Forest harvest residues available in Eastern Canada – a critical review of estimations

by Stephanie Parzei¹, Sally Krigstin¹, Kaho Hayashi² and Suzanne Wetzel^{2,*}

ABSTRACT

Accurate estimations of quantities of forest biomass, which can be economically and sustainably supplied to market in Eastern Canada, will provide the required basis for sound policy development and encourage investment in the bioeconomy. A critical review of existing estimations of forest harvest residues found that the differences in these estimations for Eastern Canada can largely be explained by varying considerations of ecological, technical, economic, and social limitations. It is suggested that spatial and temporal estimations, along with the use of cost supply curves and economic models at the finer scale, will give realistic estimates of sustainable biomass quantities, moving estimations from theoretical potential to actual market availability.

Keywords: harvest residue, forest biomass, estimation, availability, supply, market, bioenergy, Eastern Canada, BIMAT, BiOS

RÉSUMÉ

Des estimations précises des volumes de biomasse forestière, qui pourraient approvisionner de façon économique et durable le marché de l'est du Canada, permettront de jeter les bases de politiques rationnelles et d'encourager les investissements dans le secteur de la bioéconomie. Un examen critique des estimations actuelles sur les résidus de récolte forestière a révélé que les différences dans les estimations réalisées pour l'est du Canada peuvent s'expliquer en grande partie par diverses considérations liées aux limites écologiques, techniques, économiques et sociales. Nous postulons que les estimations spatiales et temporelles, ainsi que l'utilisation des courbes de coûts d'approvisionnement et des modèles économiques à une échelle plus petite, généreront des estimés plus concrets des quantités durables de biomasse, les faisant passer d'estimés d'un potentiel théorique à une disponibilité réelle sur le marché.

Mots clés : résidus d'exploitation, biomasse forestière, estimation, disponibilité, approvisionnement, marché, bioénergie, est du Canada, BIMAT, BiOS

Stephanie Parzei

Sally Krigstin

Kaho Hayashi

Suzanne Wetzel

Introduction

Diversification and innovation are vital to the Canadian forest industry, fuelling interest in the bio-based economy. In Canada, there is high potential for the bioeconomy due to our small population and relatively large number of managed forests, providing a subsequent gross timber supply amounting to 240 Mm³ annual allowable cut (NRCan 2012). Accurate knowledge of biomass accessibility and sustainable supply will encourage

the development of appropriate policies and initiatives and promote investment into developing more efficient bioenergy processes. Forest harvest residues—such as treetops, branches, and low-value wood—represent a largely unexploited supply of biomass. Several studies and inventories have been conducted with the aim to quantify the amount of forest harvest residue available within Canada's managed forests (e.g., Wood and Layzell 2003, Bradley 2007, Sidders *et al.* 2008, Dymond *et al.* 2010).

¹Faculty of Forestry, University of Toronto, 33 Willcocks St., Toronto ON M5S 3B3

²Canadian Wood Fibre Centre, Natural Resources Canada, 580 Booth Street, 7th Floor, Ottawa ON K1A 0E4

*Corresponding author. E-mail: Suzanne.wetzel@nrcan.gc.ca

However, there is a very high variation among these estimations and little consistency as to how they were derived and what assumptions were made. The approaches used have often been large-scale (national or provincial level) and focused on the possible maximum availability of harvest residue, with a lack of consideration of various limitations towards market availability of harvest residues. This makes application of existing estimations for development of a new and sustainable industry in any given location difficult. Overall, it is expected that as further considerations for technical, economic, ecological, and social limitations are made on a finer scale, estimates of forest harvest residue availability in Eastern Canada will become smaller and closer to actual market availability.

The objective of this paper is to critically evaluate and compare existing estimates of forest harvest residue availability in Eastern Canada (Manitoba–eastward), considering methods employed and assumptions made in creating these estimates. Factors expected to cause variation between estimates include spatial boundaries of study areas, restrictions on residue removal for ecological purposes, harvest systems and technologies used, consideration of site accessibility and feasibility of residue removal, and consideration of the economics of residue removal (Gronowska *et al.* 2009). Further, exploration of American and European methods of estimation will aim to determine if approaches used elsewhere allow for economic, social, or ecological limitations to be considered and thus lead to reliable market available estimations of harvest residue beyond the theoretical level, which may be of interest in the Canadian context. Suggestions of how to move harvest residue estimations closer to market availability at a smaller scale will also be provided.

Forest Harvest Residues

Forest biomass is defined as all parts of the tree, including trunk, bark, branches, needles, leaves, and roots. Harvest residues include treetops, branches, leaves, low-value residual standing trees, and other residues left in the forest or at roadside after harvesting operations (NRCan 2010). Potential advantages in utilizing these materials include the generation of additional revenue for the forest industry and reduction of the burden of biomass material disposal. Removal of small, low-value standing trees can also help to improve the growth of the residual forest in partial harvest systems, such as selection or shelterwood harvests, by reducing competition for resources for the remaining, better-quality trees. Further, removal of harvest residues can also reduce accumulation of material that feeds forest fires and can improve forest health by reducing resources for pests and invasive species (IEA Bioenergy 2002, Bartuska 2006).

Harvest residue availability can vary from site to site depending on forest type, stand maturity and age, stand composition, harvesting method, and site characteristics (Wetzel *et al.* 2006). The desired forest product and stand characteristics dictate the type of harvesting carried out in a specific location. In turn, the chosen silviculture system, as well as harvesting method, influences the amount of harvest residues produced and left in the forest or at roadside (Sidders *et al.* 2008).

Necessary Considerations for Accurate Estimates

Accurate estimation methods need to be spatially and temporally explicit and should consider economic, technical, ecological, and social limitations to residue removal. As such, they should determine market potential of harvest residue, which refers

to the amount that can be produced given a required level of economic profit and sustainability. This depends on the cost of production, as well as price of harvest residues, characteristics of biomass conversion technologies, price of competing energy sources, and energy policy scheme (Chum *et al.* 2011). The following are some necessary considerations that should be incorporated into estimation methods.

Ecological

While removal of forest harvest residues can improve forest stand health by reducing the risk of wildfire (IEA Bioenergy 2002), there are several biodiversity and ecological considerations to limit the amount of residue that can be sustainably removed from the site. Tree branches and tops that remain at sites can provide essential wildlife habitat, prevent soil erosion, maintain essential nutrient minerals in soil, reduce negative effects on surrounding water ecosystems, and help maintain soil carbon stocks (IEA Bioenergy 2002, Wood and Layzell 2003, Lattimore *et al.* 2009). Downed coarse wood can also help retain soil moisture by binding water and refracting solar radiation. Further, harvest residues can reduce scarring of landscapes by stabilizing logging roads and skid trails. Certain tree species should not be removed, as they are crucial for maintaining biodiversity, endangered species, or other species dependent on dead wood (Lattimore *et al.* 2009, Skog *et al.* 2013). On the other hand, in some cases, harvest residue left on site is in excess of that needed to sustain ecological health and the removal can in fact be beneficial. One positive effect of residue removal is advancement of tree growth in early stages of stand development (Malinen *et al.* 2001). Excess harvest residues left on site can also contribute to fire risk and introduction of invasive species, so removal can reduce the cost of controlled burning, can improve productivity, and can improve forest health of residual stands (IEA Bioenergy 2002, Bartuska 2006). Therefore, the amount of harvest residue that should be left in the forest is dependent on local conditions. Since such factors are usually very site-specific, finer-scale analysis is needed to determine the amount of biomass that is sustainably available to market (Wood and Layzell 2003).

Social

Social limitations on biomass availability are less understood, but can be linked to forest ownership or societal perceptions. Owners of private forests might be reluctant to remove residues for energy production, making this biomass potentially unavailable for removal (Markowski-Lindsay *et al.* 2012). For example, an owner might believe that residue removal is not worthwhile since harvest residues are a low-priced forest product, or because they hold the opinion that all biomass should be left on site to provide nutrients for long-term timber production (Egnell and Borjesson 2012). Further, societal perception of harvest residue removal and its impact on the forest can influence biomass policies and interventions. However, increased demand for woody biomass and thus increased biomass collection for energy can supplement incomes and help to revitalize the struggling forest sector.

Economic

Some of the major limitations of harvest residue availabilities stem from economic factors. Associated costs with residue removal include equipment, labour, transportation,

storage, and opportunity costs, which together can be substantial. Site characteristics and location of harvest residues can negatively impact operational efficiency and contribute to economic and technical limitations on residue removal (Perez-Verdin *et al.* 2009, Egnell and Borjesson 2012, Cambero and Sowlati 2014). It can be very costly to remove harvest residues from sites that are small, with low-density stocks, or with long transport distances along uneven forest terrain. Also, traditional harvest technologies may not be suited to or efficient for residue removal, especially from sites that have steep slopes or uneven ground. Existing transportation networks should be considered since the type of transportation, travelling distances, or difficulty to access the site from conversion facilities can contribute to the level of transportation costs (Chum *et al.* 2011). Through an analysis of regional and international biomass supply chains, the transport of bulky harvest residues by trucks can be economically uncompetitive and energy-inefficient for distances longer than 50 km to 150 km (Dornburg and Faaij 2001, McKeough *et al.* 2005, Chum *et al.* 2011). It is therefore unlikely that all theoretically available harvest residues can be removed for energy due to such economic and technical limitations of the operation. Potential solutions to this problem are comminution before transport of harvest residues to conversion facility, which can reduce costs of a long transport, or technical innovation to efficiently include residue removal in forest operations. This may be difficult to achieve though, since woody biomass is a low-priced commodity and costs of residue removal are currently high. Therefore, subsidies or other economic incentives will likely be needed to encourage investment for technical improvements.

In addition, other problems include economic feasibility compared to lower prices of other energy sources and prevailing energy policies, such as subsidies and taxes on other alternatives, which can make it difficult to expand use of harvest residues for energy (Egnell and Borjesson 2012).

Current Estimates

To date, Canadian estimates for the amount of available harvest residue within managed forests have mostly generated a maximum theoretical availability of residues at the national or provincial scale (Paré *et al.* 2011). While the majority of these studies start with similar roundwood harvesting estimates and conventional forest inventory systems, final harvest residue production estimates vary from study to study (Richardson *et al.* 2006, Dymond *et al.* 2010). A description of estimates of forest harvest residues available annually from Canadian forests is presented in Paré *et al.* (2011). Table 1 shows values for Eastern Canada (Manitoba–eastward).

Wood and Layzell (2003) based their estimate on a model by Penner *et al.* (1997), which converted merchantable tree volumes to biomass components per hectare. Then, they determined the amount of non-stem biomass available within each province (Wood and Layzell 2003).

A spatially explicit model, named Biomass Inventory and Mapping Assessment Tool (BIMAT) was developed by Agriculture and Agri-Food Canada (Sidders *et al.* 2008) to determine the supply amount and spatial distribution of herbaceous and woody opportunity biomass within a specified distance or radius of a point of interest. The model is publicly available online as an interactive decision support tool based on Geographic Information Systems (GIS). The model projects the roadside harvest residue availability within the commercial forest land (Sidders *et al.* 2008).

Following the creation of the BIMAT model, Bradley (2010) provided high and low estimates of harvest residue availability in Canada. The high estimate was taken directly from BIMAT and was to be the maximum sustainable level of harvest residue based on allowable annual cut (AAC) in each jurisdiction. However, since actual harvest levels are generally below AAC, Bradley (2010) calculated a lower estimate of actual available roadside harvest residue. The method used to determine this lower availability was not provided.

Table 1. Current estimates of forest harvest residue in Eastern Canada (Manitoba–eastward)

Reference	Annual residue availability (million dry tonnes)	Data based on	Constraints considered	Model used
Wood and Layzell 2003	59.51	National forestry inventory	No	by Penner <i>et al.</i> 1997
Dymond <i>et al.</i> 2010	17.27	Allowable annual cut (AAC)	No	Carbon Budget Model (CBM-CFS3)
Sidders <i>et al.</i> 2008	13.23	Mill consumption, harvesting method, location	No	BIMAT
Bradley 2010	13.23	Same as Sidders <i>et al.</i> 2008	No	BIMAT
Bradley 2008	2.58	Allowable annual cut (AAC)	No	No data
Wood and Layzell 2003	29.76	National forestry inventory	50% (Ecological /technical)	by Penner <i>et al.</i> 1997
Bradley 2010	11.09	Same as Sidders <i>et al.</i> 2008	No data (Based on actual harvest volume)	No data
Dymond <i>et al.</i> 2010	8.64	Allowable annual cut (AAC)	50% (Technical /ecological / economical)	Carbon Budget Model (CBM-CFS3)

Finally, Dymond *et al.* (2010) estimated spatial and temporal distribution of theoretical harvest residue availability across Canada between 2005 and 2020. They simulated different types of harvesting events (e.g., clearcut, commercial thinning, precommercial thinning) using the Carbon Budget Model (CBM-CFS3). The Carbon Budget Model is a spatially explicit stand- or landscape-level model that creates, simulates, and compares various forest management scenarios to assess impacts on carbon stocks (Kull *et al.* 2011). It simulates individual annual disturbance events, such as harvesting, and uses sophisticated algorithms to convert volume to biomass (Kurz *et al.* 2009). Rather than analyzing at the national level, Dymond *et al.* created 503 individual management units in their study area, Canada's managed forest south of 60°N, to track forest types and carbon stocks. Future projected harvest levels were adjusted based on current harvest levels and growth rates. Although a lower estimate should account for technical, economical, and ecological limitations, they lacked site suitability maps and data. Therefore, they used a 50% net-down factor, according to ~40% net-down factor for soil protection and additional 10% for biodiversity needs based on a EU study as well as technical and operational limitations of residue removal (Dymond *et al.* 2010).

Analysis of Current Estimates and Need for Improvements

Most of the current methodologies and assumptions are literature-based, large-scaled at the national or provincial level, and based on yield, land area, previous harvest data, residue generation rates, and/or sustainability factors (Gronowska *et al.* 2009). This makes it difficult to use the information to establish finer-scale industries in any given location. Bradley (2008) provided provincial-level values for "major forestry provinces" with little information about methods. Dymond *et al.* (2010) used a finer scale by tracking forest types and their carbon stocks through the Carbon Budget Model and then scaled up the results to provincial level. Sidders *et al.* (2008), BIMAT, provided the finest-scale estimates to date, at mill level; however, it considered only large mills with over 100 000 cubic metres of annual consumption. As smaller mills are more prevalent in Eastern Canada, finer-scale residue estimates are required for industry development.

Other common information gaps present in residue estimations made to date include limited consideration for social, technical, ecological, or economic constraints, which will lower the actual residue availability. While these estimates provide key information on theoretical availability of harvest residues, future estimations should be considered to include limitations on residue removal. The retention rates of harvest residues vary from 0% to 100% based on large-scaled residue inventories (Titus *et al.* 2009). However, retention rates should consider soil suitability, biodiversity, water quality, and other local characteristics within various forest types, and thus there is no fixed rate that can be applied to all sites across Canada. The BIMAT model is the only one model that considers spatial distribution of harvest residue based on mill requirements; however, it does not include economic cost analysis or other limitations. Although Sidders *et al.* (2008) stated that inclusion of value chain analysis and recovery and transportation costs are being considered, this is not yet available.

Lastly, most existing estimates are static representations of theoretical availability at time of study that do not consider year-to-year variations in harvest rates and economic factors. Dymond *et al.* (2010), however, did provide a preliminary temporal analysis by considering wood supply forecasts for 2005 to 2020. Temporal analysis, nonetheless, is difficult to achieve, as many factors are unknown or difficult to predict into the future. Technological change, inter-annual variability in growing conditions, climate change, and changing energy prices could affect market availability of residues from year to year. Further, harvest rates may change because of socio-economic drivers (e.g., demand for different types of products), changes in AAC, or legislation and policy changes (Dymond *et al.* 2010).

A recent study by Alam *et al.* (2012) represents an initial local-scaled analysis of harvest residue availability within an Eastern Canadian context. The study assessed annual harvest residue availability for bioenergy production from 18 forest management units (FMUs) in Northwestern Ontario. The average theoretical availability of harvest residues in Northwestern Ontario was 60 m³/ha or 52.56 green tonnes per hectare, and 3.2 million green tonnes for the entire site (167 184 ha). The technical availability considering the forest health and technical limitations based on literature review in the study site was 67% of theoretical availability, which was 40.2 m³/ha or 35.21 green tonnes per ha, and 2.1 million green tonnes for the entire site (Alam *et al.* 2012). Costs through the value chain or social limitations were not considered.

Other Studies in the World

To date, Canadian estimations of harvest residue availability have been large-scale since forest areas are extensive and interest in biomass has only recently arisen. However, in other locations where biomass research is more long-standing, such as Europe and the U.S., tools are being developed to determine supply and cost information at a finer scale (Richardson *et al.* 2006). Considering such studies is valuable in order to improve the Canadian estimation of market availability of harvest residues. Table 2 shows the comparison of those studies.

Research by Rorstad *et al.* (2010) aimed to estimate harvest residues from 23 890 stands of privately owned productive forests in Norway, projecting three scenarios with different constraints. The result was a lower residue availability in the "environmental" scenario, since ecological limitations reduced the availability (Rorstad *et al.* 2010).

In the United States, many large-scale estimates of harvest residue utilize methods similar to those in Canada and base their analysis on inventories, with little consideration for economic or ecological limitations. However, several more recent studies used a finer scale and incorporated economic analysis, biophysical characteristics, and social considerations. The USDA Forest Service provides data on county-level availabilities of forest residue across the country and predicts future harvest residue availability based on timber harvests up to 2050 (Walsh 2008). A cost model, taken from an unpublished manuscript by McQuillan *et al.* (1988), was applied to determine the estimated cost of removing harvest residues at the county level, using inventory data, removal and chipping costs, hauling distances, transportation costs, stocking densities, terrain slope, and wood type (Walsh 2008). These data were then summarized into national-level estimates for various removal costs and for several time frames.

Table 2. Example of studies in forest harvest residue in the world

Reference	Study site	Model used	Output	Constraints considered
Alam <i>et al.</i> 2012	NW. Ontario (Public)	By Reynolds <i>et al.</i> 2008	Harvest residue and underutilized wood volume per square kilometer	33% – forest health and technical constraints
Rorstad <i>et al.</i> 2010	Norway (Private)	GIS model	Profitable threshold in energy price and transportation distances	3 scenarios with and without economic /ecological constraints
Walsh 2008	U.S. (county level)	by McQuillan <i>et al.</i> 1988	Cost distribution of removing harvest residue	35% – technical constraints Also included economic constraints
Perez-Verdin <i>et al.</i> 2009	Mississippi State, U.S.	Cost–supply curves	Spatial distribution of harvest residues for ethanol production	Economic /technical /social constraints
Stasko <i>et al.</i> 2011	6 SE. States, U.S. (county level)	Cost-minimizing linear program	Spatial distribution of harvest residue and cost	Economical /technical constraints
Markowski-Lindsay <i>et al.</i> 2012	Massachusetts State, U.S. (Private and public)	FVS (Northeast Forest Vegetation Simulator) by Kelty <i>et al.</i> 2008	Residue available at sustainable level	6% – technical constraints Social constraints include forest owners' willingness to harvest residues

Other studies provide state-level estimates that consider economic, technical, social, and/or biophysical constraints. In Mississippi, Perez-Verdin *et al.* (2009) strived to estimate the amount and spatial location of harvest residues available for production of ethanol. Although technological efficiency of converting harvest residue to bioethanol was estimated to be 35% or up to 60% if electricity was co-produced, annual harvest residue production was derived as a function of production costs and technological efficiency for several intervals from 40 km to 240 km transport distance (Perez-Verdin *et al.* 2009).

Stasko *et al.* (2011) developed a finer-scale study utilizing cost–supply curves in southeastern US. Over 1600 feedstock origination locations and over 500 possible bioenergy plant locations were considered to model the cost and feedstock availability. The authors concluded that transportation cost significantly varied with location. Regions with low annual net growth or steep slopes, such as the Appalachian Mountains, tended to have higher transportation costs from the field to facilities and required specialized equipment. It is very important to include plant locations as costs vary across geographic region (Stasko *et al.* 2011).

Taking another approach, Markowski-Lindsay *et al.* (2012) studied social and biophysical constraints on harvest residue removal in Massachusetts. Unlike other studies, this research considered the preferences of private forest owners and their willingness to remove harvest residues for revenue. As revenue increased, willingness to collect harvest residue for energy increased. The resulting estimate was much lower than previous studies due to incorporation of social constraints (Markowski-Lindsay *et al.* 2012).

Overall, studies within Europe and the U.S. have moved towards finer-scale analysis that incorporates limitations on removing all theoretically available harvest residues. They tend to use economic models and cost–supply curves to determine the amount of harvest residues that can sustainably and affordably be removed from the forest given energy prices, accessibility, transportation costs, and social constraints.

Economic Models and Cost–Supply Curves

As seen in the above examples, economic studies of biomass availability use models to calculate the amount of harvest residues that could be supplied at various prices (Gronowska *et al.* 2009). Such studies create cost–supply curves illustrating how much harvest residue is economically available based on different collection and transportation costs, energy prices, land availability, yield levels, and opportunity costs of supplying harvest residues to local market. Cost–supply curves can, therefore, aid in determining the best location and size of a facility for a cost-effective business with a sustainable supply of harvest residue (Chum *et al.* 2011). These assessments provide information for establishing sustainable forest-based facilities in any given location.

In Canada, some preliminary movements towards economic models and supply chain analysis have been made. BIMAT is one of the finest-scaled estimates of residue availability. However, the model is not updated at the moment. Another encouraging project that has potential to estimate market availability of harvest residues is the Biomass Opportunity Supply Model (BiOS). This model has been developed by FPIInnovations to assess the economic feasibility of collecting forest biomass for energy using integrated supply and cost modules. The key features of the model include the estimation of biomass supply feedstocks, machine costing procedures, productivity predictions, and energy balance assessments (Cormier and Ryans 2006). The framework compares different scenarios for both integrated and non-integrated biomass harvesting systems, which depend on resources available, demand levels, government policies, and manufacturing facilities. First, potential supply of harvest residue can be calculated using stand attributes and logging inventories. The single-tree biomass equations calculate the merchantable volume and biomass components using species merchantable volume and topping diameter. Recoverable harvest residues are estimated from previous logging data, accessibility, environmental retention rates, and technical functionality. BiOS also includes a cost module based on machine-costing procedures

considering a rate per productive machine hour and productivity such as terrain conditions, operation logistics, and biomass characteristics. Currently, the model is customized and officially used by Quebec's Ministry of Natural Resources and Wildlife, as well as applied to various projects in British Columbia, Alberta, and Saskatchewan (FPInnovations n.d.) To date, this model has been built upon available information and certain assumptions were needed to fill information gaps. Therefore, additional ground-level validation studies are still required, along with actual biomass harvesting trials, in order to determine accuracy of the model (Cormier and Ryans 2006).

Conclusion

Many Canadian estimations of forest harvest residue made to date have used a broad-scale approach based on forest inventories, leading to a wide range of estimates. The discrepancy between these results makes it difficult to construct a complete and consistent picture of harvest residue supply and its geographic distribution (Walsh 2008). They have mostly determined theoretical availability of harvest residues and are likely to overestimate the actual market availability, especially if accessibility and feasibility of residue removal have not been considered. Incorporation of social, technical, economic, and ecological limitations tends to considerably lower the estimates of harvest residue availability. Therefore, future estimations of actual harvest residues available for development of a stronger bioeconomy would benefit from finer-scale analysis that includes site-specific sustainability considerations.

Moving forward, spatial and temporal estimations, along with the use of cost supply curves and economic models at the finer scale, should be utilized to estimate realistic and sustainable harvest residue supplies. Local-level supply curves are useful in determining feedstock costs for a specific biorefinery and for examining production scales in terms of available land, costs, size of facilities, and profitability (Walsh 1998). Dymond *et al.* (2010) represented a first valuable method of determining theoretical spatial and temporal distribution of harvest residues, with an approximation of ecological potential. The BIMAT model represents a positive move towards estimation of spatially explicit market availability. Further development and inclusion of value chain analysis, recovery costs, and temporal analysis should be considered to become a valuable, user-friendly tool beneficial towards developing a better understanding of actual biomass feedstock availability and subsequently strengthening the bioeconomy in Canada. The FPInnovations BiOS model is very effective in estimating actual harvest residue availability and associated profitability at local scale.

Other factors to be considered within future research and development of forests as a feedstock for the bioeconomy include technological improvements, changing forest owner and societal views, impacts of climate change on forests, energy policies, prices of competing energy sources, and demand for forest products. For example, as technology develops, operational efficiency of residue collection will increase and bioconversion technologies will improve. Such progress will likely increase market availability of residues, moving supply closer to theoretical potential (Paré *et al.* 2011). Additionally, beyond economic modelling and rigorous local-scale estimation, more research into the use of other technologies for harvest residue estimation

could be beneficial. For example, use of remote sensing and Light Detection and Ranging (LiDAR) may be useful for assessing harvest residue accumulation within specific sites. Accurate estimations of market availability, improved awareness and education, increased funding, technological innovation, and market development can lead to a stronger bioeconomy in Canada.

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