

Comparing Alternative Biomass Supply Options for Canada: What Story Do Cost Curves Tell?

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Policy makers and investors often need to consider trade-offs between alternative biomass-based energy supply options. Supply cost potentials for three bioenergy feedstocks prevalent in Canada including agricultural residues, dedicated woody crops, and forest harvest residues are summarized. Each feedstock has its own particular cost characteristics depending on the quantities involved. Importantly, this synthesis revealed significant differences in the uncertainty associated with the cost estimates, with agricultural residues having the greatest variation, followed by woody crops and postharvest forest residues, respectively. One implication of this uncertainty is that the attractiveness of each feedstock option likely depends on local market demand conditions and producer circumstances, making definitive aggregate supply estimates challenging.

Keywords: Biomass Feedstock; Supply curve; Agricultural residues; Woody crops; Forest residues

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INTRODUCTION

According to theoretical estimates, 5.1 EJ of energy per year could be physically available from biomass-based sources in Canada (Wood and Layzell 2003). While the use of bioenergy for localized power and heat generation is growing (Bradburn 2014), high transportation distances and biomass extraction costs can limit both the production and consumption of biomass-based feedstocks. Managers, policy makers, and investors need to consider cost trade-offs between alternative biomass-based bioenergy supply options. In Canada, the most prevalent biomass-based feedstocks include agricultural residues (*e.g.*, corn stover), dedicated woody crops, and forest harvest residues. Agricultural residues can be sourced annually, but quantities available for bioenergy use may be limited by competition for other purposes, such as livestock feed. These residues also may be constrained by residue extraction limits based on environmental concerns, such as preventing erosion and soil nutrient loss (Gallagher *et al.* 2003; Gronowska *et al.* 2009; Kumarappan *et al.* 2009; Perlack and Stokes 2011). Woody crops have the potential to offer more concentrated supplies but it takes time to grow them before plantations can be harvested. Woody crops may also have higher supply costs due to adoption inertia among landowners and land use competition with agriculture (Parks 1995; Parks and Hardie 1995; Isik and Yang 2004; Smith *et al.* 2005; McKenney *et al.* 2014; Yemshanov *et al.* 2015; Hauer *et al.* 2017). Forest harvest residues are readily available in some regions as a by-product of forest harvesting (Ralevic *et al.* 2008; Dymond *et al.* 2010; Paré *et al.* 2011; Niquidet *et al.* 2012).

In fact there are few studies that have generated comparative cost assessments for Canada for these feedstocks (Gronowska *et al.* 2009; Kumarappan *et al.* 2009).

Relationships between supply potentials and costs can be summarized with aggregate supply curves. Aggregate supply curves indicate prices in which producers would be willing to provide quantities of the good in question. These cost curves provide estimates of marginal costs faced by industries in providing ever-increasing amounts of supply (Henderson and Quandt 1985). For example, woody crops might be easily grown on high-productivity sites close to users, but costs will increase as production expands to less productive sites at further distances from the market. Limited amounts of land and suitable sites increase costs and eventually, in the absence of technological change, drive supply costs up to the point where curves may become vertical (*i.e.*, increases in price do not increase available quantity).

A comparative summary of Canadian biomass supply curves is provided in this study. Available cost data from Canada and northern U.S. states were examined for three common bioenergy feedstocks: agricultural residues, dedicated woody crops, and forest harvest residues. A brief comparison of these common biomass feedstocks is provided to identify and illustrate some basic economic issues associated with bioenergy production possibilities in Canada.

METHODS

The comparison is based on literature estimates and the authors' own studies of supply costs for Canada and the northern United States. Prices were converted to 2012 Canadian dollars (Bank of Canada 2015). Maximum, minimum, and average prices and corresponding supply quantities were identified and combined into aggregate supply curves (*i.e.*, price-quantity estimates). The results illustrate relationships between average price and supply quantity, and also provide a sense of the uncertainty around these estimates.

Literature that compares agricultural residues, woody crops, and forest residuals in Canada is scarce, with a few studies representing the majority of the data available. Gronowska *et al.* (2009) compares fifteen Canadian and American studies that provided estimates on available quantities of biomass at different farm-gate (and the equivalent for non-agricultural biomass) prices. The authors concluded that energy crops and logging residues would make up the majority of the supply of biomass (Gronowska *et al.* 2009). Alternatively, Kumarappan *et al.* (2009) compared farm gate equivalent prices for energy crops, agricultural residues, forest and mill residues, and urban waste in both Canada and the United States. These authors concluded that agricultural residues, post-harvest forest residues, and mill residues represent more than half of Canada's biomass feedstock supply (Kumarappan *et al.* 2009).

RESULTS AND DISCUSSION

Results

As shown in Fig. 1, biomass supply cost curves were depicted in a single frame of reference, with shaded areas defining the highest and lowest cost values. The results suggest that each feedstock has its own unique cost characteristics, with a clear distinction between the average cost values and the bounds of their variation. Agricultural residues have the lowest average supply costs, with woody crops and post-harvest forest residues

having increasingly higher average supply costs, respectively.

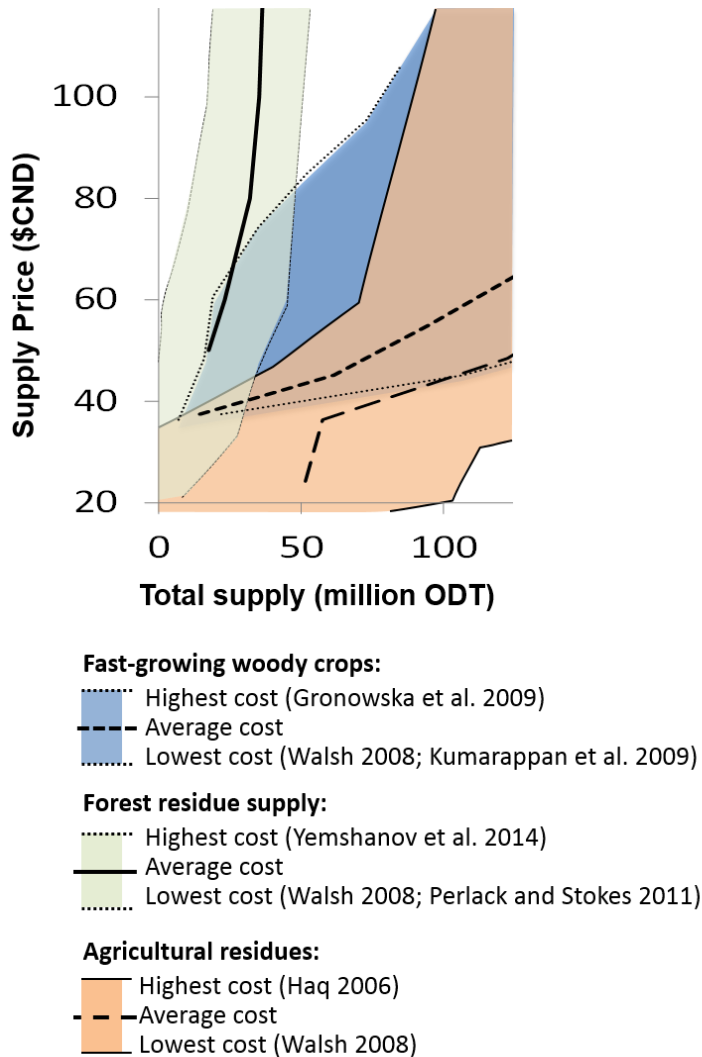


Fig. 1. Aggregate average biomass supply cost curves for agricultural residues, forest residues, and woody crops

There is considerable overlap between the estimated maximum and minimum costs for each feedstock. Agricultural residues have the widest range in cost estimates, especially for larger quantities of biomass supply, suggesting considerable uncertainty. The average cost curve suggests that large quantities of agricultural residues could be available at relatively low prices compared with the other feedstocks. However, beyond the supply threshold of approximately 57 M ODT, costs increase dramatically, suggesting an additional price premium must be paid to extract biomass from less productive sites or to redirect the supply from competing uses.

The supply of woody biomass crops has a large degree of variation at all price levels, implying considerable uncertainty about the costs estimates. Higher initial prices of the average and minimum cost curves indicate that significant investments would be required to establish production of woody biomass feedstock. The shallow slope of the average cost curve indicates that further increases in supply quantity would require relatively lower marginal costs than the other feedstock types.

Comparatively, the estimated supply of forest residues revealed the smallest amounts of biomass at the highest average costs, and lowest range of variation. This implies the projections for forest residues supply are more certain than other feedstock types, but very inelastic at large residue supply quantities. Because the availability and cost of forest residues are directly linked to the extent of harvest operations in Canada, estimates of residue supply costs appears to be less variable than for other feedstock types. The initial low cost of forest residue supply may also be explained by easy (inexpensive) access to local feedstock.

Ultimately, each feedstock type could be financially attractive under certain circumstances, but actual use will also depend on local market demands and supply as transportation costs significantly influence attractiveness. Figure 1 suggests that agricultural and forest residues are likely to be the main feedstocks used in Canada, given the relatively lower costs. The supply of forest residues could be competitive with agricultural residues at lower prices and quantities, but with costs increasing rapidly as cheaper supplies are exhausted. Agricultural residues appear likely to supply the majority of remaining demand for biomass, unless prices or other types of incentives encourage production of woody biomass crops.

Agricultural Residues

Estimates of the availability of agricultural residues for bioenergy are based on crop type, historical yield, residue fraction, and competing biomass uses. Agricultural crops in Canada have the potential to produce 48 M ODT residues annually according to Li *et al.* (2012). Geographically, the production of residues is concentrated in major agricultural regions, with the provinces of Alberta, Saskatchewan, and Ontario producing the largest volumes available for bioenergy (Li *et al.* 2012). Cost estimates for agricultural residues as a bioenergy feedstock must account for the opportunity cost associated with alternative uses. These residues are traditionally used as livestock bedding or feed, and may be left on agricultural soils for environmental reasons. If current trends in the production of agricultural commodities in Canada continue, there should be an increase in the amount of agricultural crop residue available. Agricultural yields are rising, and the demand for livestock forage is decreasing (Statistics Canada 2015; 2016), increasing the availability of crop residues for bioenergy use in the future. Currently, this feedstock does not play a large role in energy production in Canada, likely due to relatively low costs of other competing renewable and non-renewable fuels.

Woody Bioenergy Crops

Estimates of woody crop supply costs in Canada reflect the high costs of establishing plantations, maintaining plantations, and the opportunity costs associated with converting land to woody crops for an extended period of time. Although there is limited evidence of widespread woody crop production in Canada (McKenney *et al.* 2014), theoretical estimates accounting for available marginal agricultural land and varying growth rates suggest potential supplies of 9 M ODT to 20 M ODT (Mabee *et al.* 2006). Large, low cost supplies appear most likely in Alberta, Saskatchewan, Manitoba, Ontario, and Quebec (McKenney *et al.* 2014).

Cost estimates for woody bioenergy crops are often based on the profitability of converting traditional agricultural land or pasture to bioenergy plantations. Some studies suggest that the conversion to bioenergy crops could occur if the returns to land owners were greater than those from traditional land use (Yemshanov and McKenney 2008;

Gronowska *et al.* 2009; Kumarappan *et al.* 2009). Other studies suggest serious behavioral inertia and landowner concerns regarding the conversion of marginal agricultural lands to bioenergy crops (Parks and Hardie 1995; Smith *et al.* 2005; Yemshanov *et al.* 2015; Hauer *et al.* 2017). Because woody energy crops typically require longer times to grow in Canada (*i.e.*, 15-18 years or more), and although they can be managed to produce feedstock annually (McKenney *et al.* 2011), land owners may require prices above current market values. Very short rotation biomass species, such as willow coppice systems (Amichev *et al.* 2012; Allen *et al.* 2013) could improve the psychological attractiveness of tree crops for private landowners because the land conversion decision involves shorter time horizons but must still be profitable for adoption to occur (Ralevic *et al.* 2008). Without sufficiently high prices or other incentives, production of supply of woody crop feedstocks appears limited.

Forest Residues

Canada is a large forest nation, with an average of 175 million m³ of roundwood harvested annually (Environment and Climate Change Canada 2016). This translates into a range of forest residue types, including leftover biomass generated from harvesting operations, forest thinning operations, and saw, pulp, and paper mill residues. Supply estimates for forest residues are based on the volumes of harvest and the residue fractions that can be extracted from harvested sites. Mill residues estimates are based on annual roundwood harvest, less the residues being used by the mill for heating and feedstock purposes (Kumarappan *et al.* 2009; Perlack and Stokes 2011). Currently, most of the bioenergy use in Canada takes place within the forestry sector and is used to generate heat and power for sawmills and pulp and paper mills (Paré *et al.* 2011).

Harvesting practices in Canada have the potential to provide 16 M ODT to 23 M ODT of forest residues annually, depending on various environmental and technical constraints (Yemshanov *et al.* 2014). Forestry operations in British Columbia, Ontario and Quebec have the potential to provide the largest supplies of forest residue feedstock (Yemshanov *et al.* 2014). Because forest residues are typically left to decay (or are burned) on the forest floor, the supply price is primarily a function of the cost of transportation and the lower heating value of the feedstock. The price offered by bioenergy facilities for mill residues must be equal to or greater than the next most profitable use (Kumarappan *et al.* 2009), such as the cost of residue disposal (Perlack and Stokes 2011). Future projections of harvest influence expectations of forest and mill residue supplies. Long-term trends suggest that roundwood production in Canada is recovering from the 2008 and 2009 recession (National Forestry Database 2016).

Discussion

Estimating aggregate supply curves is difficult given that significant markets for biomass-based feedstocks do not yet exist (Gallagher *et al.* 2003). Literature estimates suggest considerable uncertainty in the price and quantity relationships that are available for biomass feedstocks. This is a result of varying assumptions about the economics and the logistics of biomass production, extraction, hauling, and the adoption of biomass-based projects. Studies that examine more localized decisions on biomass production seem to predict lower biomass amounts and higher supply prices than national macro-level studies (Gronowska *et al.* 2009). Few national-level studies seem to consider the proximity of supply to consumers or the type, availability, and efficiency of the transportation methods (Gronowska *et al.* 2009).

As might be expected, agricultural residues are the cheapest option for producers and consumers. However, this feedstock also appears to have the widest variation in costs, arguably indicative of numerous production and cost circumstances. Alternatively, forest residue, while appearing to be the most expensive feedstock option, has the least range of variation in the cost estimates. This suggests that there is less uncertainty which, depending on actual market prices, may increase the likelihood of uptake of forest residue as a feedstock. The notion of uncertainty in biomass cost estimates should be considered when assessing market opportunities, policy choices and investment options in different feedstock types. Supply estimates based on simple averages, without considering the bounds of uncertainty, may lead to erroneous perceptions of biomass supply opportunities. It cannot be forgotten, however, that actual market outcomes will reflect both demand and producer circumstances, with demand also being affected by prices for other energy options.

CONCLUSIONS

1. Agricultural residues in Canada are, on average, the cheapest bioenergy feedstock option for producers and consumers. However, this feedstock also appears to have the widest variation in costs and hence highest levels of uncertainty.
2. Forest residues appear to be the most expensive feedstock option, but have the least range of variation in cost estimates. The reduced uncertainty associated with this feedstock may positively affect uptake.
3. The notion of uncertainty in biomass costs should be considered when assessing policy options associated with different feedstock types. Averaged biomass supply estimates that do not consider the associated uncertainty may lead to biased perceptions of biomass supply attractiveness.

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