Potential opportunities to utilize mountain pine beetle-killed biomass as wood pellet feedstock in British Columbia

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ABSTRACT

The use of renewable forms of energy, such as bioenergy produced from wood pellets, can serve to offset fossil fuel use and, hence, reduce greenhouse gas emissions. The European Union is the world's largest user of wood pellets and British Columbia has been one of its largest external suppliers. British Columbia is currently grappling with the largest mountain pine beetle outbreak in its history. While this outbreak is expected to decrease the future timber supply in the Province, it has been suggested that one potential benefit of the mountain pine beetle outbreak is that it may provide a large amount of biomass that can be used for bioenergy production. Here we evaluate estimates of the amount of biomass available for bioenergy production in British Columbia and quantify the effects of the mountain pine beetle infestation on wood pellet feedstock supply chains. Our results, though subject to significant uncertainties, suggest that mountain pine beetle-killed wood is unlikely to be a substantial constituent of wood pellet feedstocks unless substantial subsidies are provided to offset higher harvesting costs. Even if such subsidies are implemented, it is likely that harvest residues will constitute an increasing proportion of wood pellet feedstocks as the volume of beetle-killed wood becomes depleted. Therefore, it is imperative that wood pellet producers improve the cost efficiency of harvest residue collection if they are to remain competitive in the European marketplace.

Keywords: mountain pine beetle, bioenergy, wood pellets, greenhouse gas emissions, biomass feedstocks, Biomass Crop Assistance Program

RÉSUMÉ

L'utilisation des sources renouvelables d'énergie, comme la bioénergie produite à partir de granules de bois, pourrait se substituer à celle des combustibles fossiles et, de ce fait, réduire la production de gaz à effet de serre. L'Union européenne est le plus important utilisateur de granules de bois et la Colombie-Britannique est devenue l'un de ses plus importants fournisseurs étrangers. À l'heure actuelle, la Colombie-Britannique est aux prises avec la plus importante épidémie de dendroctone du pin de son histoire. Même si cette épidémie risque de diminuer à long terme la production de bois d'œuvre de la province, on prétend que cette épidémie du dendroctone du pin pourrait en retour s'avérer profitable en libérant une très grande quantité de biomasse susceptible d'être utilisée à des fins de production de bioénergie. Dans cet article, nous avons estimé la quantité de biomasse potentiellement disponible pour la production de bioénergie en Colombie-Britannique et quantifié les effets de l'épidémie du dendroctone du pin sur les chaînes logistiques d'approvisionnement pour la production de granules de bois. Même s'ils sont empreints d'un certain niveau d'incertitude, nos résultats laissent entrevoir que le bois provenant d'arbres ravagés par le dendroctone du pin a peu de chances de représenter un élément important de l'approvisionnement pour les granules de bois, à moins que des subventions importantes ne deviennent disponibles pour compenser ses coûts d'exploitation plus élevés. De plus, même avec de telles subventions, les résidus d'exploitation occuperont sans doute une part croissante de l'approvisionnement pour les granules de bois à mesure que le bois provenant d'arbres ravagés par le dendroctone s'épuisera. En conséquence, les producteurs de granules de bois n'auront d'autre choix que d'être plus efficaces à récolter les résidus d'exploitation s'ils veulent demeurer compétitifs sur le marché européen.

Mots clés : dendroctone du pin, bioénergie, granules de bois, émissions de gaz à effet de serre, approvisionnements en biomasse, *Biomass Crop Assistance Program* (Programme d'aide à la récolte de biomasse)

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Introduction

The Copenhagen Accord established that "...deep cuts in global greenhouse gas (GHG) emissions are required according to science, and as documented by the IPCC Fourth Assessment Report with a view to reduce global emissions so as to hold the increase in global temperature below 2 degrees Celsius" (UN-FCCC 2010). Achieving this target requires drastic reductions in fossil fuel use.

Bioenergy can reduce GHG emissions relative to fossil fuels (Sikkema *et al.* 2010, Lippke *et al.* 2011, Sedjo 2011) but is hampered by its greater cost, as are other renewable energy options. This is due to the fact that biomass is less energy-dense than fossil fuels (i.e., it requires a greater amount of biomass to produce a given amount of energy), it often needs to be sourced from a large geographic area (collection costs are high) and biomass must often be converted into usable forms (i.e., sawdust and shavings must be processed into wood pellets). Policies are therefore needed to support the development of more cost-effective bioenergy supply chains.

In this regard, the European Union (EU) is at the forefront of strategic initiatives to ameliorate climate change. The Renewable Energy Directive (RED) mandates that the EU produce 20% of its energy from renewable resources by 2020 (EU 2009). Energy produced from biomass, such as wood pellets, is likely to account for over half of the expected renewable energy production (IC 2010). To achieve this goal, Member States have instituted policy initiatives that favour renewable forms of energy and/or penalize GHG emissions associated with fossil fuel use. Such policies include carbon taxes on fossil fuel emissions and feed-in tariffs for renewable energy production. The value of these feed-in premiums can be substantial. For example, the Dutch feed-in premium for renewable energy is Euro (€) 0.06–0.07 per kilowatt hour (Kwh), which amounts to roughly €120–135 per tonne of wood pellets (Sikkema *et al.* 2011). Similar premiums in Belgium amount to approximately €90 per tonne of wood pellets (Cocchi *et al.* 2011). These subsidies compare favourably with recent European wood pellet prices as traded on the APX-ENDEX exchange (APX-ENDEX 2012), which are about €140 per tonne of wood pellets for a long-term (three year) contract.

The aforementioned subsidies, and those like them in other EU Member States, have created a large market for wood pellet use in the EU. In 2010, the EU consumed 11.4 million (M) tonnes of wood pellets, a 43.5% increase since 2008. EU wood pellet production, at 9.2 M tonnes, was not sufficient to meet demand. This resulted in the importation of over 2 M tonnes of wood pellets from outside the EU. Approximately half of these

wood pellets (983 000 tonnes) were imported from Canada, largely from British Columbia (BC) (Cocchi *et al.* 2011).

In 2010, Canada was the world's second largest producer of wood pellets at 1.4 M tonnes per year, with a production capacity of 2.1 M tonnes (Bradley 2010). In 2011, BC alone is estimated to have produced approximately 1.2 M tonnes of wood pellets (Cocchi *et al.* 2011, Murray 2012). Given the renewable energy requirements stipulated in the RED, wood pellet demand is expected (under a business as usual scenario) to reach 16 M tonnes in 2020. Other projections suggest that EU demand could rise to as much as 20–50 M tonnes per year by 2020 if there is an increase in the co-firing of wood pellets in coal-fired industrial power plants (Cocchi *et al.* 2011, Sikkema *et al.* 2011). In order to meet this demand, the wood pellet industry in Canada is expected to increase its production capacity to 5.8 M tonnes per year, with 3 M tonnes being produced in BC (Cocchi *et al.* 2011).

Since very few wood pellets are used locally, the BC wood pellet industry has grown to serve EU demand (Bradley 2010). Since 1997, BC pellet production increased more than 10-fold (Fig. 1). Two key factors, in addition to the aforementioned policy-driven European demand, gave rise to this expansion. The first was the mountain pine beetle (MPB) (*Dendroctonus ponderosae* Hopkins) infestation that is currently affecting the province. This outbreak, which affects lodgepole pine (*Pinus contorta* Dougl. ex Loud. var. *latifolia* Engelm.) (a significant timber species in the Interior region of BC that is the site of the

Fig. 1. British Columbia wood pellet production (thousands tonnes). Data are from Bradley 2006, 2010; Cocchi *et al.* 2011; and Murray 2010, 2012.

Fig. 2. Millions of hectares of forest in central BC damaged due to the mountain pine beetle outbreak. Mortality rates ranged from less than 1% to 100%. Data are from MFLNRO 2012a.

province's wood pellet industry) (MFML 2010), has affected over 18 M ha and killed over 700 M m³ of merchantable timber (Fig. 2). It is projected that up to 58% of the lodgepole pine in the province will be killed by 2017 (MFLNRO 2012a). In an attempt to harvest the value in these standing dead trees, BC instituted annual allowable cut (AAC) uplifts to enable large-scale salvage logging (MFLNRO 2012b,c,d,e,f,g,h,i). The second key factor was that the rapid expansion of the outbreak, especially from 2003 to 2005, coincided with strong demand for BC timber, primarily from the U.S. housing industry. This resulted in record harvests of approximately 80 M m³ in 2004 and 2005 (MF 2005, MFR 2006) (note that the past and expected future sustainable harvest rates are about 70 M m³) (MFML 2010). The net result is that in 2005 almost 2 M tonnes of surplus mill residues were produced by BC timber mills. These excess residues, which were normally disposed via incineration in "beehive" burners, served as a cheap (approximately \$10 per tonne) source of feedstock for wood pellet production (Bradley 2010). Thus, the increase in wood pellet production provided a novel use for forest biomass that was previously wasted.

The recent downturn in the U.S. housing industry, however, significantly curtailed demand for BC timber. The resulting drop in timber prices forced producers to reduce harvest levels. By 2009, timber harvests had fallen to a modern-day low of 48.2 M m³, far below historically sustainable levels (MFLNRO 2011). As a result of declining harvests, surplus mill residues evaporated (Bradley 2010). This drove up the cost of existing residues to \$20 to \$40 per tonne (Bradley 2010, Feldinger 2012, Gordon Murray¹, personal communication, 4 September 2012) and forced wood pellet producers to turn to alternative feedstocks, such as roadside harvest residues. Estimates for the amount of harvest residues in wood pellet feedstocks vary, but range from 10% (Gordon Murray personal communication, 4 September 2012) to 20–30% (Bradley 2010). The increasing use of more expensive harvest residues further increased the cost of wood pellet feedstocks to approximately \$40 per tonne (Murray 2010). Cost pressures on wood pellet feedstocks are likely to continue for the foreseeable

future due to substantial (20%) expected declines in BC's mid-term (2025–2075) timber supply resulting from the MPB outbreak (MFML 2010).

Given likely declines in the mid-term timber supply, it is clear that the MPB epidemic will have detrimental long-term effects on the BC forestry industry. In the short term, however, it is possible that the MPB epidemic will serve as a bioenergy windfall for the province—a cheap, plentiful, albeit temporary, source of feedstock. By analyzing scientific, governmental and third-party reports, this paper aims to provide a critical examination of the effects of the MPB outbreak on the wood pellet industry. Key questions to be addressed include: 1) How will MPB-associated decreases in the mid-

term timber supply affect the future costs and composition of wood pellet feedstocks? 2) Is the utilization of MPB-killed wood as a wood pellet feedstock economically feasible in the short term?

Materials and Methods

Estimating the amount of mill residues available for wood pellet feedstocks

Calculations were based on year 2009 data from the BC Ministry of Forests, Range and Natural Resource Operations (MFLNRO 2011). In that year, 35.1 M m³ of timber was harvested in the BC Interior. Eighty percent of this timber (28.2 M m³) was processed by medium- and large-sized lumber mills that were the source of feedstocks for the wood pellet industry (small lumber mills and pulp, chip and veneer mills accounted for the remainder of the harvest). MFLNRO (2011) estimated that 14% of processed logs ended up as sawdust and shavings that can be used by the wood pellet industry. Thus, 28.2 M m³ × 0.14 equals 3.9 M m³ of sawdust and shavings. 51% (2.0 M m³) of this feedstock was utilized by the pulp and paper industry, while the remaining 49% (1.9 M m³) was available to the wood pellet industry. 1.9 M m³ is equivalent to 0.68 bone dry units (or 0.74 M oven-dry tonnes) of feedstock (MFLNRO 2011). These numbers were extrapolated for future years based on the amount (or predicted amount) of timber harvested; the proportion of sawdust and shavings available to the wood pellet industry was held constant. In addition to sawdust and shavings, timber mills produce large volumes of wood chips (39% of log input) that could potentially be used by the wood pellet industry. In 2009, all 11.0 M m³ of wood chips produced were utilized by pulp mills (Fig. 3). A future decline in the BC pulp industry could, therefore, free up large amounts of this biomass for wood pellet production. In this regard, it is important to note that BC pulp exports have remained relatively constant over the last 20 years (Schrier 2012). In addition, future declines in the timber supply will reduce the amount of available wood chips (and other biomass) (Fig. 4). In the mid-term timber supply period, we estimate that the amount of biomass available to the pulp and paper industry will fall from 15.1 M m³ (as of 2009) (Fig. 3) to 10.8 M m³ (Fig. 4). Thus, our calculations implicitly assume a 28% decline in the amount of biomass utilized by this

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Fig. 3. Mill residue and harvest residue flows for the Interior region of British Columbia. Residue flows for 2009. Data are from MFLNRO (2011). Available harvest residues were estimated to be 20% of the total harvest volume based on the work of MacDonald (2006). 2.2 million (M) cubic meters (m^3) of residues available to the wood pellet industry were sufficient to account for the 0.9 M tonnes of estimated wood pellet production (Bradley 2010, Murray 2010). The 15.1 M m^3 of residues available to the pulp and paper industry were sufficient to account for 90% of the pulp and paper production capacity of the Interior; numbers were not provided for pulp and paper production for the Interior alone, but production for said industry ran at 83% of capacity for the province as a whole (MFLNRO 2011).

industry. For this reason, we have assumed that wood chips will not be available to the wood pellet industry in the future. Finally, bark (sometimes referred to as hog fuel) is another potential source of feedstock. Bark constitutes approximately 10% of sawlog volumes (Massie and Manning 1989). Thus, a 35.1 M m^3 timber harvest would generate 3.5 M m^3 of bark. It should be noted that bark has limited utility as a feedstock due to its high ash and moisture content as well as its propensity for acquiring contaminants (Melin 2008). In addition, bark is often utilized for on-site energy production. For this reason, we do not consider it likely that significant quantities of bark will enter wood pellet feedstock supply chains.

Estimating the amount of harvest residues available for wood pellet feedstocks

MacDonald (2006) provided detailed estimates of the volumes of harvest residuals (tops, limbs and butts) that are available at roadside following the harvest of MPB-affected cutblocks in the Quesnel Timber Supply Area in BC. Amounts ranged from 14% to 55% of the original stand volume. The same report noted that the difference between gross cruise volume and as-delivered volume was typically 20%. Based on these estimates, we conservatively assume that harvest residuals will provide an additional amount of biomass that is equal to 20% of the harvest volume.

Estimating the composition of wood pellet feedstocks

We assume that wood pellet feedstocks consist solely of sawdust/shavings and harvest residues. Estimates of the amount of sawdust/shavings available to the wood pellet industry were described above. Wood pellet production levels and capacity levels for the years 2009 and 2011 were obtained from Bradley (2010) and Murray (2010, 2012). We assume that wood pellets are manufactured first from sawdust and shavings. If these feedstocks are insufficient to meet demand, harvest residues will then be utilized.

Estimating the costs of wood pellet feedstocks

Costs were determined based on estimates of CAN\$40 per dry tonne for mill residues (Feldinger 2012, Gordon Murray personal communication, 4 September 2012) and CAN\$55 per dry tonne for harvest residues (an average of previously reported estimates) (MacDonald 2006, Stennes and McBeath 2006, Skea and Day 2009, Feldinger 2012, Niquidet *et al.* 2012, Ryans 2012, Gordon Murray personal communication, 4 September 2012). For the mid-term costs, an additional \$10.89 was added to the aforementioned harvest residues costs to account for increased transportation costs resulting from greater distances

being traversed to reach timber stands than occurred prior to the mountain pine beetle outbreak (Niquidet *et al.* 2012). The CAN\$10.89 increase in costs was modeled using data from the Quesnel Timber Supply Area (TSA) and, thus, may not be representative of other TSAs in the BC Interior. Nevertheless, we have included it because it is the only study that provided detailed estimates of the temporal effects on harvesting costs in beetle-affected areas. To obtain individual feedstocks costs, each feedstock's proportional representation of the total feedstock was multiplied by its unit cost. Individual feedstock costs were then summed to obtain the total feedstock cost. The cost of using MPB-killed biomass was an average of the values provided by MacDonald (2006) and Niquidet *et al.* (2012).

Estimating wood pellet production costs

2009 wood pellet prices are from Murray (2010) and assume an exchange rate of CAN\$1.59 per €. Prices and exchange rates are held constant in future years to better illustrate the effects of rising feedstock costs. All costs for conversion, rail to port and ship to EU are from Murray (2010) and are per-tonne costs. Feedstock costs (per dry tonne) are from estimates provided by this study (Table 1) and are rounded to the nearest dollar.

Fig. 4. Mill residue and harvest residue flows for the mid-term timber supply period. Data are extrapolated from the 2009 numbers provided by MFLNRO (2011). Available harvest residues were estimated to be 20% of the total harvest volume based on the work of MacDonald (2006). The 4.6 M m³ of wood pellet residues are sufficient to account for 1.9 M tonnes of wood pellet production (the current wood pellet production capacity in the Province (Cocchi *et al.* 2011, Murray 2012). Note that maximizing wood pellet production would require the utilization of nearly two-thirds of the total available harvest residues. In addition, the 10.8 M m³ of residues available to the pulp and paper industry are only sufficient to allow production levels of 64% of the 2009 production capacity in the Interior region.

(Stennes *et al.* 2010). While acknowledging such uncertainties, we have utilized publicly available data to estimate the composition of wood pellet feedstock supply chains in the hope that such information will prove useful to policy-makers and others interested in the bioenergy sector.

To effectively analyze wood pellet feedstock supply chains, one must take into account harvest levels (and their associated mill and harvest residues), wood pellet production and capacity levels and European demand (and prices) for wood pellets. As previously noted, in the high (80 M m³) harvest years of 2004 and 2005 (MF 2005, MFR 2006), the available mill residues alone far outweighed both wood pellet production and capacity. Thus, all wood pellets were produced using these low-cost (CAN\$10 per dry tonne) residues (Bradley 2010). A different story, however, unfolded in 2009. During that year, weak demand from the U.S. housing industry resulted in a modern-day record low harvest of 48.2 M m³, 35.1 M m³ of which were harvested in the Interior region of BC that is currently experiencing the MPB outbreak and is the site of BC's wood pellet industry. This harvest resulted in 1.9 M m³ (0.74 M dry tonnes) of sawdust and shavings for the wood pellet industry (MFLNRO 2011) (Fig. 3). BC wood pellet production was estimated to be 0.9 M tonnes in 2009 (Bradley 2010, Murray 2010). Thus, mill residues only

accounted for 82% of wood pellet feedstock demand. The remaining 18% of feedstock, therefore, likely consisted of roadside harvest residues. This estimate of 18%, derived from publicly available data, roughly matches the estimates of Bradley (2010;

Results and Discussion

The past, present and future of wood pellet feedstock supply chains

Securing low-cost, sustainable, feedstock supply chains will be necessary if BC wood pellet producers are to remain competitive in a global marketplace. Unfortunately, there is a great deal of uncertainty inherent in estimating the amounts of available feedstocks. Such uncertainties were highlighted previously in a study by Dymond (2012). This study rightly noted that there are widely varying estimates of feedstock availability due to the fact that data on the availability of mill residues is incomplete. Specifically, it was shown that there is a large biomass gap, ranging from 7.4 M to 13.4 M tonnes, between Provincial reports of wood and paper product production and reported harvest levels. Much of this gap likely consists of mill residues that are used for on-site energy production. Until more complete data on fibre supply is completed, there will continue to be large uncertainties in the amount of biomass available for wood pellet (and other) feedstocks (Dymond 2012). These uncertainties are compounded by potential future changes in the demand for biomass feedstocks, which will affect the distribution of biomass among competing users

Table 1. Wood pellet feedstock composition and costs

	2009 ^a	2009 ^b	2011 ^a	2011 ^b	mid-term ^c
Harvest ^d	35.1	35.1	50.1	50.1	25.1
Production ^e	0.9	1.2	1.2	1.9	1.9
Capacity ^e	1.2	1.2	1.9	1.9	1.9
Proportion					
mill residues	0.82	0.62	0.88	0.56	0.28
harvest residues	0.18	0.38	0.12	0.44	0.72
total	1.00	1.00	1.00	1.00	
Cost	\$42.70	\$45.70	\$41.80	\$46.60	\$58.64

Feedstock composition and costs were calculated as described in Materials and Methods.

^a represents feedstock costs and composition associated with actual production levels.

^b represents feedstock costs and composition if production was 100% of capacity.

^c mid-term represents the mid-term timber supply period (2025–2075).

^d harvest levels are for the Interior region and are in millions of cubic meters.

^e wood pellet production and capacity are in millions of tonnes.

20% to 30% harvest residues) and Murray (personal communication, 4 September 2012; 10% harvest residues) that were derived from proprietary data. This translates to a feedstock cost of CAN\$42.70 per dry tonne (Table 1), which matches well with the estimate of CAN\$40 per dry tonne provided by Murray (2010). Note that these numbers reflect actual wood pellet production levels. In 2009, BC pellet plants operated at roughly three-quarters capacity (Bradley 2010). If full capacity was achieved, harvest residues would need to have constituted 38% of wood pellet feedstocks. This would have increased the price of wood pellets by about 7% to CAN\$45.70 (Table 1).

In 2011, timber harvests in the Interior of BC increased to 50.1 M m³ (MFLNRO 2012j). This generated an estimated 1.06 M dry tonnes of sawdust and shaving residues for wood pellet feedstocks. In this same year, however, BC pellet production increased to approximately 1.2 M tonnes (Cocchi *et al.* 2011, Murray 2012). This means that despite an increase in available mill residues of 0.32 M tonnes over 2009, harvest feedstocks likely constituted similar amounts (12%) of wood pellet feedstocks as they did in 2009 (18%). Once again in 2011, as in 2009, wood pellet production fell far short of capacity. If plants ran at 100% of capacity, we estimate that harvest residues would have constituted 44% of feedstocks and prices would have increased to CAN\$46.60 per dry tonne (Table 1).

The wood pellet feedstock figures for the years covering the mid-term timber supply (roughly 2025–2075) suggest that the cost of wood pellet feedstocks is likely to increase above current levels. The sustainable timber supply in the Interior is expected to fall to 25.1 M m³ (MFR 2007), a one-third reduction relative to historically sustainable levels. If wood pellet production capacity remains the same as it is today (1.9 M tonnes) and is fully utilized, harvest residues would constitute 72% of wood pellet feedstocks by 2025 and would remain so for roughly the next 50 years. In this scenario, wood pellet feedstock costs would rise to CAN\$58.64, a 40% increase over 2011 prices (Table 1, Fig. 4). Although timber supply mitigation strategies, such as reducing non-timber management objectives, could add another 4 M m³ per year to the annual harvest (MFLNRO 2012b,c,d,e,f,g,h,i),

such strategies are not likely to be adopted *in toto*.

Utilizing the aforementioned estimates of feedstock costs and estimates for the cost of converting these feedstocks into wood pellets, transporting them by rail from the Interior to ports on the coast and then shipping the pellets on ocean-going vessels to the EU (Murray 2010), one can calculate the total cost of wood pellet production and transport (Table 2). The projected increases in wood pellet feedstock costs are significant. At 2009 production levels, wood pellet feedstocks accounted for 23% of the total production and transport costs. In the mid-term timber supply period, we estimate that feedstocks will account for 29% of such costs.

Given the potential rise in future feedstock cost, the development of more efficient roadside residual collection systems may be crucial for the survival of the industry. Bradley (2007), in an analysis of roadside residue harvesting systems in the Nordic countries, noted that Sweden was able to achieve a 2% per annum decrease in feedstock procurement costs over a 20-year period. Assuming BC, with its greater transport distances, is able to achieve only a 1% per annum decrease in the cost of collecting roadside residuals, the cost of wood pellet feedstocks during the mid-term timber supply period (during which MPB-killed wood will no longer be suitable for bioenergy use) will fall from CAN\$59 to CAN\$49 per dry tonne (Table 2), only a 17% increase over 2011 production costs. Such savings in feedstock procurement costs will be critical to ensure the future competitiveness of the BC wood pellet industry.

MPB-killed wood as a potential wood pellet feedstock

Aside from the problem of increasing feedstock costs in the long term, there is the more immediate question of how to deal with the large volumes of MPB-killed wood in the Interior. Ralevic and Layzell (2006), using published data (Eng *et al.* 2006), calculated the temporary biomass available as a result of the MPB outbreak. Based on the estimate that 417 M m³ of merchantable MPB-killed biomass would be recoverable (Eng *et al.* 2006) (i.e., the trees would be harvested while they were still suitable for lumber production), Ralevic and Layzell (2006) estimated that an additional 2.4 M dry tonnes of harvest residues would

Table 2. Wood pellet production costs and market prices

	2009 ^a	2009 ^b	2011 ^a	2011 ^b	MPB ^c	MPB ^d	mid-term ^e	mid-term ^f
Price in Rotterdam	\$223	\$223	\$223	\$223	\$223	\$223	\$223	\$223
Costs								
feedstock	\$43	\$46	\$42	\$47	\$105	\$55	\$49	\$59
conversion	\$55	\$55	\$55	\$55	\$55	\$55	\$55	\$55
rail to port	\$35	\$35	\$35	\$35	\$35	\$35	\$35	\$35
ship to EU	\$55	\$55	\$55	\$55	\$55	\$55	\$55	\$55
total	\$188	\$191	\$187	\$190	\$250	\$200	\$194	\$204
Income	\$35	\$32	\$36	\$33	(\$27)	\$23	\$29	\$19

The Table is modeled after that of Murray (2010). All costs and prices are in CAN\$.

^a represents costs associated with actual production levels.

^b represents costs if production was 100% of capacity.

^c represents costs if non-recoverable mountain pine beetle (MPB)-killed wood is the exclusive source of wood pellet feedstocks. The value is an average of those provided by MacDonald (2006) and Niquid *et al.* (2012).

^d represents the costs of MPB-killed feedstocks if subsidized at \$50 per dry tonne.

^e mid-term represents the costs at the start of the mid-term timber supply period (approximately 2025), at which point all MPB-killed timber will have decayed to the point at which it is no longer usable for bioenergy production. It is assumed that wood pellet production capacity remains the same as it is day and that production levels equal 100% of capacity.

^f represents the costs during the mid-term timber supply assuming a 1% per annum decrease in harvest residue feedstock costs are obtained over a 20 year period (Bradley 2007).

be available each year for a 20-year period (at which point MPB-killed trees will have decayed to the point that they are no longer merchantable). In addition, they estimated that an additional 353 M m³ of non-recoverable MPB-killed wood (wood of merchantable size not suitable for milling but still usable for bioenergy purposes) would yield an additional 8.7 M dry tonne of biomass per year for the next 20 years. It should be noted, however, that Eng *et al.* (2006) judged that, due to lack of demand, the vast majority of this 353 M m³ would decay to the point that it was not even suitable for bioenergy purposes before it could be harvested. In a modeling study of the amount of biomass generated by natural disturbances in Canadian forests, Dymond *et al.* (2010) estimated that the MPB outbreak could generate an average of 16.8 M dry tonnes of dead wood per year between 2005 and 2020. It is important to note, however, that biomass availability is often limited by economic factors (Ralevic *et al.* 2010), which suggests that these previous studies may not adequately reflect the actual amounts of biomass that are likely to enter bioenergy feedstock supply chains.

MacDonald (2006) estimated the cost of harvesting, comminuting and transporting MPB-killed wood in the Quesnel Timber Supply Area (TSA) in central BC. The Quesnel TSA has a high concentration of lodgepole pine and has been one of the hardest hit areas during the current MPB outbreak (FPB 2009). The study utilized computer models to analyze the cost of three different harvesting systems, which were dependent upon the ratio of sawlogs (recoverable timber) to fuelwood (logs only suitable for making chips for bioenergy production) in harvested stands, which is itself a function of time (as the timber decays over time, fuelwood makes up an increasingly large percentage of the stand harvested volumes). The results showed that if stands contained less than 50% fuelwood, then the existing harvesting system, in which logs are harvested, skidded to the roadside, comminuted at the roadside and then transported to the bioenergy site was the lowest-cost system (CAN\$45–54 per dry tonne). This value is in line with previously mentioned estimates for the cost of roadside harvest residuals in BC (Stennes and McBeath 2006, Skea and Day 2009, Bradley 2010, Murray 2010, Feldinger 2012). Stands with 50% to 95% fuelwood were costed using either a local or in-town “satellite” yard to sort sawlogs from fuelwood, after which the fuelwood was comminuted and transported. The intermediate sorting step resulted in higher costs (CAN\$63–70 per dry tonne). For stands with greater than 95% fuelwood, on-site full tree chipping was used to comminute the fuelwood prior to transport. The cost for these high fuelwood stands was estimated at CAN\$53–56 per dry tonne. An additional CAN\$30–41 per dry tonne (for road development, silviculture, administrative costs, etc.) would need to be added to the satellite yard and full-tree chipping systems, respectively, because the income from the sawlogs in these stands would not be sufficient to cover operating costs due to the harvesting of insufficient volumes of high value sawlogs, as they would in the traditional roadside harvesting system. Thus, the price of MPB-killed wood as a bioenergy feedstock would increase to approximately CAN\$93–\$100 dollars per tonne over time as a greater percentage of MPB-killed wood decays to the point at which it is unsuitable for sawlogs (MacDonald 2006).

Niquidet *et al.* (2012) extended the findings of MacDonald (2006) by using a mathematical programming model to assess timber flows in the Quesnel TSA over a 25-year period. Fibre was transported to a hypothetical biomass-fired power plant in the town of Quesnel. The study showed that a cost minimization

strategy resulted in estimated costs of CAN\$54.60 per dry tonne at the start of the planning period, which is similar to previous estimates. These costs would rise, however, to CAN\$116.14 per dry tonne by the end of the planning period. The main sources of cost inflation were increasing hauling costs (due to the fact that fibre would need to be sourced over increasingly greater distances as the planning period progressed), increased logging costs (due to the necessity of harvesting lower-quality stands (decreased volume per ha) as a result of the MPB outbreak) and a decrease in the proportion of sawlogs harvested over time (as was noted by MacDonald [2006]).

The net result of these studies is that the price of feedstock procurement for wood pellet production of MPB-killed wood will rise considerably in the future to the point at which it would not be economically feasible to harvest stands with high percentages of fuelwood. This presents a significant problem for the BC forestry industry. The Forest Practices Board (FPB), BC's independent auditor of forestry operations, in a study of six TSAs in central BC, revealed that two-thirds of “pure pine” stands (defined as stands with at least 80% pine) are unlikely to ever undergo harvesting (FPB 2007). For these TSAs alone, this equates to 322 M m³ (or 133 M dry tonnes [Gonzalez 1990]) of biomass. These stands, though they will naturally regenerate, will have insufficient volume to contribute fully to the mid-term timber supply. The FPB concluded that “harvesting as much of the pure pine part of the [timber] profile ... will have a benefit on the long-term timber supply.” Thus, harvesting these stands could have immediate benefits for the wood pellet industry as well as a long-term payoff for the timber industry.

The current economic situation renders this unlikely given the current cost estimates for wood pellet production (Table 2). At 2011 feedstock costs of approximately CAN\$42 per dry tonne and wood pellet prices of CAN\$223, wood pellet manufacturers would receive a CAN\$36 profit per tonne of pellets. Harvesting MPB-killed wood would raise production costs to CAN\$250, which would result in a CAN\$27 loss per tonne of wood pellets (assuming constant prices and exchange rates). Without a substantial increase in wood pellet prices, MBP-killed timber would be priced out of the European market.

This cursory economic analysis suggests that “pure pine” stands with high percentages of fuelwood are unlikely to be harvested, which will have adverse effects on BC's long-term timber supply. To ameliorate this situation and provide an incentive to biomass suppliers to target these stands, subsidies would be required to ensure that the costs of wood pellet production from such biomass would be competitive in the marketplace. The U.S. Biomass Crop Assistance Program (BCAP) offers one possible solution to this problem (USDA 2012). This program provided up to a \$50 per tonne subsidy to biomass producers that sell their feedstocks to bioenergy producers. These matching payments were a temporary (two year) subsidy designed to assist forest land owners and operators with the collection, harvest and transport of material to a biomass conversion facility. The payments were designed to allow operators to develop more cost-effective systems for biomass collection in order for the systems to be self-sustaining by the end of the subsidy period (Sedjo 2010, Stubbs 2011). Such a system, if employed in BC, could make the recovery of MPB-killed biomass economically feasible, although given the scale of the MPB outbreak (Eng *et al.* 2006, Ralevic and Layzell 2006, FPB 2007, MFLNRO 2012a), a two-year subsidy would be woefully ineffective given the precarious position of wood pellet producers. A CAN\$50 per tonne

subsidy would reduce collection costs of pure pine stands with high percentages of fuelwood from CAN\$93–116 per dry tonne (MacDonald 2006, Niquidiet *et al.* 2012) to CAN\$43–66 per dry tonne. Assuming a subsidized cost of CAN\$55, total wood pellet production and shipping costs would be CAN\$200.00 versus today's costs of CAN\$187, only a 7% cost increase (Table 2).

At a current capacity of 1.9 M tonnes, the wood pellet industry would require almost 30 M dry tonnes (or 73 M m³) (Gonzalez 1990) of MPB-killed feedstock over the next 15 years (roughly the lifetime of MPB-killed wood) to maximize output. Applying a BCAP-style subsidy to this amount biomass feedstock would cost CAN\$1.5 billion. While such a scheme would only result in harvesting 21% of the total MPB-killed biomass available (73 M m³ divided by an estimated 353 M m³ of non-recoverable MPB-killed timber), it would enable BC wood pellet producers to remain competitive in the European marketplace. In addition, it would allow the industry to develop more efficient, low-cost roadside residual collection systems, which will be necessary to meet wood pellet feedstock supply requirements as a result of the lower expected harvests resulting from a diminished mid-term timber supply.

Conclusion

Our analysis of wood pellet feedstocks in BC suggests that the MPB outbreak is unlikely to be beneficial to the wood pellet industry in the short term. Although it is predicted that large volumes of MPB-killed timber will be available to bioenergy producers (Dymond *et al.* 2010, Eng *et al.* 2006, Ralevic and Layzell 2006), harvesting stands with low percentages of sawlog-quality trees will result in wood pellet feedstock costs that are greater than those associated with the collection of harvest residues from stands with high percentages of sawlogs. A substantial subsidy would be required to render MPB-killed stands economically feasible to harvest at a scale sufficient to generate 100% of BC's wood pellet feedstock over the next 15 years. In the long term, the diminution of harvests due to the MPB outbreak will reduce the volumes of mill residues available to wood pellet producers. While the use of bark and/or wood chips could potentially alleviate this shortfall, we believe that harvest residues are likely to constitute a substantial percentage of wood pellet feedstocks for the foreseeable future. Thus, to remain competitive in the European market, the wood pellet industry should strive to increase the cost efficiency of its supply chains, particularly with regards to the collection, comminution and transportation of these residues.

Acknowledgements

Funding for this work was provided by the International Energy Agency Bioenergy Task 43. We thank Reviewer 1 for helpful comments.

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