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Implications of Expanding Bioenergy Production from Wood in British Columbia: An Application of a Regional Wood Fibre Allocation Model

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IMPLICATIONS OF EXPANDING BIOENERGY PRODUCTION FROM WOOD IN BRITISH COLUMBIA: AN APPLICATION OF A REGIONAL WOOD FIBRE ALLOCATION MODEL

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Abstract

Energy has been produced from woody biomass in British Columbia for many decades, but it was used primarily within the pulp and paper sector, using residual streams from timber processing, to create heat and electricity for on-site use. More recently, there has been limited stand-alone electricity production and increasing capacity to produce wood pellets, with both using 'waste' from the sawmill sector. Hence, most of the low-cost feedstock sources associated with traditional timber processing is now fully employed. While previous studies model bioenergy production in isolation, we employ a transportation model of the BC forest sector with 24 regions to demonstrate that it is necessary to consider the interaction between utilization of woody feedstock for pellet production and electricity generation and its traditional uses (e.g., production of pulp, oriented strand board, etc). We find that, despite the availability of large areas of mountain pine beetle killed timber, this wood does not enter the energy mix. Further expansion of biofeedstock for energy is met by a combination of woody debris collected at harvesting sites and/or bidding away of fibre from existing users.

Introduction

Energy policy in much of the world is focused on how societies will transition from fossil fuels to cleaner and preferably renewable sources. The global drivers behind this transition are well known and include concerns about climate change and energy security (Smil 2003). Some recent studies have even shown that the adoption of renewable sources of energy is socially beneficial, with the benefits of deploying renewable energy exceeding the costs (see, e.g., Gross, Leach and Bauen 2003; DeCarolis and Keith 2005; Kumar 2009) [1].

The vast forests of western Canada constitute a large potential energy source. Many sawmills and pulp mills already use wood waste and other residue to generate heat and electricity, and there exist proposals to produce power on a large scale (300 to 600 MW power plants) using biomass from mountain pine beetle (MPB) killed trees in British Columbia and Alberta. Meanwhile, production of wood pellets in BC for the European market has increased in response to EU legislation to increase reliance on renewables and subsidies to biomass-generated electricity. The BC government considers wood biomass as one means for ensuring that future expansion of electricity production relies on renewable sources, while the Alberta government is requiring coal power plants to increase their use of renewable feedstock (e.g., wood biomass, char from wood).

In British Columbia, increasing use of biomass for energy is an attractive policy goal, because the government needs additional sources of energy to support economic growth, and it has clearly signaled additional power must come from sources with minimal greenhouse gas emissions (e.g., see BC Hyrdo 2009). Further, with expected volumes of timber killed by the MPB exceeding 10^9 m^3 within the next two decades, much of the dead biomass cannot be salvaged for traditional uses. Over time, many options for using the dead timber are no longer available as the wood becomes dry and checked (full of cracks) followed by decay. Removing such a volume from future supplies means that the numerous timber-dependent communities in the province can no longer rely on traditional logging and the joint-production of solid wood and chips for pulp mills that has supported regional timber economies for decades. Now any process that adds value through the intensification of timber use or expansion of the extensive margin is viewed as potentially minimizing future economic damage.

Engineers are highly optimistic concerning the use of wood biomass as an energy source (Kumar 2009; Kumar et al. 2008), although economists have been more cautious (Stennes and McBeath 2006). While engineering studies have employed average costs of removing MPB-killed trees from the land base, economists fret about marginal costs – the increase in costs that occur as salvaged trees are recovered farther and farther away from biomass processing or burning facilities. Further, economists are concerned about potential competition for fibre as lumber and pulp markets recover and energy producers encounter increasingly higher prices for fibre. To address economic issues requires the construction of a forest management model that takes into account costs of hauling fibre from the forest plus the competition for fibre among traditional commercial timber users (sawmills, pulp mills), existing bio-energy producers (sawmills and pulp mills that burn wastes on-site for electricity, wood pellet plants), and potential future energy users (new pellet plants, bio-fuel producers, producers of char to co-fire in existing coal plants, etc.).

Our purpose in this study is to examine the economic feasibility of different forest-based options for expanding production of bioenergy in BC. This is accomplished using a multi-year mathematical programming (constrained optimization) model that maximizes regional profit by allocating fibre across uses and among regions on the basis of relative net value. The costs of fibre collection, transport and transformation are taken into full account, as is the contribution to revenue generated from sales of final products. In our model, we overlay regional harvest projections, the spatial distribution of processing facilities, transportation routes (and costs) among regions, and market parameters for products over a ten-year time horizon. We consider the location, scale and technology of biomass-energy production, examine the supply implications of large-scale disturbance brought about by the mountain pine beetle outbreak, and project potential changes in markets for solid wood products and pulp. A major objective of the research is to examine the implications for biomass energy when the energy feedstock must compete with other uses of fibre.

Model

Our model is a ten-year recursive linear programming formulation of the BC forest sector. The province is divided into 26 districts based on the post-2005 reorganization of BC Ministry of Forests and Range districts, whose location and associated three-digit names are shown in Figure 1. In the model, the three coastal districts are aggregated into one, providing a total of 24 regions (see Appendix Table A1). Fibre supply, demand and processing occur in each of the regions and a transportation grid (with associated costs) connects the regions to each other and to markets outside the province.

The objective in the model is to maximize discounted total net revenues. Revenues enter the net return functions for final products and for raw materials that are exported. The costs of harvesting, processing and transporting fibre in both processed and raw forms are also included in the overall objective function. The fibre flows in the model are described in

Appendix Figure A1.

Figure 1: Districts and Processing Points in Current FP Transport Model

Intermediate Products: Costs and Demands

Harvested logs are processed locally, transported to mills in other BC regions, or exported directly (with anything leaving BC defined as export). All co-product streams –

chips, woody residuals and bark – are taken into account, while intermediate products are used endogenously within the model to produce pulp, pellets, medium density fibre board (known as MDF), and energy. In addition, two types of energy feedstock are available directly from the forest: Field chipped harvest residuals can be used for energy in all districts, with the ceiling set at 20% of harvested volume, while, in select districts, standing MPB-killed timber is available for harvest and chipping. This last source is assumed available in the last five years of our time horizon and the volumes available for energy are based on estimates by the BCMFR (2009). In the model, energy produced from residuals is used by the mills for heating or as electricity, or is sold specifically as electricity to the power grid. Any new electrical capacity added after the initial or base year, whether for internal mill use or grid sales, is valued at the selling price.

Demands for logs and intermediate products come from the processing needs within each district (BCMFR 2006). Needs are defined by the capacity of sawmills, 'other' roundwood, plywood, OSB (oriented strand board), MDF and chip mills, pellet mills, kraft and mechanical pulp mills, and extant energy producers (whether at mills or stand alone facilities). There is also a demand for 'final' products, which are priced and enter the objective function; final products include exported logs, lumber, plywood, pulp, exported chips, pellets, OSB, MDF, 'other' roundwood products, and electricity. Prices of intermediate products are determined endogenously based on costs and final product revenues (i.e., shadow prices), while sale of lumber to the United States is characterized by a downward sloping (price responsive) excess demand function (as discussed in more detail in the next subsection).

Each district has a unique 'representative' forest sector akin to representative farms as used in regional agricultural models (McCarl and Spreen 2004). Region specific variables include the various parameters that define the transformation of timber into products, including tree to truck costs, intra-district transport costs, chipping and loading costs for logging residuals, processing costs, and coefficients for the mass balances of product and residual streams (MacDonald 2006; Stennes and McBeath 2006; BCMFR 2008a; RISI 2006a, 2006b). For instance, the woody residual use by pulp mills or sawmills in districts with such capacity are based on the estimated use of the particular facilities and are derived from a number of sources (e.g., McCloy 2005; Nyboer and Phillips 2007). Maximum and minimum levels of annual harvests by species group and by district are set exogenously at the expected allowable annual cut (AAC) and 50% of the AAC, respectively (and further described in the Results section). Processing capacity by district is assumed to remain unchanged after 2008, but permanent changes in 2005 to 2008 are included. Exogenous changes in processing capacity are later used to develop our scenarios.

Districts can also trade with each other, with the trade routes between districts defined by distances and cost functions. If a particular district's harvest exceeds its processing capacity, logs can be hauled to another district, for example. Of course, this results in higher delivered log costs. Final products (lumber, plywood, OSB, etc) are sold domestically or exported to the US or overseas markets.

Transportation is defined within a district, over routes joining districts, and over export routes to regions outside the province. In the current form of the model, there is little structure around transportation within a specific district, particularly transportation related to logging at the forest level. This aspect is dealt with in more detail by Niquidet et al. (2008), who consider a single Timber Supply Area. Rather, in the current model, there are simple cost coefficients for transporting logs to the mill site, or moving co-products from mills to other uses (i.e., pellet plants or energy facilities) on the basis of averages within a district. More importantly, there is greater detail in the current model regarding transportation out of a district. The distances from the assumed processing node in each district to all other districts and to final domestic and export markets are provided in a large transportation matrix, with transportation costs determined by:

(1) $t_{ij} = a + b\, d_{ij}$,

where t_{ij} is the transportation cost from district i to district or market j; d_{ij} is the distance from i to j; a is the distance independent portion of costs; and b is the haul cost per unit per km. Specific transport functions are defined for hauling logs, panel products, lumber, chips and residuals between districts and from districts to final destination markets.

As fuel prices are an important cost driver, the proportion of transportation costs related to fuel prices has been isolated for both truck and rail movements, allowing for a schedule of transport costs that reflects expected changes due to increased energy prices over the time horizon. For instance, for trucking, the portion of cost that is attributable to fuel is estimated to be 23% for 2005 (Logistics Solution Builders 2006). Using a historic price series of diesel fuel prices and accounting for the impact of the British Columbia carbon tax, an index of trucking and rail cost changes for our 10-year horizon is developed. The mean compounded fuel price inflation is 7.6 percent per year.

Demand for Final Products

The most detailed information available on the demand side pertains to softwood lumber. This provides a good indication of how the forest sector in British Columbia has evolved and is currently configured. Sawlog values are the main impetus for harvesting decisions, with other processes adding value to the marketing chain as co-products, with chips for pulp production being primary. There are of course exceptions as specific logs are designated for veneer, pole mills, shakes and shingles, log homes, et cetera. The main market for BC lumber is the US, with 67% (2003-2007 average) of softwood lumber produced in BC exported to the US (COFI 2004-2007; Statistics Canada 2004-2007).

Lumber is sold in the domestic market, or exported to the US or overseas. Limits are set on both domestic sales and overseas sales, but sales to the US are more complex. In this case a stepped linear approximation to an excess demand function is modeled. The method used in this implementation derives from Duloy and Norton (1975), who model a downward sloping demand function using steps, with quantity of exports and total revenue at each step captured in separate rows as follows:

$$\text{(2)} \qquad \sum_k x_{kt} s_{kt} \leq USx_t \; \forall t, k \in S$$

$$\text{(3)} \qquad \sum_k R_{kt} s_{kt} \leq 0, \; \forall t, k \in S$$

$$\text{(4)} \qquad \sum_k s_{kt} \leq 1, \; \forall t, k \in S$$

where s_{kt} is the step variable for step k in time t, x_{kt} is the level of exports associated with step k at time t, R_{kt} is the corresponding total revenue, USx_t is total lumber for US export, and S is the set of total steps. Equations (2) and (3) simply define the respective levels of lumber exports and total revenue associated with each step, while equation (4) is the convex combination constraint that ensures that either a single step or a linear combination of two steps is chosen in the model solution set.

To characterize the excess demand function requires an elasticity estimate, and a price quantity pair representing softwood lumber (SWL) exports from BC to the US. To estimate the excess demand elasticity faced by BC lumber exporters, a spatial price equilibrium model of Canada-US lumber trade developed by the Canadian Forest Service is employed (see Mogus et al. 2006; Stennes and Wilson 2005). Trade functions are modeled for different regions in Canada and the United States. Then, by shifting the supply function for BC exports to the US and identifying movements along the excess demand function, we can simulate sufficient data to estimate the trade elasticity while taking into account the impact of competing suppliers and the interaction between US domestic supply and demand. By shifting BC's supply of softwood lumber upwards and downwards, and tracking changes in the price and volume traded in the US market, we estimated an excess demand elasticity of –4.3. This is much more elastic than the domestic US elasticity of –0.17 that is used in the softwood lumber trade model, which is precisely what trade theory predicts.

Maximum and Minimum Harvest Limits

In the model, all prices are in 2005 (base year) Canadian dollars. For most final products, we use observed prices for the period 2005-2008, with 2008 prices assumed to hold for 2009, after which prices revert to the 2001-2005 average for the final five years of the ten-year time horizon. Electricity is assumed to be priced at \$60 per MWh for the first five years, increasing to \$85/MWh for the final five years.

The model endogenously chooses annual harvests subject to maximum and minimum bounds on the harvest levels as determined from AAC calculations (with minimum harvest currently set at 50% of the maximum). Maximum AAC for each year is exogenously set in each district for our three species groups, lodgepole pine (lp), non-pine coniferous (np) and deciduous (dec). For the initial time periods (2005 and 2006), harvests are set at observed levels, but the AAC (maximum cut level) needs to be determined for post-2006 harvests. We determine the AAC for constraining future harvest levels from a number of timber supply estimates, including those from a BC Council of Forest Industries report on beetle impacts (Timberline Forest Industry Consultants 2006), updated using a number of BCMFR sources, including various "Rationale for AAC Determination" reports (BCMFR 2004-2007), and both early (Pederson 2003) and more recent (BCMFR 2007) aggregate updates by the BCMFR on timber supply and subsequent AAC. As we model the maximum allowable harvests by species group and forest district, some additional assumptions are required to convert aggregate timber supply numbers based on Timber Supply Area (TSA) or Timber Forest License (TFL) to forest districts. The assumed maximum harvest levels by district are provided in Appendix Table A1.

In regions that have not seen any increases in AAC through uplifts, we employ the province's district-level Harvest Billing System data and simply assume that maximum post-2006 harvests by species group revert to their 2001-2005 means. Consider as an example the Columbia Forest District (COL), where lp, np and dec maximum harvests all remain at the initial 2005 levels for the 2007-2014 period (see Table A1). This is because the 2005 district harvests for all species groups almost exactly equal the five-year 2001-2005 observed means.

In regions that have seen significant AAC uplifts, such as the Quesnel Forest District (QNL), the method for estimating AAC is slightly more involved. First, the uplifted district AAC must be estimated, which requires assumptions about the timber supply for TSAs and TFLs (if any) within the district, and an assumption about harvest levels from mostly private lands – those not in a TSA or TFL. Second, we assume that the np and dec harvests will remain at the 2001-2005 average means, so that any remaining harvest is assumed to be lodgepole pine (lp). The same technique is used for the post-beetle falldown AACs. It is assumed that the np and dec harvests remain at the five-year historic means and the falldown in harvest is borne by lodegpole pine. The resulting maximum harvests for each district by species group are provided in Table A1.

Results

Expanded use of wood fibre for energy purposes is inevitable given provincial government policies that encourage use of MPB-killed wood for producing energy and require additional electrical generating capacity to be carbon neutral. At the same time, European countries continue to subsidize the use of biomass sources of energy, which has led to planned further expansion of wood pellet production capacity. Therefore, we consider three scenarios: a base case scenario that incorporates the most likely expansion of capacity to use wood biomass for energy, and two additional scenarios that envision even greater expansion of bioenergy capacity. In addition, it is anticipated in all scenarios that pulp mill closures in the northern interior will reduce wood fibre needs in the pulp sector for both pulp and energy production. A summary of the exogenous changes in capacity, standardized to feedstock requirements, for the base case and two scenarios is provided in Table 1.

The base case scenario includes projects that have increased electrical generating and pellet plant production capacities; these projects were added after 2005 and completed before the end of 2008. To standardize these, they have been converted in Table 1 to a bone dry tonne (BDT) of feedstock basis. Thus, in the base case analysis, electrical generation capacity has been added for 2010 and 2014 in the northern interior requiring 228,000 BDT of feedstock, and pellet capacity requiring 400,000 BDT of feedstock in the northern interior and 65,000 BDT and 70,000 BDT in the central and southern interior, respectively. Further, a loss of pulp capacity in the northern interior reduces chip and residual requirements by the amounts indicated in Table 1.

Table 1: Exogenous Capacity Changes from 2005 Levels for Chip and Other Residual Co-Products (′000s BDT)

	2010			**2014**		
	Northern	*Central*	*Southern*	*Northern*	*Central*	*Southern*
Base Case[*]						
Pellets	+403	+65	+70	+403	+65	+70
Direct Fired Elec.	+228	-	-	+228	-	-
For Pulp	-675	-	-	-675	-	-
For Pulp Energy	-411	-	-	-411	-	-
Scenario 1						
Pellets	+403	+65	+70	+403	+65	+297
Direct Fired Elec.	+895	+24	+238	+895	+24	+238
For Pulp	-675	-	-	-675	-	-
For Pulp Energy	-411	-	-	-411	-	-
Scenario 2						
Pellets	+403	+65	+70	+403	+65	+297
Direct Fired Elec.	+1805	+1577	+1577	+1805	+1577	+1577
For Pulp	-675	-	-	-675	-	-
For Pulp Energy	-411	-	-	-411	-	-

[*] There are capacity changes over time in all three scenarios that represent either processing facilities built (+) or permanently closed (-) after 2005.

While the changes from 2005 levels of chip and other residual co-products in the base case are due to actual changes in the capacities of various production facilities, exogenous changes in the utilization capacities of facilities in scenarios 1 and 2 are determined from recent announcements concerning potential future developments. These scenarios represent incremental capacity changes to the base case. Projected capacity changes for Scenario 1 are derived from information pertaining to two midsized biomass-fired thermal power plants (with capacities of 59 MW and 65 MW) and a small one (9 MW) in the northern interior, two small power plants in the central interior (5 MW each), and a 175,000 tonne pellet plant and a further thermal power plant (45 MW) in the southern interior. All are added in the sixth year (2010) except the pellet plant which is assumed to begin operation in 2011.

The exogenous changes of Scenario 1 are not included in Scenario 2. In Scenario 2, capacity is added in 2010 in the form of four large new biomass-fired power plants with a total capacity of 800 MW (200 MW per plant); one is added in the northern interior, one in the central interior, and two in the southern interior. The criteria for site selection are based on available feedstock supply as determined from our base case simulation (including a combination of surplus residuals in 2010), available harvest residuals, and potential volumes of direct harvest for energy. However, the site selection and plant capacities are exogenous to the model. The four districts chosen are Nadina (NAD), Quesnel (QNL), Okanagan (OKS), and Arrow-Boundary (ARR). One additional change from the other two scenarios is that we assume that the non-fibre costs of the 200 MW plants are 20% lower than those of the smaller plants and the efficiency at which wood is converted into energy is improved by 14.5%. These assumptions are based on an analysis of large bioenergy plants by Kumar et al. (2008).

Base Case Simulation Results

In the base case scenario, we assume the harvest limits, processing capacity and market conditions described previously. Base case harvests for the four regions (coast, northern interior, central interior and southern interior) are provided in Figure 2. Rather than give results for the entire 10 years, we present results for the years 2005, 2008, 2010 and 2014 (the final year). These particular years represent the initial year with strong lumber and chip demand, 2008 when there is a high harvest ceiling but demand is much weaker, 2010 when both high allowable harvests and improved demand occur, and the final year when timber supply is reduced (as MPB damage reaches its maximum) but demand remains high.

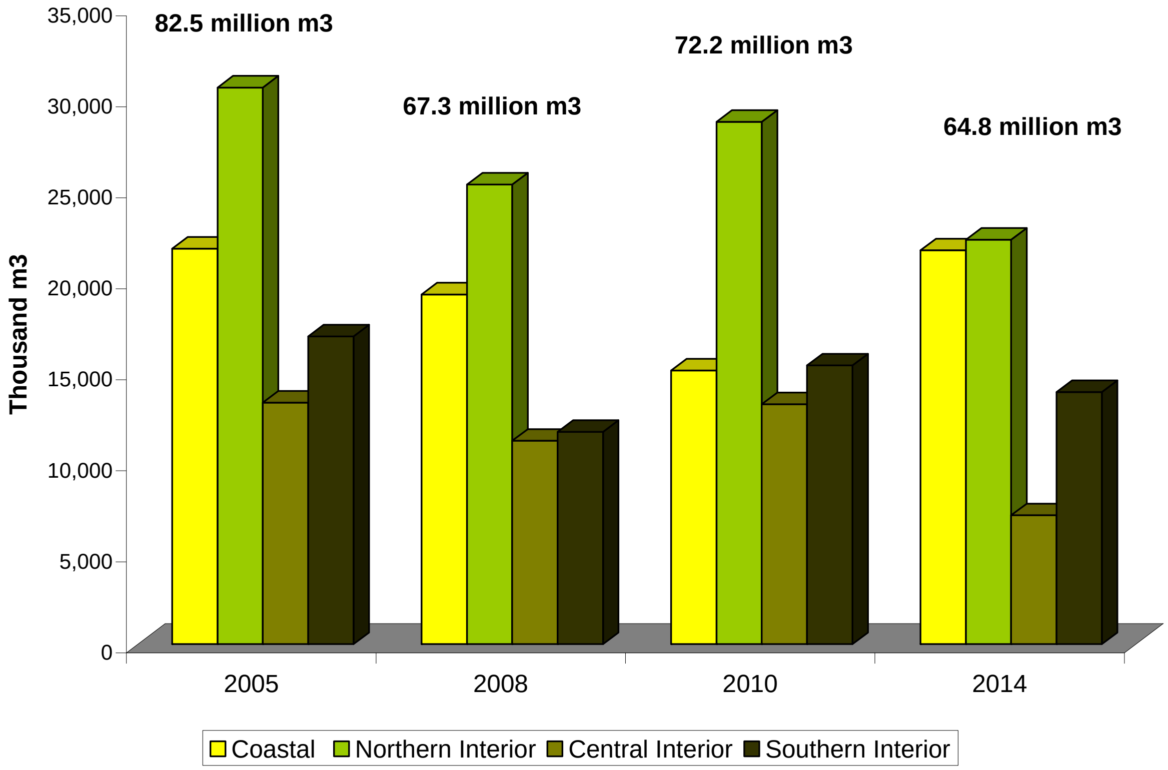


Figure 2: Base-case Harvests over the Simulation Period, 2005-2014

In our base case, the model projects harvests to decline as a result of the MPB devastation from actual 2005 harvests by some 11.5% to more than 21% in our final period, with the greatest declines occurring in the northern and central interior. It should also be noted that the ceiling on harvests is actually higher in both 2008 and 2010 than 2005, but the model chooses to reduce harvests due to demand conditions in 2008 (very poor demand) and 2010 (when demand is back to the 2001-2005 mean level). Table 2 shows how the reductions in timber translate into declines in lumber and pulp production.

Although the northern interior remains the greatest producer of timber in BC, the share of BC production is projected to move from the northern and central interior to the southern interior and the coast under the base case scenario. Hence, the largest dislocation occurs in the province's timber basket, which is also the area hardest hit by the MPB. Surprisingly, the largest reductions in pulp production do not necessarily occur in regions with a large decline in harvested volume. The greatest reduction in pulp production occurs on the coast, while the Quesnel district (QNL in the central interior) maintains pulp production despite incurring the largest reduction in harvests, mainly because of its central location with respect to sawmill capacity and thereby chips.

Table 2: Base Case Lumber and Pulp Production by Region

Year	Coastal	Northern Interior	Central Interior	Southern Interior
	------------------ Lumber (mmbf) -----------------------------			
2005	2,291	7,527	3,109	3,606
2008	2,057	5,733	2,995	2,344
2010	1,243	6,994	3,308	3,446
2014	2,576	5,029	1,784	3,355
	-------------------- Pulp ('000 tonnes) -------------------------			
2005	2,066	2,158	662	1,033
2008	1,557	1,746	662	733
2010	1,374	1,374	662	1,015
2014	1,661	1,383	537	788

The other main product flows of particular importance in this study are the flows of residuals, which are the main source of energy feedstock. The sources of feedstock residuals, which include whitewood residuals (sawdust, shavings and any chips transferred from pulp) and bark, are provided in Figure 3. Roadside residuals used for energy are also reported, although this activity does not enter the optimal solution until the final year (2014), and only in the northern and central interior regions. Although the activity is available, there is no dedicated harvest for energy in the base case.

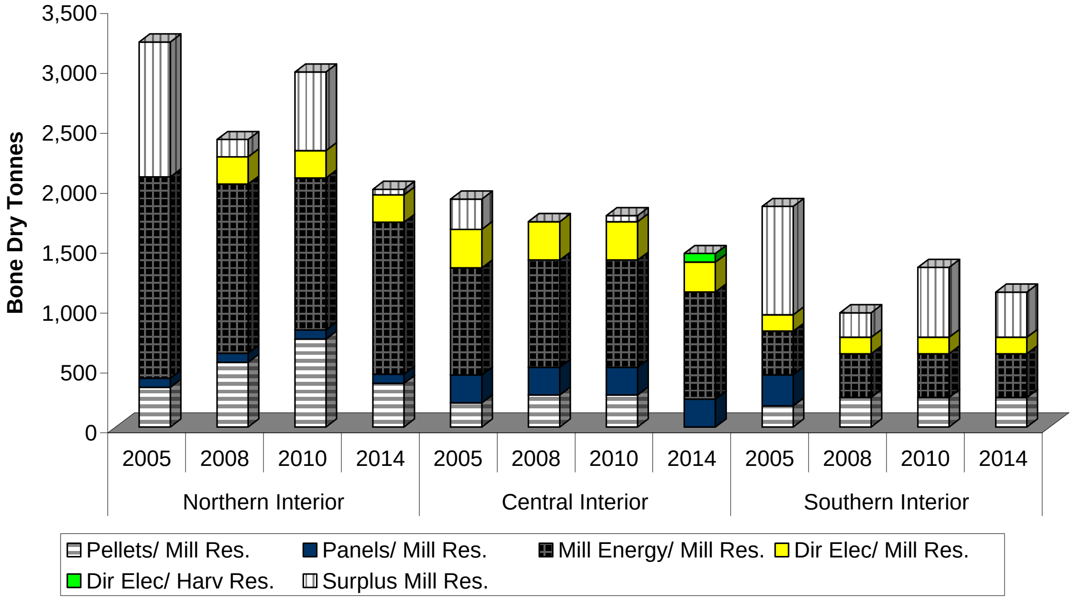


Figure 3: Woody Co-product Use in the Base Case

Pulp chips can also be used in the model for energy purposes by transferring them into the whitewood residual stream. In the final year, approximately 6% of the chips from the northern interior are directed to energy production. The Nadina (NAD) district has no internal pulp capacity and thus diverts the pulp chips to energy, but transports the chips approximately 300 km.

Scenarios with Added Biomass Generating Facilities

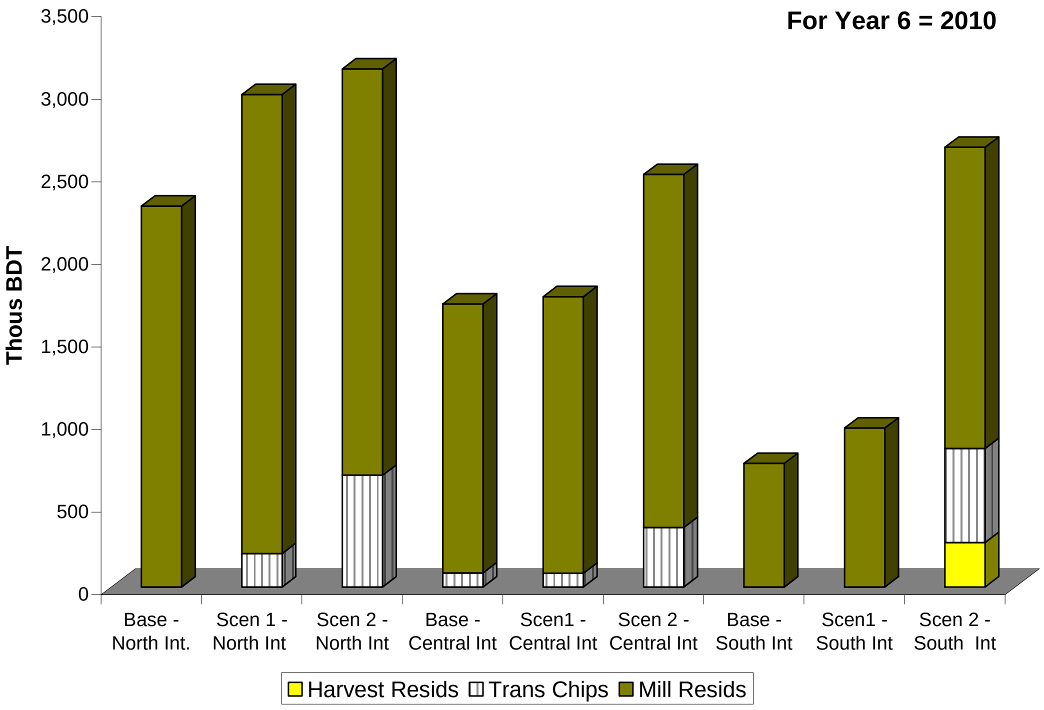
Now consider the other scenarios. As discussed earlier, in Scenario 1 we add a further 188 MW of generating capacity while in scenario 2 an additional 800 MW of power plant capacity is assumed to be in place beginning in 2010 (as described above). These are both incremental to what is included in our base case scenario. A comparison of harvests, lumber and pulp output, pellet production, and electricity generation for the two scenarios relative to the base case is provided in Table 3. Since the changes in capacity to produce energy occur only in the second half of the time horizon, we consider only the changes that occur in 2010 (year six of the simulation) and 2014 (the final year).

Table 3: Changes in Selected Model Outputs Relative to the Base Case, Scenarios 1 and 2, for Years 2010 and 2014

	Scenario 1		**Scenario 2**	
Product	**2010**	**2014**	**2010**	**2014**
Harvest (′000s m^3)	+98	0	+957	0
Lumber (mmbfm)	+24	0	+261	0
Pulp (′000s tonnes)	-52	-155	-570	-670
Pellets (′000s tonnes)	0	-88	-26	-380
Energy (′000s MWh)	+1,500	+1,480	+6,300	+6,230

For the base case, the model solution does not harvest at the ceiling in 2010, with many districts harvesting at levels between the upper and lower limits. When the additional energy capacity is added, it triggers an increase in harvests and lumber production. Harvests and lumber production increase because value has been added to the system through better use of lumber residuals and, in some districts, chips. In essence, the economic margin for sawlog harvest is expanded, especially in Scenario 2 where almost 1 million m^3 of additional timber harvests occur. In the final year, this is no longer the case as the model tries to harvest everything it can in all three scenarios in reaction to the decreased allowable harvests.

Increased energy production in the final year comes from the following combination of strategies: (i) increased field chipping of harvest residuals; (ii) some transfer of pulp chips and previously employed mill residuals to electrical production; and (iii) greater movement of residuals between regions. Increased transport of residuals results in added CO_2 emissions that offset benefits from more bioenergy production. Details on the source of energy feedstock supplies for 2010 and 2014 across all three scenarios and for all three interior regions are summarized in Figure 4.



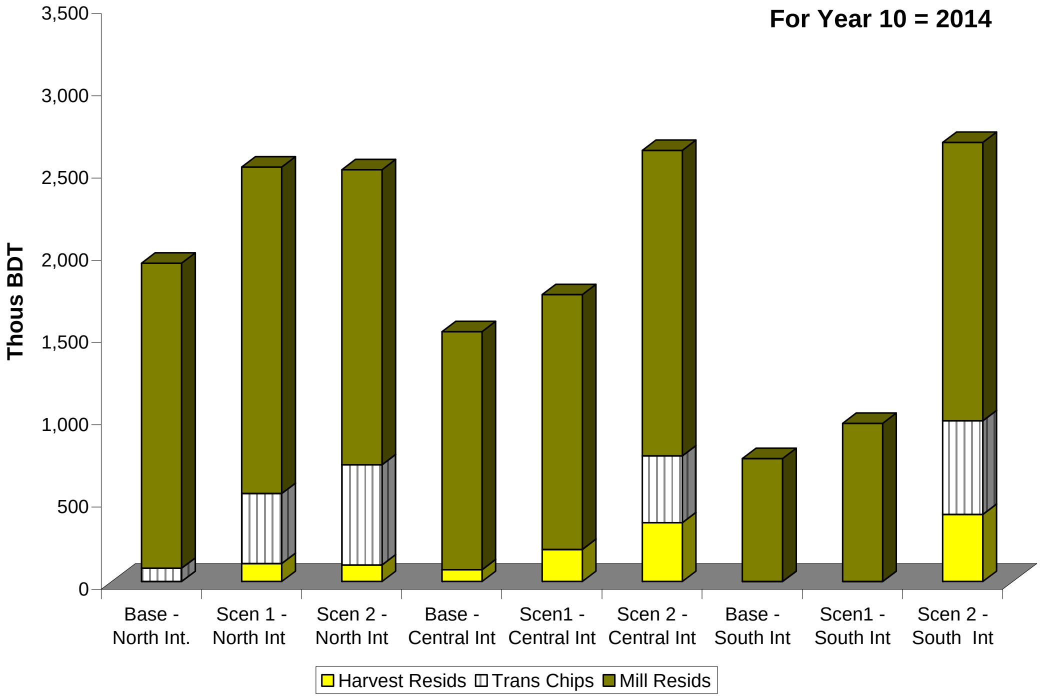


Figure 4: North, Central and Southern Interior 'Residual' Feedstock Supplies in 2010 and 2014

When the supply crunch hits in our final year, almost all districts are harvesting at the maximum allowable harvest in all three scenarios. Residual fibre streams are also reduced, and some of the biofeedstock supply is enhanced through increased field chipping of roadside residuals. The southern interior districts of Arrow Lakes & Boundary (ARR) and Kootenay (KOO) employ field chipped residuals at the upper resource limit; the associated shadow price of biofeedstock supply is approximately $12 per BDT. In these districts, therefore, additional harvests of fibre for bioenergy are worthwhile if the additional marginal cost does not exceed $12/BDT, which is in addition to the cost of field chipping harvest residuals.

The Scenario 2 solution projects a large drop in pellet production of nearly 400,000 tonnes and a 700,000 tonne reduction in pulp production compared to the base case for the same year. Although the value of the objective function (net discounted returns) progressively increases from the base case to scenarios 1 and 2, there are considerable changes in how fibre is utilized.

Discussion

It is difficult to examine feedstock supply for energy in isolation from other sectors. Our research indicates that the timber supply reductions due to the mountain pine beetle will result in a deficiency in feedstock for sectors relying on joint products from lumber production. Some additional fibre is needed simply to meet ongoing needs for the production of pellets, energy and pulp. As a result, increasing the current biomass generating capacity will affect other sectors that rely on wood fibre. This holds true even with additional fibre available in the forest in the form of harvest residuals and access to dead or dying standing timber as these sources are costly. As supplies are spatially optimized, regional surpluses are utilized, but not always in the region where they are harvested. Importantly, before more expensive fibre supplies are utilized and as biomass generating capacity is increased, fibre gets diverted from existing uses to energy use. Even relatively high-value pulp chip supplies are affected in cases where pulp mills are located far from sawmill locations.

Effects on the other forest sectors as bioenergy capacity is increased largely depend on the degree of tightness in supply. When fibre supply is relatively unconstrained, as is the case in year 6 of our base case simulation (many districts are harvesting less than their maximum AAC), the effect of increasing the value of residuals has a positive impact on harvesting and associated lumber production. Other users of non-chip residuals are also relatively unaffected, although in Scenario 2 pulp production falls by nearly 600,000 tonnes as chips are diverted from pulp to energy production.

Modelling expected supply reductions due to the beetle has different consequences in our final year. The increased capacity no longer results in any expansion of harvests or lumber production as timber is not available. Pulp mills at locations remote from lumber processing facilities and existing pellet producers (and other users) are required to compete for fibre in this case as feedstock is diverted to energy production.

Finally, it should be noted that the added energy capacity is exogenous to the model. It is not clear whether these lumpy investments in new capacity, particularly for scenario 2, would occur under the power price structure we model. Once in place, given the costs and prices assumed in the model, these facilities do run at full capacity, using feedstock obtained by additional harvest or chipping of fibre and, notably, bidding some fibre away from other users. What seems apparent is that, if in an effort to salvage marginal pine beetle stands BC policy makers choose to price power to reflect higher incremental feedstock costs, unintended impacts on other parts of the forest sector will occur.

Endnotes

[1] These examples relate to wind and biomass only; there are many more examples in these and other sectors. For instance, using meta-analysis, van Kooten et al. (2004) demonstrate that tree planting projects where harvested wood is subsequently used for energy can sometimes provide a low-cost alternative for reducing atmospheric CO_2.

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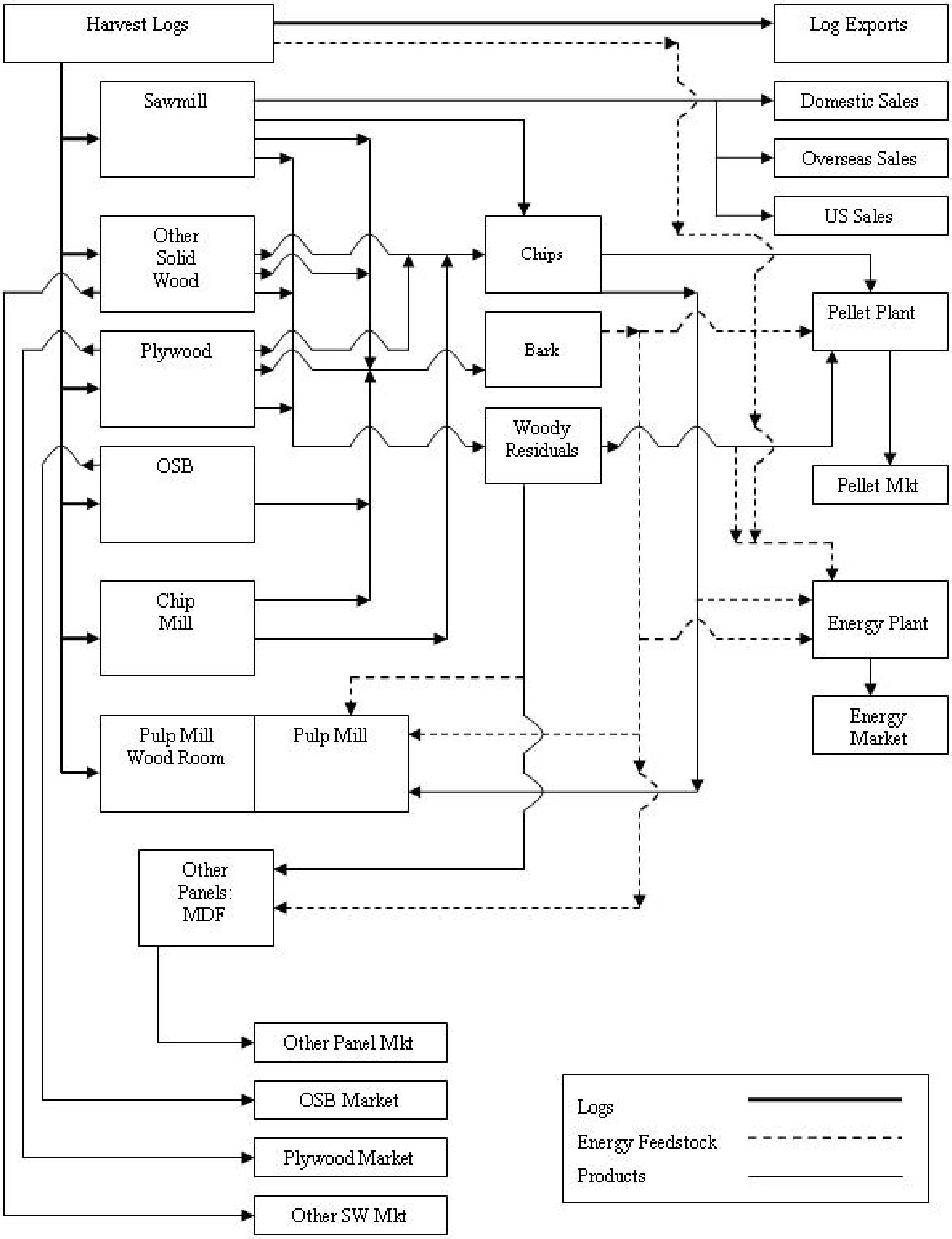
Harvest Logs
Log Exports
Sawmill
Domestic Sales
Overseas Sales
US Sales
Other Solid Wood
Chips
Pellet Plant
Plywood
Bark
Woody Residuals
Pellet Mkt
OSB
Chip Mill
Energy Plant
Energy Market
Pulp Mill Wood Room
Pulp Mill
Other Panels: MDF
Other Panel Mkt
OSB Market
Plywood Market
Other SW Mkt
Logs
Energy Feedstock
Products

Figure A1. Physical Flows in Fibre Allocation Model

Table A1. Maximum Annual Allowable Cut by District

	Species		Proportion of 2005 Levels		
District	Group	2005	2008	2010	2014
Northern Interior					
FNE	lp	25.4	1.32	1.32	1.32
	np	502.0	1.09	1.09	1.09
	dec	675.6	1.15	1.15	1.15
KAL	lp	2.5	1.06	1.06	1.06
	np	563.3	3.23	3.23	3.23
	dec	0.9	1.51	1.51	1.51
MAC	lp	1793.9	1.11	1.11	1.11
	np	830.0	1.46	1.46	1.46
	dec	65.8	0.60	0.60	0.60
NAD	lp	4275.8	0.79	0.79	0.28
	np	1288.3	1.42	1.42	1.42
	dec	6.4	0.58	0.58	0.58
PCE	lp	1165.3	1.56	1.56	1.09
	np	1227.3	1.13	1.13	1.13
	dec	1432.5	1.38	1.38	1.38
PG1	lp	1866.0	1.17	1.17	0.24
	np	1037.0	1.42	1.42	1.42
	dec	7.4	1.00	1.00	1.00
PG2	lp	5720.9	0.91	0.91	0.85
	np	2957.9	0.81	0.81	0.81
	dec	139.8	1.56	1.56	1.56
PG3	lp	4301.3	0.97	0.97	0.43
	np	788.5	0.84	0.84	0.84
	dec	20.2	2.55	2.55	2.55
SSK	lp	81.2	1.52	1.52	1.52
	np	388.3	1.46	1.46	1.46
	dec	2.6	1.58	1.58	1.58
Central Interior					
CCA	lp	2675.1	1.48	1.48	0.85
	np	1075.4	0.81	0.81	0.81
	dec	22.8	1.56	1.56	1.56
CHC	lp	652.3	1.49	1.49	0.69
	np	56.0	1.04	1.04	1.04
	dec	0.1	0.01	0.01	0.01
HDW	lp	577.7	0.68	0.68	0.17
	np	985.8	1.13	1.13	1.13
	dec	22.7	1.06	1.06	1.06
MIL	lp	1618.4	0.94	0.94	0.31
	np	512.1	0.91	0.91	0.91
	dec	59.6	0.82	0.82	0.82
QNL	lp	4186.2	1.24	1.24	0.01
	np	1142.6	0.93	0.93	0.93

	dec	33.1	1.00	1.00	1.00

Table A1 (Cont.). Maximum Annual Allowable Cut by District

District	Species Group	2005	Proportion of 2005 Levels 2008	2010	2014
Southern Interior					
ARR	lp	803.5	0.73	0.73	0.91
	np	1770.5	1.02	1.02	1.02
	dec	6.1	2.11	2.11	2.11
CAS	lp	1843.8	1.50	1.50	1.25
	np	904.7	0.91	0.91	0.91
	dec	0.2	1.43	1.43	1.43
COL	lp	149.7	1.00	1.00	1.00
	np	722.8	0.99	0.99	0.99
	dec	0.9	1.00	1.00	1.00
KA1	lp	2054.3	1.27	1.27	0.26
	np	1490.7	0.69	0.69	0.69
	dec	22.4	1.06	1.06	1.06
KOO	lp	248.5	0.84	0.84	0.84
	np	511.1	1.19	1.19	1.19
	dec	1.3	0.81	0.81	0.81
OKS	lp	2002.3	0.76	0.76	0.38
	np	2287.6	1.04	1.04	1.04
	dec	14.9	1.06	1.06	1.06
RMT	lp	1479.4	0.75	0.75	0.58
	np	632.4	1.39	1.39	1.39
	dec	0.8	1.03	1.03	1.03
Coast					
LMD[*]	lp	7.9	1.06	1.06	1.06
	np	3238.6	1.14	1.14	1.14
	dec	166.8	0.97	0.97	0.97
SCST[†]	lp	9.4	1.78	1.78	1.78
	np	11956.5	0.95	0.95	0.95
	dec	151.4	1.13	1.13	1.13
NCST[‡]	lp	20.1	1.18	1.18	1.18
	np	6024.8	1.03	1.03	1.03
	dec	59.3	0.51	0.51	0.51

Notes:

[*] Coastal districts FRA, SS1 and SQU (Figure 1) have been an aggregated into LMD (Lower MainlanD).

[†] The South Coast (SCST) district includes Vancouver Island districts of Campbell River and South Island

[‡] The North Coast (NCST) district includes coastal districts north of Campbell River on

Vancouver Island and coastal districts north of Squamish (SQU) district.
Source: Adapted from BCMFR (2004-2007, 2007, 2008b) and Timberline Forestry Consultants (2006).