products, including wood vinegar, gases, and carbon removal offsets for long-term contracts.[26]

For forestry applications, smaller-scale production options such as the flame-cap kilns offer portable and adaptable biochar production for localized woodlots or agricultural use. For example, the Ring of Fire kiln can be adjusted in size by adding panels and is relatively easy to operate. This method is used by Napachar to dispose of wood biomass in vineyards in California and has been trialled by the Lands Council and Kalispel Tribe in Washington. There is an additional benefit of leaving the biochar on site, as this reduces the transportation costs of the biochar. Within vineyards in Napa, there is a high value placed on the use of biochar and the benefit that this has to grape vines.

Mobile pyrolyzers can be used in the Canadian forestry industry to dispose of under-utilized wood biomass, reduce wildfire fuel loads, and support ecological restoration. There are specific considerations that need to be taken into account when selecting a pyrolysis technology, including location, feedstock supply, and size. Interviewees mentioned that large landing areas are required for units such as the Tigercat, although there are units of varying sizes and some units have different landing size requirements. [10] Some options are highly efficient and portable but would still require consideration for mobilization costs and set up. Generally a flat landing site would be required as well as consideration for loading machinery, water tankers, and a buffer zone for embers. Biomass piles for loading might also require a designated area to maintain clean and efficient burning.

Pyrolysis technologies are increasingly available in mobile models, which helps forestry operations to deploy these technologies in remote locations. [27] For example, Tigercat is looking to develop a smaller version of their machinery. Mobile units eliminate the need for transporting bulky, unmerchantable biomass over long distances, which reduces costs and emissions associated with haulage. One challenge is the need for accessible paths to transport and maneuver large mobile machines, which is especially difficult in regions with rugged terrain.

This can sometimes require upgrades to existing road infrastructure or careful transport planning to avoid steep or narrow roads.

Biochar Production Rates

Advanced mobile pyrolysis technologies, such as ACBs are able to process much larger volumes of biomass compared to kilns and produce biochar output that can be either used on site, distributed locally, or sold. This offers greater potential for a revenue stream from the biochar production process. In the context of Creston Community Forest, this may also be a more efficient option, depending on the amount of feedstock that is available to be processed. The interviews highlighted that the main benefit from utilizing mobile pyrolyzers in forestry operations was the reduced amount of debris that needed to be removed from the site. One interviewee highlighted that the biomass is reduced by 30 times, resulting in cost and carbon emissions savings—1 truckload would be needed to move the waste rather than 30 truckloads. In the context of Creston Community Forest, this is less of an issue as wood biomass is not transported off-site. It is recommended that additional financial analysis is undertaken to clearly understand the economic feasibility of the production methods, including data on the amount of feedstock that is produced by Creston Community Forest.

A ranger based in the US who uses traditional kilns for biochar in forest management reports that the CharBoss's processing capacity has the potential to be 15 times greater compared to kilns that they had used in the past. There is also the added benefit of being able to continue burning in the winter months due to reduced emissions. [28] In winter, there can be long periods of time where burning cannot take place due to low venting days caused by cold and dry weather. The Ventilation Index is a forecast released daily by Environment and Climate Change Canada that estimates how well the atmosphere disperses smoke on any given day. Open burning is restricted on low venting days, but technologies such as ACBs can sometimes be used. [29]

Flame-cap kiln methods are efficient in producing biochar, but the production methods are more labour-intensive and less biomass can be processed in the same amount of time. These methods may be less suited to the collection and transportation of biochar as this requires additional labour at the end of the process as opposed to raking the biochar in-situ. Interviewees who were involved in producing biochar using flame-cap kilns mostly reported using the biochar in-situ, either on the land for forestry and soil benefits or water retention benefits. This is also likely due to smaller quantities of biochar being produced in the initial piloting stages.

Labour

Operating biochar production technologies requires specialized training and safety protocols to handle the equipment, especially as temperatures can exceed safe handling limits. The level of training depends on the technology.

In all production methods there can be risks to human health and the environment if strict processes are not followed and materials are not handled appropriately. ACBs and more advanced technologies require more skilled training and can have higher operating costs as a result. For example, the Tigercat carbonator takes responsibility for training operators, as there can be risks such as forest fires if the machine is not managed correctly.

Flame-cap kiln options provide employment opportunities as they can be operated by volunteers or workers with minimal training. There is a much lower capital cost investment, and this method is much safer and more efficient than open burning. However, there is greater skill required than traditional pile burning in the preparation of the materials and ensuring that the process is as efficient as possible. This can provide a social benefit to the local workforce and encourage greater knowledge and training in the importance of wildfire risk reduction work.

Additional insights from the interviews highlighted the importance of providing contractors and labourers with clear information about processes ahead of time to avoid reprocessing of feedstock and ensure maximum efficiency. For example, it is important to ensure that the feedstock is piled correctly, in the right location, and is clean rather than packed in with soil and dirt. One interviewee, using the TigerCat carbonator, mentioned that dirt and debris had smothered the fires, making them more challenging to burn as the intent for using the unit had not been known beforehand. Similarly, in one case the wood was chopped and left too close to the tree line in a location that the carbonator could not be used due to fire risk, so the material had to be moved, leading to inefficiencies.

Permitting

In BC, the Environmental Management Act regulates air pollution. Permits may be required to operate ACBs and other pyrolyzer technologies. The Open Burning Smoke Control Regulation (OBSCR) was enacted on September 15, 2019. This applies to all burning of vegetative debris unless specifically exempted. Creston and some surrounding areas including Goat Mountain and Arrow Creek are in a High Smoke Sensitivity Zone. Burning requirements are stricter in these zones due to the proximity to communities. The other surrounding areas are in a Medium or Low Smoke Sensitivity Zone. [30]

Some ACB technologies could potentially be used in June and July which increases the burn window for forest operations as they are able to use the machinery during fire bans. There may also be opportunities to use ACB technologies in winter on low venting days that often occur in the winter months. The Ventilation Index is a forecast released daily by Environment and Climate Change Canada that estimates how well the atmosphere disperses smoke on any given day. In winter, there can be long periods of time where the ventilation index is poor due to cold and dry weather, which can impact burning. [29] If the ACB is located between 100 to 1km from residences and businesses, and 500m to 2km from schools, hospitals, and care centers, the ACB can be used when the ventilation index is good or fair from one hour after sunrise until sunset and with certain conditions. If the ACB is located more than 1km from residences and businesses and over 2km from schools, hospitals, and care centers, the ACB can be burned at all hours, whilst adhering to certain conditions. [31] Similarly, since the smoke is contained and recirculated by the air curtain, burning can be conducted under a range of diverse weather conditions to include wind, rain, and snow. [21] It is recommended that further information is sought based on a short list of potential mobile pyrolyzer options by contacting obscr@gov.bc.ca to gain further information on OBSCR compliance, permits, and potential exemptions. [32] [33]

During the interviews, several respondents mentioned permitting as a challenge. Two interviewees based in BC mentioned that the rules and regulations around new technologies can be obscure. Exemptions are available, but there can be costs associated with permitting applications and the associated administrative tasks. One interviewee mentioned that this cost could be up to $12,000 per day for mobilization. Permitting timelines, ranging from 3 to 12 months or longer, can also introduce uncertainty. This will also depend on the technology selected and the proposed use case.

In Washington (US) another organization piloted a biochar study using the Oregon Kilns and the Ring of Fire kilns to convert biomass into biochar. The biochar was then applied to forest soils to improve sapling growth and stream health, demonstrating its utility in ecosystem restoration. [34] The success of the project led the organization to purchase a BurnBoss, but they are currently unable to use it due to air quality regulations. Similarly, during the pilot phase, the state government conflated flame-cap kilns with burn barrels, despite being cleaner and more efficient—this was raised as a challenge in the initial pilot phase. There is also a challenge with having available resources to challenge local government policies and reach agreements in terms of permitting. On the other hand, organizations operating in California highlight that biochar production processes and technologies are well-understood which can streamline permitting and support efficient operations.

As technologies evolve, there will be a need to engage in discussions with the municipal and provincial governments and ensure resources are available internally to address the permitting process when implementing biochar production technologies. The Regional District of Central Kootenay (RDCK) has been actively engaged in discussions pertaining to this project and is interested in the potential for biochar production within the region. The RDCK does not have any burning restriction bylaws in place and encourages residents and visitors to visit the BC Wildfire Service web page. [35]

Feedstock

Depending on the technology used, several considerations need to be factored into the preparation and availability of feedstock. First, the volume of feedstock needs to be assessed to determine the appropriate technology option and ensure that it is economically feasible.

While open burns can handle mixed wood, uniform feedstock (size, moisture, species) yields the most efficient results. A homogenous feedstock will convert biomass to charcoal at a consistent rate. The key feedstock variables that influence the qualities and benefits of biochar are size, moisture content, temperature, feedstock type, and pH level. In wildfire risk reduction work and in the case of Creston Community Forest, the wood will come from a handful of coniferous species, but it would be unlikely to be a singular species.

ACBs and larger machinery have specifications for debris size and moisture content, although newer models may have more flexibility and be able to accommodate logs and larger feedstock. Biochar kilns can only accommodate smaller feedstock dimensions. In this case, options for pre-processing the material would need to be considered. In some cases, logging operators could potentially add a chipper to their operations. The feedstock size and requirements for each mobile pyrolyzer are included in Table 1.

In all cases, the drier the material, the cleaner the burn. ACBs may be able to accommodate feedstock with a moisture content of up to 50%, whereas flame-cap kilns require the feedstock to be drier than 25%.

Feedstock size and moisture content are critical for the nonpowered methods and technologies, but even ACBs will work more efficiently and produce more biochar from fuels that are smaller and drier. [10]

Interviewees who used the Tigercat mentioned that the material needs to be piled appropriately to avoid soil and dirt, which can smother the fires. Similarly, users of flame-cap kilns highlighted that the feedstock needs to be well-prepared and managed throughout the burning process.

Community

As a key focus for Creston Community Forest, opportunities for community engagement and development as part of biochar production are an important factor. Interviewees highlighted that there is ample interest in biochar across many sectors in the region. There are opportunities to build on this community interest and share benefits with the local area. One interviewee mentioned the benefit that smaller kilns can have to local small landowners in supporting fire risk mitigation, particularly around residential buildings. The cost of fire risk mitigation in the Kootenays can vary depending on the method but can range from $6,000 to over $20,000 per hectare. [36] Centralized or community biochar production units or facilities could help to offset these costs for other parties and promote wider benefits of biochar application, as discussed below.

The Salt Spring Biochar Working Group in BC operates kilns that are low cost and regularly holds biochar workshops and training sessions to those in the sector and the local community. As of June 2022, there are 20 open cavity kilns that are available for use on Salt Spring. The Working Group plans to have a similar number of collectively owned kilns available to borrow. [37] Similarly, in McKenzie River a CharBoss air curtain burner was used following the Holiday Farm Fire in 2020, where downed timber and stumps were damaged and unusable but needed to be removed. The biochar was used to enrich the soil and improve water retention to avoid further runoff and mudslides. [38]

Given the cost of ACBs and more advanced pyrolysis technologies, there may be opportunity for shared ownership or leasing arrangements with other parties that would benefit from the technology. For example, as previously mentioned, the RDCK is also interested in identifying opportunities for sustainable wood waste management.

Lessons Learned from Biochar Producers

The following lessons learned are insights derived from the literature review and interviews with industry partners: [39]

- Ensure a clear understanding of the processes before starting biochar production to avoid reprocessing feedstock and maximize efficiency.
- Drier materials result in quicker burn processes.
- Full kilns produce the most efficient burn.
- Shaking out soil, dirt, needles, and leaves ensures a cleaner burn and reduces greenhouse gas emissions.
- Continually clearing material from around the burn site is beneficial.
- Organized piles increase the ease of loading.

- Early engagement with the province and local governments is crucial to gain support and clarity on permitting rules and exemptions.
- When determining the benefits of biochar production, consider reduced log and wood waste hauling costs as part of the financial analysis—the transportation of logs can cost up to $10 per tonne. However, this is of limited concern at Creston Community Forest as under-utilized wood biomass is burned on site.
- In most cases, biochar is generally being dispersed on the sites where it is produced.
- Consider the cost of the equipment, grinders, the transportation of the machinery, as well as the potential requirement of a loader feeding the carbonizer.
- Measure, record, track, and verify data to enable demonstration of the value of carbon sequestration and ecosystem services.
- Biochar created in-woods can be left in place to improve soil health and ecosystem resilience, or it can be transported off-site as a valuable forest product for use in agriculture or other environmental management in other locations. [10]

Biochar Application and Market Research

This section provides an overview of biochar application examples, the benefits of biochar, and case studies. In general, biochar enables the long-term storage of carbon in the soil, which can reduce atmospheric carbon dioxide levels and mitigate climate change. The process of biochar production can also lead to less GHG emissions compared to traditional slash-and-burn methods for wood waste management. Biochar has also been shown to have multiple other environmental benefits when used in different applications, including adsorption of contaminants such as heavy metals and organic pollutants, water filtration, and soil remediation. When applied to agricultural soils, biochar can promote soil fertility enhancement, water retention, soil structure, nutrient management, carbon retention, and salinity mitigation. [40]

Potential Benefits and Applications

Agriculture

Biochar as a soil amendment in agriculture and horticulture is the most commonly known and well-established application. Studies have shown that biochar enhances soil fertility by improving nutrient retention, increasing cation exchange capacity, and fostering microbial communities. This can, in turn, enhance crop yield and reduce the need for chemical fertilizers. [40] One study identified that biochar application can increase crop yield by 5 to 51%, depending on the location and crop type. [41] As previously mentioned, the benefits vary depending on the soil type and the properties of the biochar.

Studies also note that biochar can alter soil conditions to reduce pest populations and has the potential to mitigate salinity in soils by enhancing soil structure and infiltration, allowing salts to properly flush out of poorly drained soils. Biochar is highly porous, which can increase the water holding capacity of soils and the soil moisture content. This makes it highly suitable for remediating degraded soils. Biochar can also be used as a mix with compost or in livestock manure to adsorb nutrients, decrease nutrient loss, and reduce odour. [21]

In terms of agriculture and farming around Creston and in the Kootenays, there are more small-scale farms producing fruit and field crops. Ranching is also a primary activity on many farms. Many small-scale farms work with low profit margins and are limited in how much they can spend on soil amendments, which can present a challenge in terms of profitability, leading to a greater focus on fertilizer for crops rather than improving soils and nutrient management, as these impacts are more visible. While the majority of farmers interviewed knew what biochar was, they were not willing to risk profit loss and purchase biochar, given the unknown profit increase biochar may provide without previous regional data. Many farmers do not have the resources to conduct their own biochar trials. Biochar also works best in marginal soils, while many of the farms in the Creston Valley are on fertile soils due to the alluvial deposits from the Kootenay River. The water-holding capacity of biochar may become more desirable to farms in the future—currently, farms are charged for water use per acre; however, the Creston region is due to switch to metered water. This will incentivize farmers to monitor and reduce water consumption to avoid large water bills. Water retention may become more of a focus in the region as hotter and drier summers continue. In particular, sandier soils, such as the Erickson/Wyndell soil type, where orchards, vineyards and market garden farms have become quite popular, can see greater water retention benefits from biochar.

Some farmers mentioned that seeing examples of benefits on other farms would be an asset. The utility of biochar varies depending on the feedstock used and the type of biochar produced, so there is a level of performance uncertainty. For example, the various inputs can produce different biochars, which in turn will behave differently in different soils and crops. There is a need for further research and clarity in specific cases of the application benefits of biochar in the region. Interviews with farmers in the local area highlighted challenges with soil, including drainage and nutrient holding capacity, which suggests that there could be good benefits from biochar applications.

The challenge of biochar variability is less of a concern in vineyards, as noted by Napachar. In California, the soils also have a historical precedent for charcoal, and there is a history of humans burning the land—there is an element of biomimicry when returning charcoal to the soil. One study by Climate Action Reserve shows different yield results of biochar use on various crops in California, including pistachios, wine grapes, almonds and walnuts. [42] All crops achieved additional crop value per year per acre with biochar application. Wine grapes in particular achieved an additional crop value of $975 USD per acre. The study shows a highly positive effect on these crops. The modelling also suggests that lower value crops, such as wheat, may not present a viable biochar market when accounting for the cost of biochar production and transportation. However, lower value crops still may benefit from biochar applications, leaving open the possibility of using subsidies or other policy mechanisms to encourage biochar applications, given the high carbon benefits and other co-benefits.

Similarly, due to the synergistic effects of biochar and compost, the combined application is recognized as a promising and efficient method of soil improvement. Biochar-compost has shown positive performance in the remediation of both dry and saline soils by reducing the threat of soil water scarcity and improving the consequent deterioration of soil conditions. [43] Biochar-compost tends to perform better than biochar or compost alone in soils contaminated with heavy metals or organic pollutants. One study noted that biomass yield of poor soils was dramatically raised by 305% after applying co-composted biochar (2%, w/w), but the biomass yield was decreased after applying original biochar. [44]

In terms of benefits in an agricultural setting, compost mixed with biochar contributed to the compost quality, including nutritional value, safety, and stability. Mixing biochar with compost provides a more complete fertilizer. One interviewee suggested mixing biochar with chicken manure compost from the Fraser Valley. This process would need to be completed by Creston Community Forest, which would be an additional cost.

All interviewees mentioned that there is strong interest in the agricultural benefits of biochar within the community. However, most also emphasized the need for data to identify and implement marketable applications. Many farmers across the region mentioned that they would be happy to trial biochar or help connect Wildsight and Creston Community Forest to trial sites. To facilitate the adoption of biochar, additional evidence is needed to clearly demonstrate its impact of biochar on carbon sequestration and other benefits for soil and crops. Furthermore, tangible economic advantages, such as increased crop yields or its viability as a lower-cost soil amendment, must be substantiated. Farmers also need clear and concise instructions regarding application methods, optimal quantities, and appropriate timing, alongside confirmation of compatibility with their existing farm operations in terms of having the right machinery for spreading the biochar on their fields. Trials and results from pilot projects need to be demonstrated over a longer period of two to three years to understand the impacts.

The market for biochar as a soil amendment in Canada is in its early stages, despite considerable interest. Biochar needs to be cost competitive and is currently quite expensive to make. This was identified as a potential barrier by one interviewee who was looking to secure funding for a biochar production project. Though the interviewee has since secured a buyer for biochar, they noted that demonstrating the market is often linked to the availability of funding. The interviewee recommended identifying one large wholesaler when marketing biochar to avoid uncertainty. Additional considerations need to be made for the cost of packaging and marketing biochar, including the labour involved. One interviewee suggested greenhouse container pods, smaller farm shops and backyard farmers as a potential market. Although regional soil amendment and seed businesses noted that biochar that is available for sale in the area is rarely purchased by either farmers or gardeners. Any marketing strategy should highlight the environmental and carbon sequestration benefits. One farmer mentioned that it would be a more desirable product if the product was cost competitive with $15 per bag of mushroom fertilizer (a by-product of the mushroom farming industry, which is a mixture of organic materials, including straw, hay, animal manure, and crop residues). Understanding farmers' existing fertilizer investments and biochar's competitive cost and advantages requires further research to support business case development.

Forestry

The forestry industry is a significant contributor to the Kootenay economy, supporting approximately 10% of the workforce. As previously mentioned, biochar that is of a high-carbon content, is highly porous, and consistent in size, can be suitable for remediating degraded soils found at forestry roads, log landings, and trails. Additionally, biochar can have benefits such as supporting erosion control, water retention, habitat restoration, and carbon sequestration. [45, 46]

Identifying beneficial use cases for biochar on site at Creston Community Forest would reduce costs associated with transporting biochar off site, which has been raised as a key consideration by interviewees. There may also be opportunities to market biochar to other forests in the region.

Biochar may be applied to forest sites in order to positively influence soil properties (enhanced soil structure, nutrient retention, water holding capacity), but its biggest benefit may be in facilitating reforestation of degraded or contaminated sites and in sequestering carbon in soils. The majority of data on biochar applications on forest sites focuses on seedling responses and short-term impacts on nutrients, soil physical properties, and microbial changes. Long-term field research is necessary to determine water use, carbon sequestration, nutrient use, and GHG emissions, and the subsequent alteration of forest growth and stand dynamics. [47] Biochar has been found to significantly enhance microbial activity in forest soils, particularly in the short term. This enriches the soils and plays a pivotal role in energy transfer and nutrient cycling within the soil ecosystem. [10,48,49]

The use of biochar for site rehabilitation or as part of site preparation during the silviculture phase of forestry could have an immense impact. In this context, biochar can support the fertilization of sites after logging and prior to planting, making it particularly beneficial for areas that have experienced significant abiotic damage from naturally occurring events such as fire, wind, or pests. Roads that are being decommissioned and need to be restored can benefit from biochar applications. They can be difficult to restore due to compaction, lack of water holding capacity, and invasive species. U.S. National Forests tested the use of biochar as a restoration medium, as opposed to alternative wood straw or wood strands used for erosion control. [50] They found that biochar created on or near the site can increase soil water by as much as 26% and decrease invasive species. This is likely due to improved nutrient availability and soil microbial benefits. [10] One study found that biochar can mitigate the allelopathic effects of invasive species by absorption of toxins however, this will be effective in only some cases. [51]

Studies also show that biochar can support post-wildfire rehabilitation and seedling generation. Wildfires can cause significant changes to soil carbon and thermally alter soil organic matter. Rain events following a wildfire can also result in increased runoff and erosion. Biochar applied with a mulch can replace some organic matter and increase plant survival in postfire soils. [10, 52]

In North America, the cultivation of 1.6 billion tree seedlings annually relies heavily on peat moss. Peat is a type of wetland that is critical for preventing and mitigating the effects of climate change, preserving biodiversity, and minimizing flood risk, and is the largest natural terrestrial carbon store. [53] In 2021, Canada's GHG emissions from peat extraction reached 2.1M tonnes. While peat moss is effective under moderate conditions, it struggles during droughts. When dry, peat moss becomes resistant to rehydration, pushing moisture from seedling roots and increasing mortality. This is particularly severe in Southern BC's Interior, where rising droughts and wildfires demand frequent replanting, escalating emissions, and operational costs. Currently, there are no large-scale viable alternatives for growing these seedlings. Innovatree Carbon Group has been working on a proprietary-amended biochar, derived from bioenergy facilities across BC, as a large-scale replacement for peat moss. This innovative substitute for peat moss has excellent moisture and nutrient retention, increasing seedlings' resilience. [54]

Biochar can improve infiltration, soil water holding capacity, hydraulic conductivity and plant available water. Retaining water in soil improves vegetation success and helps the survival of native soil microbes, microfauna and insects. This property can also lead to improved soil health and resilience, especially in the context of drought, by increasing soil water holding capacity and available water. Improved soil moisture also improves live fuel moisture, which can result in reduced risk of fire ignition as more fine fuel stays green longer into late summer. [10]

The porous structure of biochar is known to absorb contaminants and nutrients from water. This improves soil quality and prevents groundwater contamination. It can also improve water quality and support clean water initiatives. For example, biochar can be installed as strips near roads and waterways as a way to remove nutrients or pollutants before runoff reaches streams. This is particularly relevant for forestry practices that involve managing watersheds similar to Creston Community Forest. Stormwater runoff picks up pollutants such as chemicals and oils that can pollute rivers, streams, and lakes. Incorporating biochar can enhance the effectiveness and reduce the cost of stormwater management practices. In Chesapeake Bay, watershed biochar amendments have been used for water infiltration and retention. For soils with poor water infiltration, the biochar amendment attenuated peak flow by 77% and runoff volumes by 53%.

As forests are enjoyed by the local communities and are often involved in education, there is an opportunity to highlight the benefits of biochar to local landowners and other visitors. Demonstrations of biochar can highlight the benefits of carbon sequestration and encourage other private forest or landowners to come to the site to learn about and replicate the practice. The biochar can also be used for water sanitation for recreation sites and public facilities. Biochar could also be used in campgrounds and in public toilets to reduce odours, landscaping, and for cleaning drinking water.

Making and using biochar reduces GHG emissions compared to open pile burning. Converting biomass to biochar can prevent as much as half of the biomass carbon from oxidizing into carbon dioxide. Biochar carbon is slow to decompose and will reside in soil for hundreds to thousands of years, providing climate mitigation and soil carbon benefits. Similarly, in warming climates, the rate of soil organic matter decomposition can increase. Biochar can stabilize soil carbon and improve microbial metabolic efficiency. [10]

Wilson et al recommend that biochar can be applied at a variety of rates from 1 to 9 tonnes per acre, depending on biochar and soil properties and project goals. When biochar is applied on the surface of an intact forest soil, it will naturally be incorporated into the organic soil horizon over time. Biochar can be applied on the surface of the forest litter layer without needing incorporation into the soil profile, as needle and leaf fall from the overstory will accumulate on top of it. [10]

Construction

Biochar can also be used as an enhancement to building materials, including as a replacement for cement and aggregate in cementitious composites. [55] Biochar can be added to concrete in varying proportions, typically ranging from 3% to 10% by weight of concrete. The optimal ratio depends on the specific requirements of the construction project. [56] The addition of biochar can increase strength and improve insulation by reducing thermal conductivity. There is also the potential for biochar-containing building materials to contribute to lower embodied carbon of buildings. This is important as municipalities and developers look for ways to reduce their carbon footprint in line with national and local emissions-reduction targets. [57]

Habitat for Humanity built a zero-carbon, 1,500 square foot home from concrete that used a sand replacement made of biochar. The study highlighted that the biochar sequesters carbon without diminishing concrete durability and energy performance. [58] There may be an appetite for similar applications in nearby areas surrounding Creston Community Forest.

Pilot projects could involve incorporating biochar materials into the construction of skate parks or sidewalks as an initial testing period. Utilizing biochar as a carbon sequestration method under the construction of buildings or roads could also be an option for developers.

Mine Reclamation

As discussed, biochar properties, including its porosity, make it suitable for remediating degraded soils, often found at abandoned mines. Biochar's negative charge, high surface area and pores, and surface groups give it unique abilities to remove emerging contaminants. These physical properties mean that biochar can bind to various compounds making them unavailable to the soil for uptake and preventing them from entering waterways.

A project at Formosa mine in Oregon tested if biochar can help mitigate pollution discharge into waterways. Acid mine drainage contaminates surface and subsurface waters in the area, and wind and water erosion—due to lack of vegetative cover—moves contaminated soil off site. Mineralized soil, water acidification, and erosion (caused by lack of vegetation) make plant establishment a challenge at abandoned mines. Each degraded and contaminated area will be unique and require biochar testing to determine what works best. However, the addition of biochar to highly weathered acidic soil can positively influence seed germination, plant growth, vegetation cover, and nitrogen and phosphorus use efficiency. Material such as wood chips and compost can be added to increase soil moisture and protect germinating seeds. The Kootenay region has a history of mining and there may be a number of abandoned mines in the region that can benefit from biochar applications in the reclamation process.

Industrial Applications

The pyrolysis process generates energy and, depending on the technology used, the heat produced from burning wood waste can be converted into a renewable energy source. The burner directs heat to a heat exchanger that produces hot water, which in turn supplies a thermal generating unit.

Due to the porosity and high surface area of biochar, it can also enhance the efficiency of chemical reactions. There are some examples of biochar being used in batteries, particularly lithium-ion, due to its high surface area and electrical conductivity.

Similarly, as a sorbent, biochar can be instrumental in treating wastewater, such as sewage and removing pollutants and heavy metals from contaminated water. The feasibility depends on the feedstock, but some studies show that pine needle-derived biochar can remove certain contaminants from water.

Market Background and Potential Revenue Streams

The global biochar market size was valued at $680.84M USD in 2023 and is projected to grow from $763.48M USD in 2024 to $2097.72M USD by 2032, exhibiting a compound annual growth rate (CAGR) of 13.47% during the forecast period. [59] This means investments have grown by 13.47% annually on average over a specified period.

In 2022, Canada accounted for 23.2% of the global biochar market. The market shows significant growth potential driven by technological advancements, increased consumer demand, and evolving regulatory frameworks. Biochar is more widely available in the US, and the market and understanding of biochar as a product is more advanced there. However, efforts are underway to expand large-scale production in Canada, including the refinery being built in Saskatchewan by BC Biocarbon. This refinery will expand the company's feedstock capacity by 8 tonnes per hour and sequester 44,000 tonnes of carbon dioxide equivalent (CO_2e).

The adoption of sustainable agriculture practices is also expected to further drive the global market for biochar and as the main viable technology for carbon sequestration, the market is expected to increase with the growing demand for carbon credits. It is important to note that biochar producers will also need to contend with the rising demand for feedstock from the expanding biofuels and sustainable aviation fuel sectors. [60]

Opportunities for Selling Biochar

Biochar

Despite the market potential, the current market availability of biochar was flagged as a challenge in interviews. There is a willingness from farmers and landowners to trial biochar, but this is currently at a smaller scale and in a controlled environment. One biochar producer in BC's forestry sector has secured a buyer, and research suggests that interest is growing.

Potential target customers for biochar include retailers and landscapers that maintain residential gardens, public agencies, garden centres, nurseries, parks, golf courses, commercial gardens, and organic farmers. [61] Cost competitiveness with other fertilizers or amendments is a main consideration for farmers and landowners. Campaigning can support awareness raising of biochar's benefits and encourage uptake. Dooley et al noted that, "the willingness-to-pay for biochar products will remain flat unless consumer awareness rises." [61]

BC businesses are selling biochar at varying quantities and costs. At a smaller scale, some websites show bags of biochar being sold at $39 for 25 litres, [62] five 0.5 litre bags for $49, [63] and $29 per bag. [64] One interviewee mentioned that biochar can cost $500 to $1000 per tonne to produce, not including the cost of transportation, packaging, and differing production methods. The high transportation costs relative to product value require access to nearby markets.

Processing biochar into a saleable product as a soil amendment is complicated. Landowners highlighted that they would be interested in using biochar but require empirical data on benefits and clear instructions and labelling to understand the application requirements. If biochar is marketed as a soil amendment in Canada, it must comply with the Canadian Food Inspection Agency (CFIA)'s fertilizer requirements, including registration and adhering to specific quality and labeling standards. [65] This would require a full understanding of the carbon content, pH, porosity, nutrients, and heavy metals. Further challenges are posed if different feedstocks are used. The right amount of biochar is required for different soils.

Vendors have had difficulty selling biochar as a soil amendment due to the complexity of getting the nutrient and microbial components right and matching this to the benefits of different soil types and crops. Research suggests that mixing biochar with compost can overcome some of these challenges. There may be increased interest in other end-use applications for biochar such as in forestry applications, wastewater decontamination, and as a concrete additive.

The lack of market development and policy support have also been cited as key barriers to biochar production and commercialization. Incentives such as an offset on stumpage would encourage biochar production and support market development. For example, at the moment, community forests need to pay a stumpage on logs, or a tax per cubic meter of harvested logs. If this was offset for those that are producing biochar this could promote production. [61]

Biochar Mixed with Compost

The use of biochar during the compost process yields a product comparable to those obtained with mineral fertilizer additions with a lower environmental impact. Adding biochar when building compost can enhance the composting process. [66] Biochar additions to no-turn, low-oxygen techniques can generate a rich compost in 2 to 4 months.

Research suggests that adding 5 to 10% by volume of biochar at the start of the composting process can:

- Speed up the composting process by 20% through better aeration of the pile and increasing microbial activity;
- Capture odours; and,
- Generate a compost with more nutrients because biochar retains nitrogen. [67]

Other studies suggest that adding biochar to composting may reduce processing time and costs by requiring less frequent turning, saving labour and fuel. Adding more than 20% or 30% of biochar can interfere with biodegradation and is not recommended. As mentioned, the combining of biochar and compost when applied to agricultural soils negates some of the challenges with matching biochar and suitability for specific soils. [43]

BC Biocarbon sells biochar on their website in 3 sizes, recommending the <2 mm and 2-6 mm particle size for gardening applications and >6 mm for water filtration and soil reclamation applications. The specifications are listed online, including the benefits of adding inoculated biochar (biochar mixed with compost) to soil. To the biochar, the website suggests mixing it into compost at a 1:1 ratio, and letting the biochar 'charge' or mix with the nutrients and microbes of the compost for at least 14 days before adding the mixture to soils. Once the biochar has been inoculated, it is ready to be blended into soil. The instructions suggest that a 2 cm to 10 cm layer of biochar is added on top of garden beds in the spring and is worked into the soil to a depth of 20 cm. [68] BC Biocarbon also offers the sale of liquids including aromatic hydrocarbons, wood vinegar, and wood tars, and offers carbon removal offsets for dedicated long-term contracts.

Creston Community Forest will need to consider different options for obtaining compost. There could be an opportunity for collaboration with composting facilities at the municipal level with RDCK. If the transportation of compost from out of province or another region of BC is required additional costs should be considered. Similar costs associated with selling biochar apply to the sale of biochar-compost, including transportation and packaging of the final product, mixing, and certification processes. Interviews with local farmers and landowners highlighted that there is interest in biochar that is mixed into an agricultural grade compost—this is more desirable than biochar being sold on its own.

Opportunities for Selling Woodchips

Another opportunity for managing wood waste from Creston Community Forest is creating woodchips and either selling or providing these to local landowners and farmers. During interviews with local farmers, all participants highlighted that they do have a use for woodchips, and there could be large demand. Respondents are currently paying varying amounts for woodchips, ranging to around $1000 CAD per 2.5-tonne truck. Some respondents expressed concern about woodchip quality, presence of needles, or requiring woodchips from specific tree species. This could impact the ability to sell woodchips. There may be greater and more readily available demand for woodchips in the region, posing a possible entry-level source of income—or complementary income—to biochar production.

Opportunities for Selling By-Products

Depending on the preferred technology, there may be useful by-products that could be generated by the pyrolysis process.

- **Wood vinegar:** This is a refined by-product that can be used as a natural insecticide, soil conditioner, fertilizer, and food preservative. It can also be used in the production of cosmetics and pharmaceuticals. BC Biocarbon has exported wood vinegar to international markets.
- **Syngas:** Syngas is a mixture of carbon monoxide, hydrogen, and other gases that can be used as a fuel for heat and electricity generation. Syngas can be refined into hydrogen and sold, or burned on-site as a fuel.

Leveraging the additional by-products could make the process more economically viable depending on the type and location of the equipment. Syngas is a common product from the pyrolysis of biomass and, depending on the volume produced, could be of interest to local natural gas utilities looking to reduce the carbon intensity of their gas supply.

Challenges in this case are similar to biochar as the market is not developed and additional information is required including the concentrations at which it is produced. One interviewee noted that in regions where energy costs are high, biochar production is more successful because selling by-products like syngas as a competitive fuel source improves economic viability.

BC Biocarbon produces wood vinegar as a by-product of their biochar manufacturing from wood waste process. It is used in agriculture and gardening as a soil amendment to enhance plant growth. Other uses include as a natural herbicide and pesticide, smokey flavouring for food, and insect repellent.

Carbon Credits and Ecosystem Services

As the main technologically viable carbon sequestration method, companies such as Microsoft are purchasing biochar carbon credits as part of strategies to become carbon neutral or 'carbon negative.' According to CDR.fyi, biochar carbon credits accounted for more than 90% of durable carbon dioxide removal credits delivered in the voluntary carbon market in 2023. Sales of biochar-based carbon dioxide removal (CDR) credits also increased 20-fold from 2005-2021, encouraging some project financing for biochar producers. [69] Carbon markets are complex with many players who work to move credits through the system and offer payment to producers. It is an evolving marketplace.

- **Producers** are the biochar companies and farmers who make biochar. Producers sell the credits, while also selling the biochar they produce.
- **Carbon financers** can play a role in facilitating the carbon market and funding projects.
- **Standards and verifiers** include organizations such as Puro.earth, carbon futures, and verified carbon standards. They verify and certify carbon reduction and removal projects.
- **Brokers** are optional intermediaries that facilitate the buying and selling of carbon credits.

- **Buyers** are organizations such as Microsoft, Barclays, and Shopify that wish to purchase carbon credits to offset carbon emissions as a result of their operations.

Biochar producers can currently sell into the voluntary carbon market through platforms such as Puro.Earth or Carbon Future. In order to sell biochar carbon removal credits in the voluntary carbon market, a biochar producer must enroll in a recognized third-party certification system. Participating in the carbon market has fixed costs that are associated with the certification process and there must be a sufficient amount of biochar production to cover these ongoing costs. In general, an annual production of at least 90.7 tonnes of biochar makes the carbon market feasible. [70]

Current programs require biochar producers to report air emissions (including methane), operating temperature, and provide proof that up to 70% of the heat energy is for a productive use—for example, displacing the need for fossil fuel. Therefore, small-scale biochar production systems are typically not eligible. [70]

Most feedstocks used for biochar are eligible for carbon crediting. However, the raw feedstocks must be 'biogenic' like forestry residues, woodchips, agricultural residues, and straw. Non-biogenic materials like tires, plastics, or municipal solid waste are not eligible. [70]

Supercritical notes that there is a lack of high-quality supply of credits in the market, the average price sitting at $153 per tonne, while high-quality biochar has an average price of $220 per tonne. [71]. Only 13% of credits in low-quality biochar projects for 2024 and 2025 have sold, compared to 41% of credits in high-quality projects. The quality of the credits and therefore the cost can be influenced by several factors, including project quality, data availability and assurance, the type of removal technology (nature-based vs. tech-based), and permanence of removal. [72]

Examples of projects in BC include the Cheakamus Community Forest Project that are using carbon offsets as quantified with the BC Forest Carbon Offset Protocol and verified to the BC Emissions Offset Regulation available through managing the forest under ecosystem based management principles. [73]

The verification process involves evaluation of the biochar's feedstock, production facility and end-use application. The methodologies require that producers evaluate each step of the product life cycle which includes sourcing and transportation of biomass feedstock, the transformation process, and the end-use of the biochar. A guide by the International Biochar Initiative and Hamerkop Climate Impacts provides an overview of the various methodologies established by existing certification standards. This resource can assist producers in selecting the most appropriate approach for specific biochar projects. [74]

If using more traditional kiln pyrolysis production methods, one biochar producer recommended adhering to the process outlined in the paper "Producing, Characterizing and Quantifying Biochar in the Woods Using Portable Flame Cap Kilns." The paper outlines simple techniques for quantifying and characterizing the biochar produced and a method for measuring impact. It also discusses qualifying for carbon removal certificates to help recuperate cost of the work.

Summary and Recommendations

Biochar production offers promising opportunities for Creston Community Forest and similar BC entities to advance sustainable wood biomass management and carbon sequestration. Although opportunities for the sale of biochar may be more challenging, there are strong examples of success within the region and evidence of growing markets. Additionally, there are many opportunities for biochar production to provide cost savings in terms of wildfire mitigation work within the local area and opportunities for other beneficial applications on Creston Community Forest's land.

Recommendations for next steps are outlined below:

1. Undertake further detailed cost analysis of a select few biochar production methods and any potential packaging, transportation, and marketing of the product for sale.
2. Look to incorporate a mix of low-tech and high-tech biochar production technologies for use across Creston Community Forestry operations.
3. Identify partnership and funding (including grant) opportunities to offset the upfront capital costs of technology and promote wider community benefits and involvement.
4. Focus on opportunities to use biochar on site and in-situ to ensure economic savings with a view to looking into biochar and/or biochar-compost for sale in the future.
5. Securing one large-scale buyer for biochar will demonstrate to project partners and funders the economic viability of larger versions of this model.
6. Small, in-field testing pilot projects are recommended to determine when and where biochar production and application can be most effective. If successful, these projects will help raise awareness of biochar use.
7. Monitor, track, and verify data from the start of pilot projects to develop a clear and quantifiable value proposition in terms of carbon benefits and ecosystem services.
8. Monitor and track wood waste data to have a clear understanding of feedstock availability.
9. Share the results of this research and development work with interested parties across BC to encourage further research, learning, and sector development.

Appendix

For the anonymous data from the survey with local farmers, please see the supporting spreadsheet document or contact Wildsight's Youth Climate Corp.

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