

Biochar Primer

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Executive summary

Biochar is receiving increased interest as a bioproduct from lower-value biomass streams, including wood harvest and processing residues, agricultural residues and manures, and waste organics from post-industrial or post-consumer streams. It is produced by a variety of technologies. The current dominant choice for biochar production is pyrolysis, which is the combustion of biomass in the absence of outside air. There are at least eight technology pathways which are in use for biochar production, and in some cases technologies are combined (such as pyrolysis and gasification) to produce biochar of specific properties or with specific co-products. These technologies utilize temperatures that range from low (150°C) to extremely high (1200°C). The yields of biochar drop as temperature rises. Current production of biochar is in excess of 350 kt per year.

The key properties of biochar which dictate potential end uses include conductivity (the ability of biochar to conduct or insulate electrical charges), surface chemistry (and particularly the presence or absence of functional groups which can hold elements in place), porosity (which changes related to temperature and which influences the amount of moisture that can be held on the surface), stability (the ability of the biochar to remain whole with limited reactivity to the local environment), and surface area (which is influenced by particle size and porosity).

Because biochar yields are highly variable, the cost of feedstock to produce a tonne of biochar is also highly variable, ranging on average from C\$200-800 per tonne, with some extreme values in excess of C\$1200 per tonne. This cost is directly related to the cost of biomass residues; for this study we use C\$120/t of wood residues as a starting point.

Potentially, the most valuable biochar applications will be found with graphite replacements; other applications, including steelmaking, bioproducts development and water filtration are of interest, while soil amendments, animal feed, and cement additives are likely the least valuable products. The potential value of syngas (from gasification) and bio-oil (mostly from fast pyrolysis) are also very high.

Recommendations to promote the biochar sector in Ontario are provided in the next section.

Recommendations

To develop Ontario's biochar industry, four key recommendations have been developed:

1. **Scale operations to match feedstock availability.** Biochar production is limited by overall residual biomass availability, and much of the available biomass is highly distributed. Mobile technologies may be one answer to help access these sites; biochar production can also be hubbed based on access to feedstock and end users. Research is necessary to understand the best locations and to relate markets to feedstocks.
2. **Capture maximum value from biochar applications.** Relatively low-cost biochar has a value as a soil amendment, animal feed amendment, and carbon capture mechanism. Stacking these values delivers greater returns to users and could allow producers to derive higher returns. Research is needed to identify potential barriers to stacking services from biochar, and to describe ways to communicate these values to consumers.
3. **Invest in product innovation.** The highest value product identified as a potential biochar use is currently as a graphite replacement; however, the quality of biochar required to undertake this use is high and would require extensive processing compared to many other uses. A research program designed to investigate biochar upscaling – improving the key attributes of surface chemistry, stability, and porosity - could help to lower costs and increase the likelihood of entering these sorts of markets.
4. **Consider certification and potential standards for biochar production.** A number of certification schemes exist for biochar, many related to carbon sequestration. The users of biochar in various applications will likely require certainty that products are safe and produced in a sustainable fashion. Embracing certification, or pursuing a standard under the Canadian Standards Association, could be a way to increase confidence and expand access to markets.

Contents

Executive summary	ii
Recommendations.....	iii
1 Introduction.....	1
2 Technology overview	3
2.1 Process	3
A - Pretreatment.....	4
B1 - Hydrothermal carbonization (HTC)	4
B2 - Torrefaction.....	4
B3a - Slow pyrolysis.....	4
B3b - Vacuum pyrolysis	5
B3c - Intermediate pyrolysis.....	5
B3d - Fast pyrolysis	5
B4 - Flash carbonization	5
B5 - Gasification.....	6
Reactor types.....	6
Summary of process yields.....	7
2.2 Important physical characteristics.....	8
Conductivity	8
Surface chemistry	8
Porosity	8
Stability	9
Surface area	9
3 Market opportunities	10
3.1 Summary.....	10
3.2 Environmental services	12
Soil amendment	12
Animal feed	13
Water filtration	14

Mine tailings reclamation.....	15
Carbon sequestration.....	16
3.3 Material applications.....	18
Concrete additive.....	18
Bioproducts	19
Metallurgical applications	21
Graphite replacement	23
3.4 Energy coproducts	24
Syngas.....	24
Bio-oil.....	25
4 Biochar certification.....	26
Carbon Removal Certificates.....	26
European Biochar Certificate.....	26
Verified Carbon Standard (VCS)	26
5 Current producers.....	27
5.1 Canada	27
5.2 International	28
6 Literature cited.....	29

1 Introduction

Biochar is the term that refers to solids generated through pyrolysis of biomass at moderate temperatures. Biochar is sometimes described as a subset of charcoal with some similar properties, although most literature considers the two to be separate and distinct product categories. The production of biochar reduces the proportion of volatile hydrocarbons in the final product, usually through higher temperatures or longer residence times, which makes it less suitable as a fuel (except with advanced technologies such as gasifiers). Biochar is a more stable product than charcoal, capable of sequestering carbon over long periods. In contrast, charcoal is produced primarily as a fuel and the process to generate that product is designed to maintain volatile components.

Evidence of biochar being used specifically as a soil amendment dates back at least 2500 years to Indigenous groups in the Amazonian region of South America, who produced 'Terra Preta', a dark fertile soil that contained high amounts of charcoal-like products and organic wastes; cultures in East Asia also utilized similar approaches to improve soil quality (Soentgen et al. 2017).

Typically lower temperatures will deliver biochar with properties more suitable for soil amendments; higher temperatures will produce more 'pure' biochar with improved surface morphology and thermal stability which could be used for applications such as graphite replacements or energy storage. Biochar typically has a very high carbon concentration (>75%) coupled with low hydrogen (1-5%) and oxygen (<5-20%) (Mishra et al. 2023). Note that higher temperatures and/or elevated pressures tend to lead to higher carbon content and lower hydrogen and oxygen. Biochar can be used as a fuel source, particularly using a gasification approach as this approach introduces the necessary oxygen to achieve combustion of the material (You et al. 2017). However, biochar used as fuel is often referred to as charcoal.

Canada's first dedicated industrial biochar plant was launched in 2025 in Port-Cartier, Québec; it will use 58 kt of forest residues to produce 10-30 kt of biochar annually (Canadian Biomass 2025).

Physically, biochar is a black substance of varying particle sizes. Biochar can be ground to produce a homogenous powder product; particle size can be important for some applications.



Figure 1-1 Biochar from forest residues

Source: Flickr Creative Commons (Oregon Department of Forestry 2015)

2 Technology overview

2.1 Process

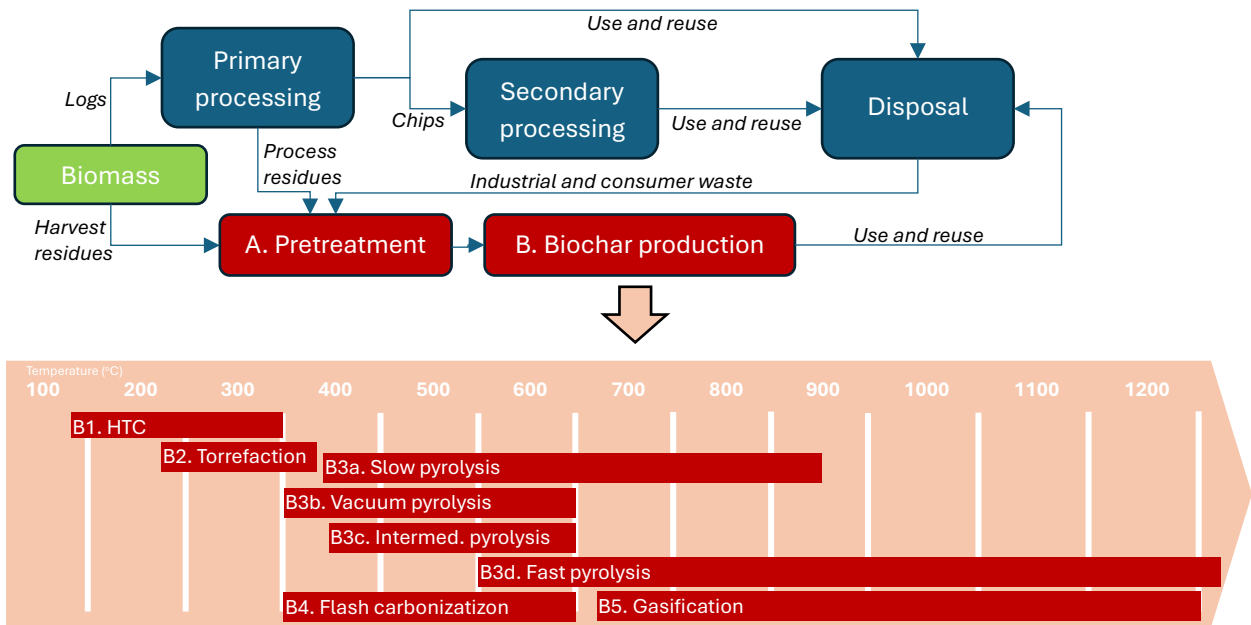


Figure 2-1 Overview of biochar production pathways

Source: Author's creation

Table 2-1 Summary of process conditions for each primary technology

Source: Author's creation, based on review below

	Temp. (°C)	Ramp rate (°C/min)	Residence time	Pressure (MPa)	Particle size (mm)
B1. Hydrothermal carbonization (HTC)	180-280	10-300	>15	1.3-6.7	<.01
B2. Torrefaction	225-950	0.1-5.0	550-950	0.1	5-50
B3a. Slow pyrolysis	350-950	0.1-1.0	200-300 min	0.1	5-50
B3b. Vacuum pyrolysis	300-600	0.1-20	30-120 min	0.02-0.05	5-50
B3c. Intermediate pyrolysis	500-700	1.0-10	0.5-15 sec	0.1	1-5
B3d. Fast pyrolysis	500-1250	200-300	5-20 sec	0.1	<1
B4. Flash carbonization	300-600	>1000	1-30 min	1-2	<0.5
B5. Gasification	600-1200	3-30	1-5		<0.5

A - Pretreatment

Research has shown that the physical characteristics of biomass feedstocks plays a large role in effectiveness of different thermochemical conversion processes. A pretreatment designed to reduce particle size and to achieve some homogeneity in physical size is required to produce a consistent mix of solid, liquid, and gaseous products from the different downstream processes. These pretreatments can be simple such as wood chipping, which produces materials ranging up to 5 cm in diameter, or hammer-milling which produces wood dust with particle size of 1 mm or less. One study highlights that the use of wood pellets in a gasification system produces greater process heat and a more valuable biochar product (Gutiérrez et al. 2021).

B1 - Hydrothermal carbonization (HTC)

The HTC process uses a combination of high temperatures (150-300°C) and high-pressure water (1.3-6.7 MPa) over a period of approximately 30-60 min to produce biochar (sometimes differentiated from other biochar products as hydrochar). Yields can be high using this process, but decrease as temperature rises; at lower temperatures (<200°C) yields of 80-92.5% (mass/mass basis) have been reported (Kim et al. 2015). Higher temperatures (>250°C) produce a biochar with increased calorific values but at decreased yields (35-50% m/m) (Kim et al. 2015, Ercan et al. 2023). It is noted that hydrochar yields at higher temperatures tend to be lower than biochar produced by other pathways (such as slow pyrolysis). Applications for hydrochar include water adsorption, catalytic degradation, and solar evaporators (Zhang et al. 2025).

B2 - Torrefaction

This process usually uses moderate temperatures (225-300°C) and standard pressures, with a ramp rate of 5°C/min and total reaction time of 60 min (Ercan et al. 2023). The environment in a torrefaction vessel can be inert or mildly oxygenated (Zhang et al. 2025). Torrefaction yields can be very high (70-90% m/m) and are in an inverse relationship to process temperature (Ercan et al. 2023). Torrefaction is typically used to produce solid fuels which have improved hydrophobicity and thus are less likely to attract and retain moisture.

B3a - Slow pyrolysis

Slow pyrolysis occurs in an inert environment (the absence of outside air) under moderate to high temperatures (350-950°C), standard pressure, slow temperature ramping (10°C/min) and longer residence times (200-300 minutes) (Song et al. 2025). Yields tend to max out around 45% at low temperatures and decline as temperatures rise to about 30% (m/m) (Ercan et al. 2023, Song et al. 2025). Slow pyrolysis works by gradually reducing

different wood components; at lower temperatures (220-315°C), hemicellulose breaks down, followed by cellulose (315-400°C) and finally lignin (160-950°C) (Zhang et al. 2025). The slower introduction of heat means that lignin monomers are more easily converted into aromatic carbon rings, adding to the degree of aromatization and improving its utility.

B3b - Vacuum pyrolysis

Vacuum pyrolysis occurs in an inert environment which is subject to vacuum, usually under moderate temperatures (300-600°C), reduced pressure (0.02-0.05 MPa), fast temperature ramping (20°C/min) and extended reaction times (30-120 min) (de Jongh et al. 2011). Some authors report using higher temperatures (up to 800°C) (Yan et al. 2021). Yields of biochar range from 45-55% at lower temperatures, but drop down to 35-45% at higher temperatures. Yields also decline slightly as residence time increases, and as pressure within the system decreases (de Jongh et al. 2011).

B3c - Intermediate pyrolysis

Intermediate pyrolysis occurs in an inert environment (the absence of outside air) with moderately high temperatures (350-600°C), standard pressure, moderate temperature ramping (20-100°C/min), and short residence times (10 min) (Ochieng et al. 2023, Tabal et al. 2023). Yields decrease with process temperature, and range from 23-48% (m/m) (Ochieng et al. 2023, Tabal et al. 2023).

B3d - Fast pyrolysis

Fast pyrolysis occurs in an inert environment (the absence of outside air) with high temperatures (500-1250°C), standard pressure, fast temperature ramping (200-300°C/min), and short residence times (5-20 seconds) (Song et al. 2025). While most research suggest that biochar yields from fast pyrolysis are lower than those seen with slow pyrolysis (ranging between 10-32% w/w) (del-Campo et al. 2015, Maaoui et al. 2023), some suggest that higher solid yields ranging between 52-61% are possible (Song et al. 2025). Rapid heating in fast pyrolysis suppresses secondary reactions such as volatile loss more observed in slow pyrolysis, and thus solid yields tend to be higher. Note that while some studies use very high temperatures (>800°C), the majority of work has been done in the lower temperature range, as this maximizes bio-oil yields.

B4 - Flash carbonization

Flash carbonization is carried out in a reactor at moderate temperatures (300-600°C) with a packed bed pressurized to 1-2 MPa. Flame travels through the reactor almost instantaneously, giving a temperature ramp rate of greater than 1000°C/min. Process time

is typically less than 30 minutes (Manyà 2012). Yields from this process are moderate (28-32% m/m) (Zhang et al. 2025).

B5 - Gasification

Gasification uses higher temperatures (usually 600-1200°C) and usually uses air as a combustion agent, although gasification can also be carried out in an inert environment (Manyà 2012, Reyes et al. 2021). Ramp rates for gasification are relatively fast, ranging from 3-30°C/min; faster ramp times can be done using an entrained flow gasification system. The yield of biochar varies with temperature. Under relatively low temperatures, biochar yields from gasification and pyrolysis are similar (10-20%, w/w basis) (You et al. 2017, Gutiérrez et al. 2021). Biochar yield generally declines as peak process temperature rises.

Pilot work has been done to link pyrolysis and gasification, where gaseous products of pyrolysis are fed into a 'riser' which serves to further process the outputs, improving the quantity and quality of syngas and biochar outputs. Biochar yields from a combined pyrolyzer/gasifier were shown to range from 29-45%, and 35% for wood sawdust feedstocks (w/w basis) (Zhou et al. 2022). An overall evaluation of the relative cost for building a more complicated, two-reactor system is not yet available.

Reactor types

Pyrolysis is often carried out in rotary kilns, which spin around a horizontal axis and which employ a slight inclination to assist in material flow through the reactor (Wajda, Bragoszewska 2025). This system is a continuous process which is well suited to large volume production. The ability to control temperature throughout these reactors is more challenging than with a screw-type reactor, and the capital investment is large (Wajda, Bragoszewska 2025).

By contrast, a retort reactor is a simple chamber where the feedstock is loaded in a batch fashion. The chamber is oriented vertically, and the bed of the chamber (either fixed or fluid-bed) is heated until the material in the chamber has been fully processed. Heat is obtained through the combustion of pyrolysis gas which is captured from the process and reintroduced through the bed. Retort reactors are generally used for slow pyrolysis (Wajda, Bragoszewska 2025).

Summary of process yields

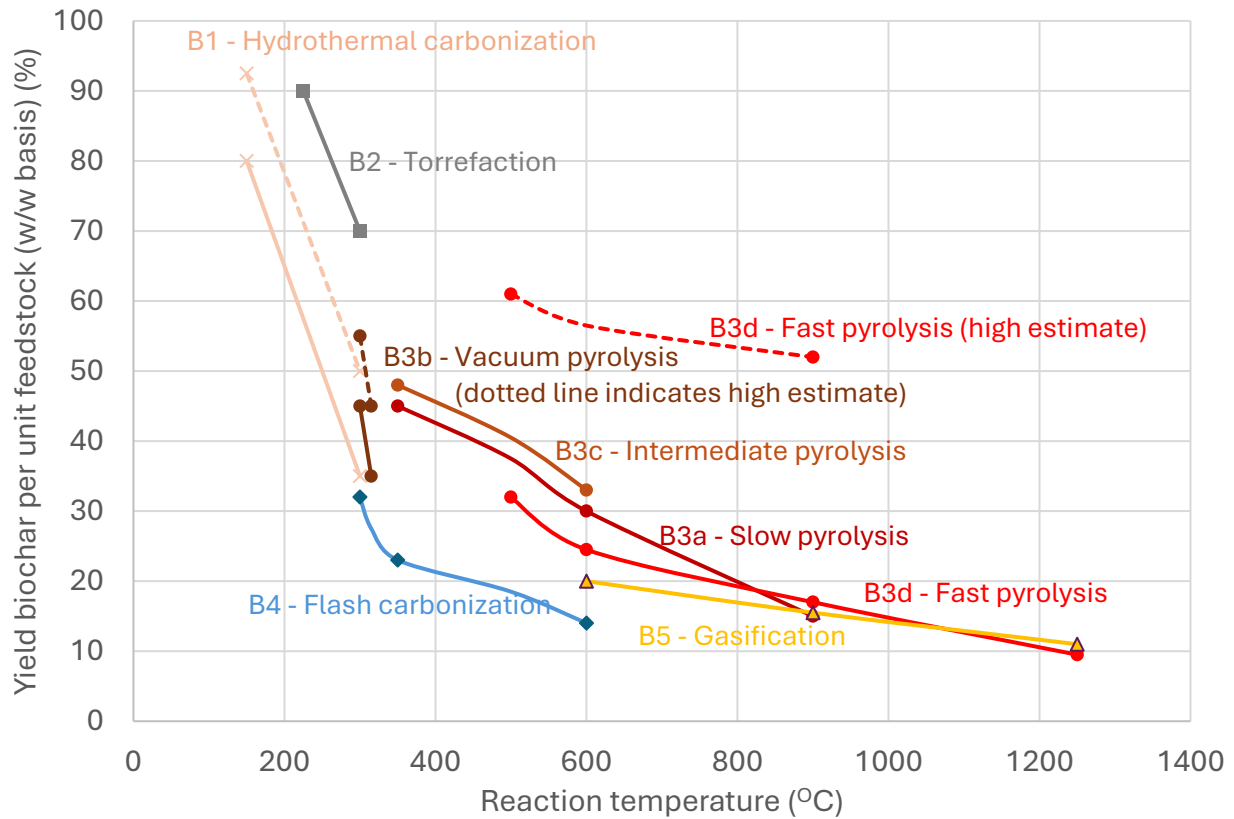


Figure 2-2 Yield of biochar by process and reaction temperature

Source: Author's creation

In Figure 2-2, the approximate yields of biochar by process temperature and by technology are shown. There is a generic trend – higher temperatures equate to lower yields – with variation based on the technology selected. The most biochar per unit of input is in the 80-90% recovery range, but this falls quickly as temperatures rise. As shown in the following section, some of the most desirable biochar properties are typically associated with biochars delivered at higher temperatures, which results in yields that normally range between 10-30%.

2.2 Important physical characteristics

Conductivity

Fused benzene rings found in biochars can allow for electron mobility through the graphite structure. The introduction of transition metals into the biochar production process (e.g., Fe, CO, Ni, or Mn) can help reduce the activation energy required for biochar formation with a higher degree of graphitization (Zhang et al. 2025). Further, it has been shown that biochar produced via slow pyrolysis has improved electrical conductivity compared to fast pyrolysis, with some studies reporting 280X increases in conductivity comparing slow pyrolysis biochars to the product of fast pyrolysis (Song et al. 2025). As biochar evolves, the breakdown of hydroxyl bonds in the biomass leads to a higher pH which makes the product more acidic. Increasing pyrolysis temperatures generally leads to an increase in electrical conductivity (Mishra et al. 2023).

Surface chemistry

Biochar surfaces contain oxygen-based functional groups, such as carboxyl and hydroxyl sites, which can interact with different ions (Singh et al. 2026). These sites give the surface of biochar a negative charge which makes it suitable for the exchange of cations, including calcium, magnesium and potassium (Mishra et al. 2023). These cations are important soil nutrients, which makes biochar useful as a soil amendment in agricultural and horticultural applications. This characteristic also makes biochar useful in applications such as concrete additives, where the ability of the surface to serve as a chelation site for calcium lowers the barrier for the formation of concrete (Singh et al. 2026). Typically, biochars generated at lower temperatures are more likely to maintain the appropriate surface chemistry for these applications (Singh et al. 2026). Surface chemistry of biochar can also be modified through exposure to acids such as sulfuric and nitric acid, which serve to create additional hydroxyl (-OH) or carbonyl (C=O) groups on the surface of the biochar itself (Golbaz et al. 2026). Modified biochars produced at higher temperatures can combine larger pores (increased surface area) with more reactive surfaces.

Porosity

Porosity of biochar is important because the product forms a home for soil bacteria and for water retention. Micropores (< 2nm) are likely be more useful for nutrient management; mesopores (2-50 nm) and macropores pores up to 50 nm are likely to play a stronger role in water management (You et al. 2017). Porosity and density can be enhanced using activation methods. It has been shown that generation of biochar in the presence of guanidine phosphate at 450°C results in more phosphorous (P) and nitrogen (N) groups, which are useful for bonding with various nutrients in the soil and thus essential for nutrient

management. A range of activation chemicals have been shown to improve different characteristics including mesoporosity (NaOH, H₃PO₄) and microporosity (KOH, H₂O₂, KHCO₃) (Zhang et al. 2025).

Pore size and specific surface area are related to temperature. During slow pyrolysis, temperature rises can increase both surface area and pore volume, while average pore size tends to increase with rising temperatures from micropores to mesopores. During fast pyrolysis, pore volume increases but pore size declines, although overall pore size remains larger overall (in the mesopore range). It has been shown that micropores in biochar can occupy more than 80% of the total active surface area, which suggests that biochar pore structure is comprised entirely of micropores when produced at lower temperatures (Mishra et al. 2023). Porosity in biochar produced via gasification tends to be lower than porosity in biochar from slow or fast pyrolysis; the best distribution of pores tends to be found in biochars from slow pyrolysis (Mishra et al. 2023).

Stability

Biochar is not a structural material, as it loses a good deal of the structure of wood due to the loss of water during heating, which removes oxygen as well as hydrogen and which decreases oxygen to carbon and hydrogen to carbon ratios. However, this also increases the bulk density. Biochar can be a very stable product, showing little degradation over time. Process factors that favour stability include higher processing temperatures, slow ramp rates, long residence times, and higher pressures (Leng, Huang 2018). Aromaticity (proportion of aromatic rings) tends to be higher in gasification biochar vs pyrolysis biochar, and rises as process temperatures rise (You et al. 2017). This suggests a more stable chemical structure and thus the potential for longer-term carbon sequestration. Other work confirms that biochar produced at lower temperatures tends to be more prone to the formation of biochar colloids – very small biochar fragments that become suspended in, and can move through, soil-water systems (Meng et al. 2021). Thus, biochar designed for long-term sequestration is best produced at higher temperatures, or utilized in applications (such as concrete additives) that immobilize the biochar product (Singh et al. 2026).

Surface area

Higher surface areas tend to be related to wood, including softwoods and hardwoods, while lower surface areas tend to be related to fast-grown energy crops such as switchgrass (You et al. 2017). Biochar produced through gasification tends to have smaller specific surface area than biochar produced through slow or fast pyrolysis; generally, increased temperature in the process will deliver higher surface areas as the number of biochar particles increases (Singh et al. 2026)

3 Market opportunities

3.1 Summary

The biochar market has been subject to intensive speculation. Estimates of total global market have ranged between US\$365M-\$3B over 2025-28 period (IBI-USBI 2023). A recent report suggests that the global biochar market reached US\$2.2B in 2024, and will rise to US\$6.3B by 2033, with a combined annual growth rate of 10.9% (Research and Markets 2025). The top end uses for biochar include its use in agriculture and horticulture as a soil amendment, followed by use in livestock feed, water filtration, and as a source for building materials, concrete and asphalt, and carbon for steelmaking (IBI-USBI 2023).

The cost of producing biochar is dependent upon three things – the base cost of biomass (estimated at C\$120/t for wood residues), technology cost, and biochar yields. In Figure 3-1 below, the range of feedstock costs associated with different technologies are shown; a trend of increasing costs and wider ranges of cost is shown. Thus higher yield technologies (e.g., HTC) have lower feedstock costs. Note that technology costs are not included here.

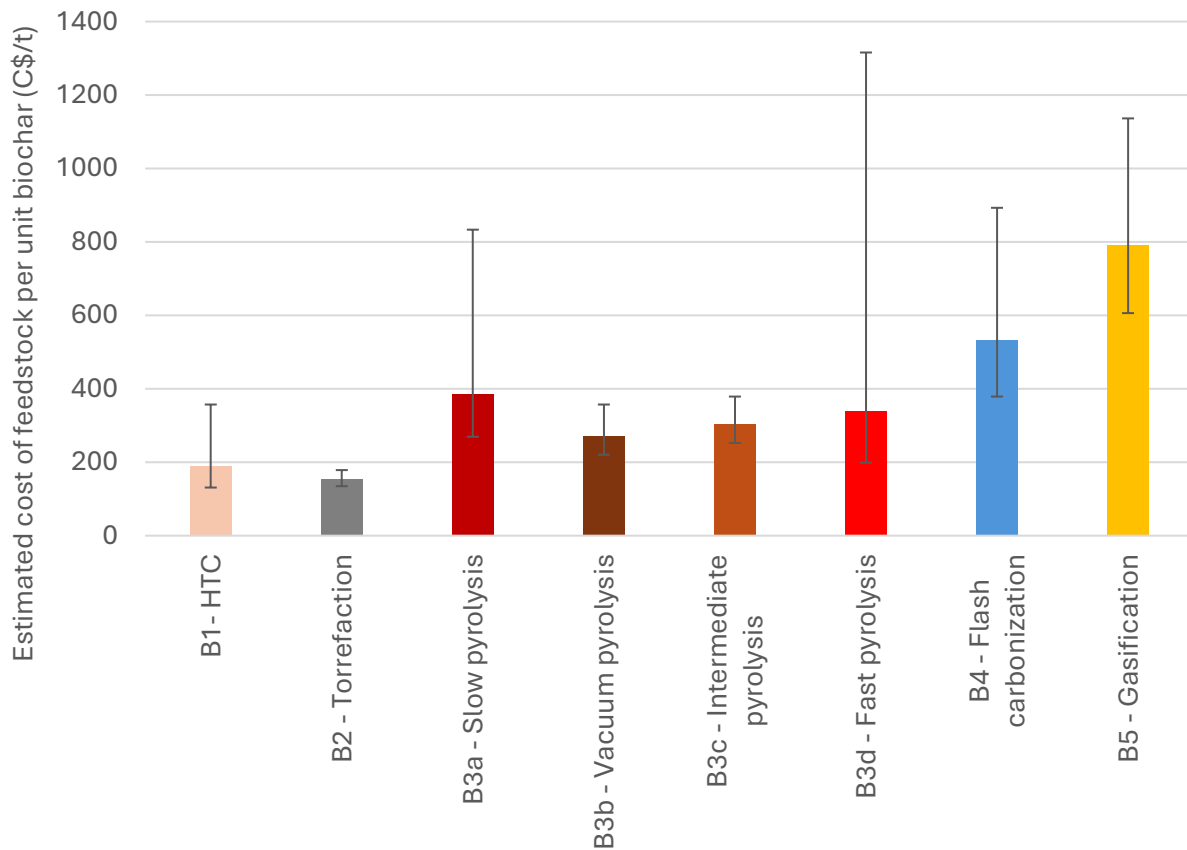


Figure 3-1 Relation between technology and estimated feedstock costs

Source: Author's creation

While it can be assumed that most biochar being produced today is being sold as a soil amendment, the size of the market is difficult to assess as statistics are not kept on biochar applications. Biochar production in 2023 was estimated to be 352 kt, growing from 96 kt in 2021 (IBI-USBI 2023).

Biochar products currently sell for a range of prices. Much of it is sold at the consumer scale, which means that per unit costs are very high. Revenues to biochar producers in 2023 were reported at US\$330M, while distributors earned another US\$38.9 and equipment manufacturers earned US\$241.3M. This suggests that producers earned an average of US\$937.5/t of biochar, although it should be stressed that these figures were self-reported (IBI-USBI 2023). Ranges of values for different products are shown in Figure 3-2. Details on each product group are found in the following sections.

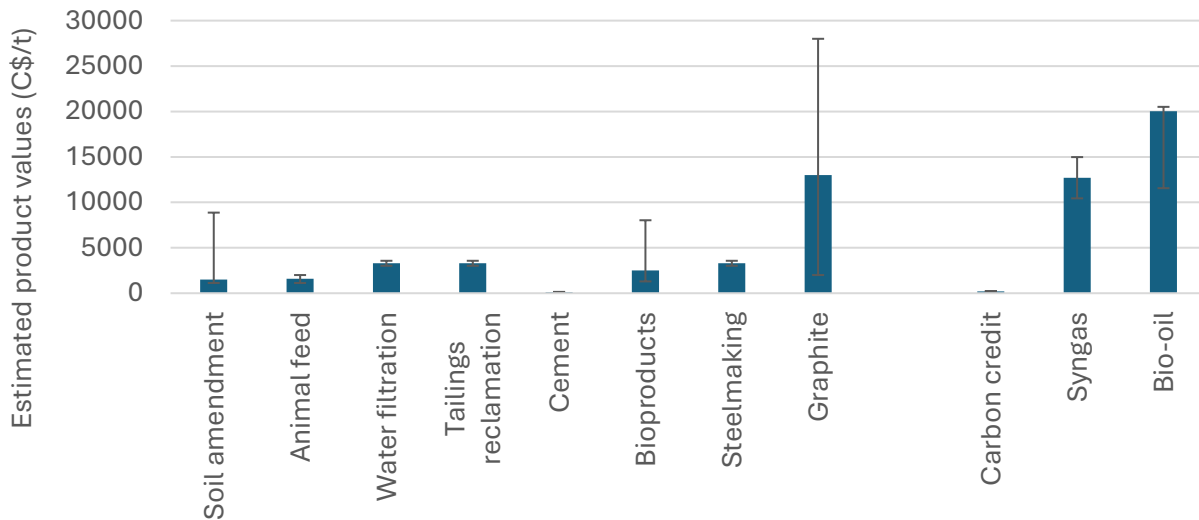


Figure 3-2 Estimated product values for biochar applications

Source: Author's creation

3.2 Environmental services

Soil amendment

Biochar can increase the ability of soil to retain water; one study suggests that biochar-treated claysols could see increased water availability of between 10-24%, depending upon the biochar feedstock, the process temperature, and the amount of biochar applied (Yang et al. 2025). The primary factor that



Figure 3-3 Biochar as a soil amendment

Source: Flickr Creative Commons (CenUSA Bioenergy 2013)

drives water adsorption and water availability in the soil is likely biochar porosity, but work has shown that this factor is not a perfect predictor of increases or decreases in soil water availability (Rasa et al. 2018). It has been shown that wood biochar increases water content in sandy loams, while poultry litter biochar decreases water content in the same soils (Yi et al. 2020). Biochar in its native form is not a fertilizer and does not bring additional nutrients into the soil; however, it's role in maintaining soil moisture is also important in increasing access to nutrients (Tlustos et al. 2019). Recent work has shown that 5% application rates of biochar resulted in optimal improvements to soil nutrients including calcium, potassium, magnesium, and phosphorus; increasing the application rate of biochar beyond the 5% rate did not result in any improvement and indeed was marked by a decline in nutrient availability (Shembo et al. 2025). Many biochar producers see a potential for a combined biochar/fertilizer application; in 2023, this was the number one priority of surveyed biochar producers (IBI-USBI 2023).

Biochar is present on Canada's list of Primary Fertilizer and Supplement Materials, as maintained by the Canadian Food Inspection Agency (CFIA 2026a), which allows for pyrolysis products of at least 60% carbon to be used as a soil amendment under Canadian law. For example, Haliburton Forest Biochar sells biochar at C\$60 for a 7.5 kg bag, which translates into C\$8,000/t (Haliburton Forest Biochar 2026). An 8 kg bag of 'activated and inoculated' biochar can be had for C\$139.99, which translates into close to C\$17.5k/t (Jocelyn's Soil Booster 2026). In both cases, these are gross value that does not discount the processing, packaging, distribution, and stocking costs which would be incurred by the producer and intermediary. Bulk shipments of biochar can be purchased in the US for costs ranging between US\$1,124/t (C\$1530/t) (for an unmodified biochar) to US\$6,458/t (C\$8870/t) (for a 50/50 blend of biochar and compost) (Wakefield 2026).

Animal feed

Biochar can be used as a supplement in animal feeds, having been shown to positively influence animal growth in terms of weight gain and nutrient intake, and also being linked to reduced enteric methane emissions from ruminants (Man et al. 2021). The use of biochar in animal feed relies on the stability of the structure and its ability to absorb water and



Figure 3-4 Livestock feed

Source: Flickr Creative Commons (United Soybean Board 2013)

nutrients, which allows the biochar structure to help deliver nutrients throughout the digestion process, particularly in ruminants (Kazemi 2025). While some suggest that biochar additions could lower feedstock costs (Kazemi 2025), other research suggests that the uptake of biochar as a feed additive will depend on factors including carbon credit prices; for example, with a biochar price of US\$2000/t and a carbon credit value of US\$25-75/t, one study suggests that farmers would not receive a profit unless animal growth increased by 5% (Bilotto et al. 2024).

It has been shown that the majority (70-90%) of biochar fed to cattle survives digestion, which then finds its way into soil through manure (Walz et al. 2026). This suggests that the same biochar can perform as both a feedstock amendment and a soil amendment, effectively doubling the value of the biochar itself. To date, this has not been reflected in cost-benefit analyses of this product use.

A challenge with this use case is the need to gain regulatory approval for any new feed amendment. In Canada, these rules are set down in the Feeds Regulations (Canada 2024). At the current time, biochar is not listed under the Canadian Feed Ingredients Table (CFIA 2026b).

The market for animal feed additives is very large; in Canada, it is predicted to grow from US\$798M (C\$1.1B) in 2024 to US\$1.28B (C\$1.75B) in 2035 (Spherical Insights 2025). Biochar pricing for these products is likely to follow bulk biochar pricing (rising from C\$1530/t).

Water filtration

Biochar has been proposed as a tool for water filtration. The primary mechanism that supports this use is the conductivity of the biochar, as studies have shown that biochar is most effective at screening charged molecules as the biochar carries a charge itself (Peterson et al. 2021). Biochar has been suggested as an alternative to anthracite carbon



Figure 3-5 Water filtration results

Source: Flickr Creative Commons (Canadian Light Source 2026)

in water treatment, and performs at a comparable level in the removal of contaminants such as dissolved organic carbon (da Silva et al. 2025). Interestingly, biochars produced at lower temperatures (280°C) were found to be most effective (da Silva et al. 2025).

Biochar has been used in modified slow sand filters to improve the uptake of heavy metals such as arsenic in drinking water purification; studies point out that while other mechanisms may clear heavy metals faster, the biochar option is generally a local and lower-cost option in many parts of the world (Khan et al. 2025). One challenge raised with the use of biochars in water filtration is the potential production of disinfection by-products; chlorinated products such as chloroform and dichloroacetonitrile were found with eucalyptus-sourced biochar, suggesting the potential for the formation of other by-products over time (Youngwilai et al. 2022).

Certain bioproducts can be generated using biochar for water treatment, including Cu-Fe bimetallic biocomposites designed for wastewater treatment. This type of product is made using advanced oxidation processes that include metallic catalysts; testing with this product suggested that higher pyrolysis temperatures (800°C) tended to work best, as the biocomposites generated could reduce up to 90% of methylene blue from wastewater within 20 minutes (Jalilian et al. 2026). Research on these types of biocomposites is still at early phases.

Biochar would most likely replace activated carbon in the water filtration space. This market is very large, valued at US\$5.6B (C\$7.7B) in 2025 and expected to grow to US\$11.9B (C\$16.4B) in 2034 (Fortune Business Insights 2026a). Activated carbon currently sells at prices ranging between US\$2200-2600/t (C\$3020-3570/t) (Intratec 2026).

Mine tailings reclamation

Research into the use of biochar as an additive to mine tailings has been ongoing for a number of years. The primary factor that allows biochar to perform this role is a combination of porosity, surface area, and cation exchange capacity (Rengarajan et al. 2025). Work in Italy highlighted the ability to use biochar to reduce the mobility of toxic metals including cadmium,



Figure 3-6 Mine tailings

Source: Flickr Creative Commons (arbyreed 2024)

lead, titanium, and zinc in the tailings by applying biochar at up to 10% content (Fellet et al. 2011). Biochar is often included as part of a phytoremediation strategy, where accumulator plants designed to take up contaminants in mine tailings are planted in biochar-amended areas; the addition of biochar reduces the speed of uptake of heavy metals in the plants significantly (>50% reduction for most heavy metals) and thus improves their chances for long-term success (Williams, Thomas 2023, Rosas-Ramírez et al. 2025). When mixed with fertilizers, biochar amendments mixed up to 5 cm in depth in mine tailings supported growth of tomato crops in Pakistan, with tomato plants avoiding uptake of heavy metals from the tailings for at least five years (Achakzai et al. 2025).

Biochar can also be used to remove metals from mine drainage. One study used manganese- and quinizarin-modified biochars in constructed wetlands and found that biochar could support increased removal of aluminum, iron, copper, zinc, and arsenic from mine drainage (Atilano-Camino et al. 2026). Other studies have considered the use of biochar, usually in combination with manure or other fertilizers, in stabilizing tailings mud from tailings ponds, finding that biochar has a positive impact on overall soil stability (Muñoz et al. 2016).

As in water filtration, biochar acts very much as activated carbon in the treatment of mine tailings. The activated carbon market is very large, valued at US\$5.6B (C\$7.7B) in 2025 and expected to grow to US\$11.9B (C\$16.4B) in 2034 (Fortune Business Insights 2026a). Activated carbon currently sells at prices ranging between US\$2200-2600/t (C\$3020-3570/t) (Intratec 2026).

Carbon sequestration

Biochar can be a stable option for long-term storage of carbon, as the chars break down very slowly. Some work suggests that it would take 400 years for biochar to lose 1% of its carbon content, while other studies suggest a mean carbon



Figure 3-7 Carbon capture opportunities

Source: Flickr Creative Commons (Greenfleet Australia 2016)

residence time ranging from 732-1061 years (Fang et al. 2015, Li,

Tasnady 2023). The primary factor that drives carbon sequestration is product stability; biochars delivered from higher temperature processes tend to be more stable and thus biochars produced at higher temperatures produce longer-lasting chars that sequester carbon over a longer period (Fang et al. 2015).

As of early 2026, 5% of the cumulative global investment into durable carbon dioxide removal (CDR) was reported to be in biochar, representing US\$180.5M (C\$250M) over the period 2021-2025. While biochar lags behind direct air capture technologies (US\$2.2B, C\$3B) and mineralization (US\$505.4M, C\$695M), it is the third largest area of investment, and the largest related to biomass use (CDR.fyi 2026). Between 2022 and the first half of 2025, about 3.04 Mt of biochar carbon removal credits were contracted; 1.6 Mt of these were sold in the first half of 2025. The largest purchasers are Microsoft, Google, BCG, and JPMorgan (CDR.fyi 2025). Biochar is at the present time (early 2026) the largest durable carbon dioxide removal credit category in the world, with over 290 unique purchasers making transactions in excess of 10 t; this outpaces enhanced weathering (60 purchasers) and direct air capture (58 purchasers) (CDR.fyi 2025). The credits being sold only represent a portion of total biochar production: 2023 data indicates that 242.7 kt of biochar carbon credits were contracted, which is equivalent to about 127.7 kt of biochar, as one t of biochar delivers 1.9 t of carbon dioxide sequestration (IBI-USBI 2023). Total production of biochar reached about 352.3 kt (IBI-USBI 2023, CDR.fyi 2025), suggesting that only 36% of biochar produced is being used for carbon removal credits. More than 58% of surveyed producers in 2023 reported not receiving income from carbon credits (IBI-USBI 2023).

There are at least three well-accepted methodologies for generating biochar credits, from Puro.earth, Verra, and Isometric. These methodologies each address both feedstock and production, but have different areas of focus; Verra focuses on biogenic wastes with accredited technologies, while Puro.earth addresses a range of feedstocks and reactors,

and Isometric has strict rules on feedstocks but less guidance on reactors (Sylvera 2026). The average price paid for biochar carbon credits in 2025 was US\$164/t (C\$225/t), up from US\$131/t (C\$180/t) in 2023 (Sylvera 2026). Carbon credits can be monetized through a number of pathways, including policy & compliance pathways (e.g., meeting emission reduction frameworks imposed by a subnational or national government), voluntary carbon market credits (e.g., credits sold on spot or contract basis, usually to corporations looking to meet ESG goals), long-term offtake agreements (e.g., credits sold under contract for future carbon removals, again generally to large enterprises or carbon funds), or through carbon removal as a service (e.g., credits delivered through a long-term agreement with monitoring, reporting and verification, usually to companies looking to meet ESG goals). Carbon values can be embedded into the price of biochar products being sold for different purposes (Polaris 2026).

3.3 Material applications

Concrete additive

Biochar can be added to concrete mix at various concentrations, which can serve to increase strength and lower weight while also sequestering carbon and reducing the amount of sand or cement required. In these applications, surface chemistry is the most important factor. It has been noted that biochar finer particles can accelerate the setting time of



Figure 3-8 Concrete surface

Source: Flickr Creative Commons (J E Theriot 2008)

cements through surface chemistry interactions, particularly when biochar is produced at lower temperatures (<500°C) (Singh et al. 2026). One study suggested that 2% biochar prepared at 500°C would deliver increases in compressive strength (23%) and electrical resistivity (27.6%) (Bhavya et al. 2026). Similarly, the incorporation of biochar produced at between 500-700°C within concrete at 1-10% substitution (w/w basis) leads to faster CO₂ uptake, improved calcium carbonate formation, and better strength properties (Murali, Kravchenko 2026).

Generally speaking, up to 10% of cement or up to 60% of sand in concrete can be replaced with biochar, delivering increases to compressive strength (10-40%), flexural strength (15-107%), and tensile strength (5-25%), while reducing density by 5-20% (Singh et al. 2026). A Canadian study report optimum levels of biochar additions have been reported at around 2%, which can increase compressive strength by 19%, flexural strength by 12%, and tensile strength by 20%, while also reducing porosity and thus water absorption into the finished concrete (Patel et al. 2025).

Amrize (formerly Lafarge Canada) is working with Carbon Lock Tech on the incorporation of biochar into concrete products, although it is not clear to what extent this partnership has progressed (Carbon Lock Tech 2026). The total volume of cement produced in Canada in excess of 13 million tonnes per year (Statistics Canada 2019); the current value of ready-mix concrete is between C\$206-346/m³, which is about equivalent to C\$88-147/t (Canadian Building Materials 2026). If 2% of the cement production in Canada was replaced by biochar, this would suggest a market of 270 kt per year.

Bioproducts

A range of bioproducts utilizing biochar have been explored, including biocomposites for water treatment (Jalilian et al. 2026) as discussed elsewhere. Porosity is a key factor in determining the suitability of biochar for combination with other materials to produce unique bioproducts, as porosity increases the ultimate surface area and allows increasing numbers of bonds.



Figure 3-9 Plastic with additives

Source: Flickr Creative Commons (Mendel Heit 2010)

One interesting biochar application is in combination with fire retardants to create a bioplastic product. The larger pores found in biochars produced at higher temperatures ($>500^{\circ}\text{C}$) are suitable for bonding with fire retardants such as ammonium phosphate, which in turn can be combined with other materials (such as wheat gluten) to form bioplastics with unique fire resistant properties (Das et al. 2023). Similarly, polyamide/biochar biocomposites (50/50 w/w basis) have been developed with significantly improved tensile strength (+44%) and improved thermal stability, allowing the bioplastic to resist decomposition at elevated temperatures (Baniasadi et al. 2025).

The surface chemistry of biochar influences its interaction with other materials, and may need to be modified depending on the desired blend. For instance, work with polylactic acid (PLA)/biochar blends demonstrate that an unmodified biochar derived from lignin can adversely impact the strength and thermal properties of the composite product, whereas a modified biochar has a positive impact. The surface chemistry of biochar can be modified via an acid treatment as discussed previously, generally using sulfuric or nitric acid washes to increase the number of bond sites on the surface. A modified biochar blended with PLA at 3:100 (w/w biochar:PLA) delivered higher tensile strength, with between 22-140% increases in the tensile strength at break depending upon the degree to which surface chemistry was modified (Golbaz et al. 2026).

Biochar has been mixed with various polymer compounds in 3-D printing applications (Day et al. 2026), in biofoams (Chang et al. 2021, Uram et al. 2021), and in automotive parts manufacture (Tadele et al. 2020), at mixes of between 3-20% w/w basis. The specific application and compound in question dictate the required biochar properties, but

typically increased surface area, consistent particle size, and surface chemistry are the primary considerations in biochar blends.

The market for bioplastics is huge, estimated at US\$18.4B (C\$25.3B) in 2025, expected to grow to US\$67.4B (C\$92.6B) by 2033 (Grand View Research 2025). The value of different bioproducts can vary widely, however; for example, PLA is often sold as a spooled filament for 3-D printing at prices between C\$1300-2500/t (3D Printing Canada 2026). Polyamide (or nylon) prices tend to be higher, averaging US\$5847/t (C\$8030/t) (ChemAnalyst 2026).

Metallurgical applications

Biochar has been proposed as both an energy source for iron and steel production and as a carbon source in steelmaking. Iron and steel is mostly produced through two major technologies – the blast furnace and the electric arc furnace, with the former accounting for 70% of global steel production and the latter accounting for 20% (Wajda, Bragoszewska 2025). Electric arc furnaces are primarily used to melt scrap steel for recycling (Sarker et al. 2024). As a fuel, biochar helps to reduce overall global warming potential by reducing greenhouse gas emissions; one study suggests that about 73.7% of emissions could be reduced using wood-based biochar in the blast furnace (Meng et al. 2024).



Figure 3-10 Steelmaking

Source: Flickr Creative Commons (Vladimir Korolev 2012)

Biochars used for energy purposes must have low ash content (<5%) and high elemental carbon content (75-90%), and furthermore should have low porosity, high strength, and high energy density/calorific values (Wajda, Bragoszewska 2025). One area where biochar could be used is in the manufacture of metallurgical coke, which is typically derived from anthracite coal and which is preferred for use in blast furnace-basic oxygen free processing to deliver steel. Coke itself is produced through carbonization of coals; biochar can be blended into the coking blends in various ratios, usually between 2-10% on a w/w basis. Increasing beyond this ratio lowers fluidity and coke reactivity as well as coke strength (Sarker et al. 2024).

Biochar can also be used in sintering (the preparation of iron for steelmaking) and in the blast furnace itself. Where coke is the primary input into steelmaking, biochar substitution is limited by its lack of structural strengths, which generally suggests that the maximum substitution level is about 20% (Al Hosni et al. 2024). The structural strength of coke is important for ensuring that the bed of the blast furnace maintains permeability, allowing gases to pass through and support the reaction. For iron and steelmaking using coal dust, the maximum substitution of biochar ranges between 50-100% (Safarian 2023, Sarker et al. 2024).

One tonne of steel can be produced using 1.4 t of iron, 0.8 t of coal/coke, 0.12 t of recycled steel, and 0.3 t of limestone (Sarker et al. 2024). This suggests that a plant that utilizes biochar might use between 0.16-0.4 t of biochar for every tonne of steel produced. In

Ontario, demand for coke is presently in decline. At Algoma Steel (Sault Ste. Marie), the blast furnace process has been decommissioned in favour of electric arc steel production, meaning that coke use is essentially ended at that facility. The ArcelorMittal Dofasco plant (Hamilton) has been promising a shift to new production pathways that would shift to natural gas and reduce the need for solid fuels (van Dongen 2025), although they currently operate coke ovens and blast furnaces on site. CHAR Technologies has a partnership with ArcelorMittal Dofasco, in which the latter has invested C\$6.6M into CHAR; CHAR's biocarbon has been used in both blast furnace and electric arc furnace facilities operated by ArcelorMittal Dofasco (CHAR Technologies 2023), although it is not clear if this is the case in the Hamilton coke ovens.

The Stelco plant (Hamilton) no longer produces steel, but does produce coke as well as finished steel products (from the Lake Erie site) with a reputed 1.3 Mt/year capacity for coke production. There has been work done with Stelco partnering with Walker Industries to utilize wood waste in the form of railway ties as a source of energy and carbon in coke production. At the Walker facility, railway ties are ground up and sent for processing to produce 'biocarbon', which is then blended with coal in coke production at the Stelco site; the process has used 20,000 t of used railway ties (Walker Industries 2024). It is likely that the production of biocarbon is carried out in partnership with CHAR Technologies, which is in operation in Thorold and which uses the HTC process to produce biocarbon and biochar (CHAR Technologies 2026). Stelco also operates the Lake Erie Works, with a capacity of 2.5 Mt of steel production per year, which suggests coke requirements of 2.0 Mt per year (Stelco 2021).

Graphite replacement

Biochar has been examined as a potential substitute for graphite, which can be used in supercapacitors and batteries. The primary factor that influences the suitability of biochar to serve as a graphite replacement is carbon content, with higher carbon contents, is



Figure 3-11 Batteries

Source: Flickr Creative Commons (StefanSzczelkun 2012)

product stability. Batteries usually use mineral or synthetic graphite as an anode. Mineral and synthetic graphites are highly ordered and stable, meaning that they do not interact with the lithium within the batteries which gives the battery longer life. Typically, biochar needs to be subjected to graphitization – extended heating at high temperatures - before it is suitable for battery use (Weijers et al. 2025). Gasification-derived biochar has been considered for use in batteries because this biochar tends to be more stable, with a high specific surface area and a lower content of polyaromatic hydrocarbons (Weijers et al. 2025). Biochar derived from a gasifier operating at 836°C was obtained at a yield of 1.2% (w/w) and with a carbon content of 96.06%.

To be suitable as a graphite replacement, biochar needs to be subjected to graphitization. This essentially means reheating the biochar in the presence of a catalyst to drive the formation of crystalline graphite structures. A pulverized biochar can be mixed with a catalyst like iron nitrate, nitrogen nitrate, or magnesium nitrate at high concentrations (e.g., 20% w/w catalyst to biochar) to drive the graphitization process, and then subjected to intensive heating at 1000-1300°C, with fast ramp rates of 10-20°C/min and residence times ranging between 3-5 hours; the final product is then cleaned of remaining catalyst (Shi et al. 2024, Weijers et al. 2025). Graphitization was shown to increase the crystallinity of the biochar dramatically, rendering it into a highly suitable biographite product (Shi et al. 2024). One major challenge with utilizing biochar for biographite production is the relatively low yield of biochar, particularly with higher carbon content. Decreasing yields have a negative impact on the overall life cycle, leading to a negative carbon footprint (Ubando et al. 2025).

The market for graphite, specifically for use in battery and energy storage applications, is strong, with demand reaching 5.7 Mt in 2024 (NRCan 2026); natural graphite typically sells at US\$8000-11000/t, (C\$11000-15000/t) while synthetic graphite has a value of US\$20000/t (C\$27500) (Westwater Resources 2026). The global market for graphite is expected to reach a value of US\$15.3B (C\$21B) by 2034 (Fortune Business Insights 2026b).

3.4 Energy coproducts

Syngas

Synthesis gas (or syngas) is a mixture of hydrogen, carbon dioxide, carbon monoxide, methane, and nitrogen that is often used in the production of energy (heat and power) or as a feedstock for fuel production (e.g., hydrogen or Fischer-Tropsch fuels) (Vásquez et al. 2025). Most syngas is used on site rather than being sold, although hydrogen derived from



Figure 3-12 Gas works

Source: Flickr Creative Commons (Punchup 2007)

syngas may become a tradeable commodity (Seraj et al. 2026). While gases are produced through pyrolysis, they tend to have more contaminants and are not usually denoted as syngas; gasification, which focuses on producing gaseous outputs, tends to provide a cleaner syngas and more complete breakdown of the substance (Antelava et al. 2021). Pyrolysis gas yields from fast pyrolysis may be as high as 38.5% (w/w) with biochar yields of approximately 23.8% (Seraj et al. 2026). By comparison, syngas yields from gasification of wood have been reported to reach 80-90% (Suparmin et al. 2024, Pai et al. 2026), with biochar outputs of as low as 5% (Pai et al. 2026).

While most syngas is used on-site or within a local industrial complex, it may be possible to isolate hydrogen as a product that can be pipelined to other locations and thus sold as a commodity output. Recent work suggests that hydrogen could be produced from a combined system which incorporates hydrothermal carbonization as well as gasification, with a minimum selling price of about US\$10900/t (C\$14980/t) higher than the present-day price for hydrogen derived through steam gasification (US\$7600/t, C\$10440/t) (Seraj et al. 2026).

Bio-oil

Bio-oil is the liquid fraction derived through different pyrolysis approaches. When bio-oil is the desired product, processes such as fast pyrolysis tend to deliver higher yields.

Research has shown that inert gas rate and residence time tend to be the factors that are most correlated to bio-oil generation

(Karimi et al. 2026). It should be noted that bio-oil production comes at the cost of biochar yields, with slow pyrolysis most suited to generating higher fractions of biochar, and intermediate or fast pyrolysis able to deliver higher fractions of synthesis gas and bio-oil (Mukherjee et al. 2022). Yields of bio-oil from fast pyrolysis can be in the 50-66% range, compared to about 10-20% biochar (w/w basis) (Carrier et al. 2013).

The market for bio-oil is estimated to grow, from US\$370.1M (C\$510M) in 2024 to US\$435.3M (C\$598M) by 2030 (Market Research.com 2025). Producers in Canada include Ensyn (Ontario; fast pyrolysis) and Arbios Biotech (BC; hydrothermal liquefaction). The value of bio-oil, corrected on a per tonne basis, has been estimated to range between C\$11560-20510/t (Snowden-Swan et al. 2016); however, the market for this product is still somewhat limited, and the production pathway is likely restricted to fast pyrolysis technologies.



Figure 3-13 Bio-oil

Source: Flickr Creative Commons (PNNL 2014)

4 Biochar certification

Carbon Removal Certificates

Carbon Removal Certificates (CORCs) are issued by Puro.Earth; these were developed and first issued in 2019 and are designed to provide a credible framework for carbon removal technologies. CORCs are only awarded to projects that can demonstrate durably stored carbon with net negative emissions. Biochar is one pathway acknowledged by this system.

The issuance of a CORC requires suppliers to make a claim, which is audited by independent assessors trained by Puro.Earth; the cost of the audit is borne by Puro.Earth to assure independence. CORCs can be sold to any venue, marketplace, or broker as well as directly to other companies. CORCs are tracked through the Puro Registry, which uses a blockchain type approach to ensure that these credits are not double-counted (Puro.Earth 2026).

European Biochar Certificate

The European Biochar Certificate (EBC) is a voluntary industry standard based in Europe. At least one country (Switzerland) has set this standard as obligatory for biochar vendors in that nation. This standard was developed by the Ithaka Institute, which is based in a number of countries including Switzerland. The EBC is focused on biomass feedstocks (ensuring that they are produced and procured sustainably) as well as a range of uses, including soil amendments, animal bedding, and as an additive in construction materials as well as batteries (European Biochar Certification 2026).

Certification through the EBC involves a technical pre-audit, followed by sampling which is tested in an endorsed laboratory, and finally ongoing monitoring of each biochar batch which must be tested. EBC certification is in effect for one year after a batch is produced (Carbon Standards International 2026).

Verified Carbon Standard (VCS)

The Verified Carbon Standard program (VCS) is operated by Verra described as the world's most widely used GHG creditation program. This standard is currently on its 5th iteration, and involves a rigorous methodology. It claims to have accredited about 2600 projects around the world with 1.3 Bt of GHG emission reductions. Verra is headquartered in Washington DC, USA. The approach includes detailed accounting methodologies that are used to quantify the GHG benefits of a given project, as well as a public Registry Systems (the Verra Registry) (Verra 2026). The VCS standard is currently offered by the Standards Council of Canada (SCC 2026).

5 Current producers

5.1 Canada

Company	Location	Production	Notes
Airex Energy https://airex-energy.com/carbonity-plant/	Quebec	10-30 kt/year biochar	Biochar, biocarbon, biocoal outputs (2 plants)
BC Biocarbon https://www.bcbiocarbon.com/	British Columbia	?	Produces biochar, CO2 removal certificates certified by Puro.earth (C\$173/t CO2e) (Foresight Canada 2023)
Biomass Energy https://biomassenergytechniques.com/	Alberta	-	Sells rotary drum pyrolysis chambers (C\$392/m3 biochar) (Foresight Canada 2023)
Charterra https://www.charterra.ca/	Alberta	?	Sells biochar to greenhouses and farmers (C\$292-365/m3 biochar) (Foresight Canada 2023)

5.2 International

Company	Location	Production	Notes
Air Burners https://airburners.com/	USA	-	Sells a series of air curtain burners
American Biochar https://ambiochar.com/	USA	80k acres improved	Sells biochar
Applied Carbon https://www.appliedcarbon.com/	USA	?	Uses mobile pyrolyzers, sells credits
ArSta eco https://arstaeco.com/	India	?	Charcoal, biochar, biocarbon
Arti https://www.arti.com/biochar/	USA	?	Sells technology as well as biochar outputs
Arukah https://www.arukahcapital.com/	Singapore	10 kt CO ₂ e/year	Pyrolysis, anaerobic digestion
Biochar Now https://biocharnow.com/	USA	?	Biochar sales
Biochar Supreme https://www.biocharsupreme.com/	USA	?	Biochar sales (Black Owl Biochar)
BioEnergia https://aperambioenergia.com.br/en/	Brazil	220 kt charcoal	Eucalyptus to charcoal
Carboneers https://www.carboneers.earth/	Ghana, India	119.2 kt CO ₂ e	Pyrolysis; cumulative removals (biochar)
Carbofex https://carbofex.fi/	Finland	1 kt/yr biochar 0.6 kt/yr bio-oil	Biochar, bio-oil, and 8000 MWh clean energy
Charm https://charmindustrial.com/	USA	11.76 t CO ₂ e	Mobile pyrolyzers; cumulative removals (bio-oil and biochar)
Coaltec Energy https://www.coaltecenergy.com/	USA	?	Manure-based ecochar
EcoEra https://ecoera.se/	Sweden	?	Biochar from pyrolysis of pellets; district heat; CDR credits
ETIA https://etia-group.com/	France	-	Pyrolysis units for biochar and bio-oil production
Exomad Green https://www.exomadgreen.com/	Bolivia, Chile	108 kt biochar	Largest supplier of CDR (carbon dioxide removal) credits
Genesis Biochar https://genesisbiochar.com/	USA	?	Biochar supplier
High Plains Biochar https://www.hpbiochar.com/	USA	?	Biochar seller, equipment supplier, provides tech support (C\$446/m ³ biochar) (Foresight Canada 2023)
Oregon Biochar Solutions https://www.chardirect.com/	USA		Biochar producer (C\$268/m ³ biochar) (C\$266/t CO ₂ e) (Foresight Canada 2023)
Pacific Biochar https://pacificbiochar.com/	USA	?	Modify biopower plants for biochar (C\$107/m ³ biochar, C\$270/t CO ₂ e) (Foresight Canada 2023)
Planboo https://planboo.eco/	Thailand, Laos, others	-	Digital measurement, reporting and verification technology
Pyreg https://pyreg.com/	Germany	30 kt CO ₂ e/year	Installed 50 plants
Varaha https://www.varaha.earth/	India	?	Works with small landowners – usually agricultural residues
V-Grid Energy Systems https://vgridenergy.com/	USA	10 bioservers in operation	Technology, biochar and bioliquids (C\$360/t CO ₂ e) (Foresight Canada 2023)
Wakefield Biochar https://wakefieldbiochar.com/	USA	?	Sells biochar as soil amendment (C\$336/m ³ biochar) (Foresight Canada 2023)

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