Estimated Costs for Harvesting, Comminuting, and Transporting Beetle-killed Pine in the Quesnel/Nazko Area of Central British Columbia

A. J. MacDonald, R.P.F.

Senior Researcher
Harvesting Operations Group

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Forest Engineering Research Institute of Canada
2601 East Mall
Vancouver, BC
V6T 1Z4

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Abstract

The Forest Engineering Research Institute of Canada (FERIC) estimated the costs of harvesting, comminuting, and transporting pine trees killed by the mountain pine beetle in the central Interior of British Columbia. Costs were based on computer models that used three different harvesting systems depending on the ratio of sawlogs to fuelwood in the stand. For stands with less than 50% fuelwood, the existing roadside harvesting system was used to harvest sawlogs and generate roadside residuals, followed by a separate operation to comminute and transport the feedstock. This system had the lowest cost. Stands with 50-95% fuelwood were costed using a satellite sortyard. This system was best suited to sort the sawlogs from stands containing predominantly fuelwood, but it also had the highest cost. Furthermore, stands suitable for processing through satellite yard comprised more volume than any other system in an example study area. Stands with more than 95% fuelwood were costed using on-site, full-tree chipping. According to FERIC's shelf-life model for predicting fuelwood content, no stands suitable for this system exist at 5 years after mortality, but the number of full-tree chipping stands comprise about 40% of the total volume in the study area by 20 years past mortality.

FERIC conducted field measurements of the volume of residuals generated by roadside harvesting, and found that 14-55% of the original stand biomass remained at roadside after harvesting, depending on the sawlog utilization standards. There was also a substantial volume of biomass dispersed across the cutblocks, however, it was mainly in pieces too small for harvesting, and was not considered to be a potential source of feedstock.

KEYWORDS: Mountain pine beetle, harvesting system, comminution, transportation, costs, volume determination, interior British Columbia, fuelwood, bioenergy, biomass, residues

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1 Introduction

The current infestation of mountain pine beetle (*Dendroctonus ponderosae* Hopkins) is having a significant effect on the lodgepole pine (*Pinus contorta* Dougl.) forests of interior British Columbia. The impact of this infestation is unprecedented in recorded history, and the volume of pine that will be killed by the mountain pine beetle in some areas is forecast to exceed the capacity of the existing logging and milling industry to deal with it effectively. Forest companies have increased their harvest of dead pine, but despite this increased harvesting activity, significant volumes of beetle-killed pine will remain unharvested and its commercial value may be lost. One option for salvaging more value from the dead pine is to harvest it for fuelwood.

In 2005, BIOCAP (Kumar *et al* 2005) proposed to use the unharvested pine as feedstock for an electrical generation power plant located near the epicenter of the beetle infestation, at either Quesnel or Nazko. Such a power plant would consume approximately 65 million m^3 of pine over its twenty-year lifespan. The proposal was based on some elementary estimates of the pine volumes and spatial distributions, and of the harvesting and comminution costs. The Forest Engineering Research Institute of Canada proposed to review those volume and cost estimates to provide more confidence in their accuracy.

Near the same time, the BC Ministry of Energy, Mines, and Petroleum Resources (MoEMPR), BC Hydro and the BC Ministry of Forests and Range (MoFOR) partnered with Forintek Canada Corp. to provide information about ways that forest biomass could be included in BC's energy strategy. The use of beetle-killed pine as feedstock for power generation would be included as one of the options. In order to properly address the dead pine in the energy strategy, such an analysis would require information about the harvesting cost.

As part of its mandate to the MoEMPR and MoFOR, Forintek Canada Corp. contracted FERIC to provide volume and cost estimates for harvesting, transporting, and comminuting beetle-killed pine to a site where it could be used for power generation.

2 Objectives

FERIC's analysis was to include:

- A description of the appropriate harvesting and transportation systems for the dead pine trees;
- Estimated costs of harvesting and comminuting the beetle-killed pine from typical harvesting sites using the most appropriate harvesting system;
- Estimated costs for transporting the feedstock from the harvesting sites to the potential sites for power generation; and
- An example of applying the costs and volumes to a specific area using the Quesnel/Nazko corridor as a case study.

FERIC's analysis was for direct harvesting and transportation costs, and was not to include:

- planning and administration costs;
- road development, maintenance, and deactivation; and
- reforestation.

The primary goal of the project was to deal with costs; volumes were considered only as they influence machine productivity and to illustrate the effects of "scaling-up" the analysis from individual cutblocks to a larger operating area. Determining the amount of annual harvest and the sustainability of the fibre supply were beyond the scope of the project.

This report is in fulfillment of FERIC's contract with Forintek to document the harvesting costs and "orders of magnitude" volume estimates of biomass from the beetle-killed pine.

3 Methods and Results

A literature search was undertaken to determine what harvesting systems and equipment were being used in other jurisdictions to harvest, comminute, and transport residual and standing biomass (Badger 2002, Blair 1998, Bolding and Lanford 2005, Forrester *et al* 2006, Lewis and Hartley 2006, Loeffler *et al* 2006, Pottie and Guimier 1985). FERIC attended the "Smallwood 2006" conference (Forest Products Society 2006), which emphasized harvesting small trees for the purpose of supplying feedstock to power plants. After the conference, FERIC undertook a field tour through southeast USA to observe the systems and equipment that are commonly used for harvesting fuelwood in that area. FERIC met with operational planners in the BC Interior to discuss their ideas on harvesting in the beetle-killed stands. The information from these sources was used to specify the harvesting systems that will be appropriate for large-scale fuelwood salvage of the beetle-killed pine.

3.1 Field measurements of residual volumes

Potential fuelwood from the beetle-killed pine occurs in two classes: the residuals (tops, butts, and limbs) that are left after conventional harvesting operations, and dead standing trees from areas that are not harvested under current practices. Estimating the volumes in these two classes requires different approaches.

FERIC recently completed two projects (MacDonald 2004, 2006) to measure the roadside residual left after harvesting, however, these projects were conducted under significantly different conditions than the beetle-affected areas. Accordingly, FERIC conducted fieldwork to measure the volume of residuals after harvesting from pine-dominated stands in the Quesnel/Nazko corridor. In July 2006, the cooperating companies suggested cutblocks from their recent harvesting areas that would be appropriate for measuring the residual volumes. Parts of the cutblocks that were visibly associated with specific residual piles (e.g., between spur roads and bounded by the cutblock boundary) were used for measurement. The residual volume was measured in two categories: the tops, butts, and limbs that were piled at roadside, and the small, broken, or overlooked pieces that were dispersed across the cutblock.

The volumes measured for this project were meant to assess the biomass that was left on-site after conventional timber harvesting, and do not reflect on the measurement of avoidable waste as defined by regulations. Only gross volume was considered; there was no accounting for form or quality of the biomass, nor its suitability for conventional timber products. Likewise, any volume that was intentionally left on-site to meet non-timber objectives such as retaining coarse woody debris for wildlife habitat was not differentiated from any other volume.

3.1.1 Roadside residuals

Top piles are left near the roadside after the logs are processed mechanically, often by means of a dangle-head processor. Dangle-head processors retrieve whole trees from the supply pile, delimb and top them, pile the processed logs near the road, and discard the tops into piles (Figure 1). The top piles usually start about 10-13 m from the centreline of the road in order to leave enough room for the processed logs to be piled. Subsequently, the log loader travels on the area where the logs are piled, unimpeded by the residual top piles yet within reach of log trucks on the road. Depending on the particular operation and the volume of residual material, the tops may take the form of continuous or discontinuous rectangular piles, or teepee-shaped discrete piles (Figure 2).

***Figure 1:* Two dangle-head processors working in tandem in a roadside logging operation.**

***Figure 2:* Teepee-shaped piles on both sides of the logging road through a typical cutblock.**

The volume of the roadside residuals was estimated by measuring the dimensions of every roadside pile in each measurement area. The bulk volumes of teepee piles were calculated using Hardy's (1996) paraboloid equation, while the volumes of linear piles were calculated as irregular solids. The piles' dimensions were measured directly using logger and carpenter tapes.

FERIC measured roadside and dispersed residual volumes from 15 areas in 12 cutblocks from four companies. Each company implemented a different utilization specification in regard to small-diameter tops, and these differences manifested themselves in different amounts of roadside residual volumes. One company routinely harvested tops to a 5 cm (2 inch) diameter, while others used 10 cm or larger for their target top diameter.

In the volume calculations shown in Table 1, the bulk volume includes all the airspace between the tops, butts, and limbs in the pile. The bulk volume was converted into residual volume, expressed as oven-dry tonnes per hectare, by multiplying the bulk volume by a bulk density factor, and dividing by the area of the cutblock that contributed to the residual pile. The cutblock areas were determined by GPS traverses of the areas associated with the specific residual piles. A bulk density of 200 kg/m^3 at 40% moisture content, or 120 kg/m^3 dry equivalent, was used for all piles. Owing to the constraints of this project, it was not feasible to conduct field measurements of the bulk density, therefore, the bulk density was adapted from previous FERIC field work and other sources (MacDonald 2006, Oregon Department of Energy 2006, Hamelinck *et al* 2003, WoodEnergy.ie 2006). The literature showed a wide range of bulk densities (~150 – 250 kg/m^3), and FERIC's previous work was in spruce and aspen forest types in Alberta which may not be directly applicable to the pine forests of the beetle-affected area. FERIC felt that 200 kg/m^3 at 40% moisture content (120 kg/m^3 dry bulk density) was a reasonable value to calculate "orders of magnitude" volume estimates, but recommends that field measurements be undertaken to verify the value.

The inventory stand volume was taken from the MoFOR dataset for the Quesnel Timber Supply Area (TSA). Note that inventory volumes are not normally applied to individual cutblocks, however, this value was the only volume estimate that was available consistently for all cutblocks. The cutblocks were all in pine-dominant stands with at least 90% pine content according to the MoFOR inventory dataset. FERIC obtained some cruise-based, individual cutblock volume estimates from the cooperating companies, and these values were generally 3-5% higher than the inventory volume. The inventory volume was converted to estimated original biomass by multiplying the inventory cruise by 420 kg/m^3 and adding 5% to account for cruise overruns, then adding the volume of roadside residual. Finally, the volume of roadside residual was expressed as a percentage of the original stand volume.

Table 1: Roadside residual volumes expressed as a percentage of the original stand volume.

Company	Cutblock	Area (ha)	Bulk Volume Including Airspace (m^3/ha)	Residual Volume (ODt[1]/ha)	Inventory Stand Volume (m^3/ha)	Estimated Original Stand Biomass (ODt/ha)	Roadside Residual as Proportion of Original Stand Volume (%)
A	1	7.60	184	22.1	298	131	14%
A	1	4.51	317	38.0	279	123	24%
A	1	9.55	334	40.0	279	123	25%
A	2	17.90	313	37.5	218	96	28%
B	1	22.43	390	46.8	198	87	35%
B	2	14.19	399	47.8	219	97	33%
B	3	14.71	536	64.3	266	117	35%
B	4	4.66	265	31.8	243	107	23%
B	4	6.98	509	61.0	232	102	37%
C	1	3.62	824	98.8	265	117	46%
C	2	4.42	251	30.2	230	101	23%
C	3	8.24	1194	143.3	310	137	51%
D	1	0.72	596	71.6	273	120	37%
D	1	2.44	826	99.1	270	119	45%
D	1	0.45	1208	144.9	270	119	55%

Roadside residual volumes ranged from 14% to 55% of the original stand volume (Figure 3). FERIC observed that the company following the 5-cm top diameter utilization standard had among the lowest residual volume, while the company that targeted its top diameters at more than 10 cm had among the highest levels. Furthermore, FERIC observed many tops within these piles that were larger than 10 cm (Figure 4). The residual pieces with large diameter were usually affected by severe checking that made them unsuitable for sawlogs.

The volumes calculated here are significantly different than the cull volumes experienced by forest companies. FERIC was told by one cooperating company that the typical difference between gross cruise volume and as-delivered volume was about 20%, not the 45-55% that was shown here. This statement reaffirms the necessity to do additional measurements of roadside residual volume, especially to confirm the bulk density of the residual piles.

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[1] ODt: Oven-dry tonne. Equivalent to bone-dry tonne (BDt)

***Figure 3:* Typical roadside residual pile with 10-cm top diameter target.**

***Figure 4:* Large diameter top with severe checking.**

3.1.2 Dispersed residuals

The dispersed residuals were measured using the line intersect method (Sutherland 1986). Plots with two, 20-meter perpendicular lines were established at random locations throughout the cutblock at a density of approximately one plot per hectare. Every sound piece of softwood residual with a minimum diameter of 1 cm and length of 60 cm was tallied. In addition, the length and mid-stem diameter of every piece over 5 cm diameter where the sampling line intersected the piece was recorded. Volume was converted into its biomass equivalent using a conversion rate of 420 kg/m^3.

The line intersect method measures the total volume of all the dispersed residuals larger than 1 cm diameter and 60 cm long. Clearly such small pieces cannot be harvested economically, but they were measured in order to compare the total biomass between cutblocks. By collecting additional size measurements, FERIC calculated the dispersed biomass volume that met the strict, but more economically feasible, utilization specifications of 15 cm diameter and 3 m length (Table 2). FERIC made no attempt to assess the quality of these larger pieces, and it is unknown whether they meet sawlog quality specifications. FERIC also calculated the volume of pieces that were larger than the strict minimum size limit but smaller than 20 cm diameter and 4 m length; such pieces were deemed to be smaller than contemporary utilization limits. This volume (shown as the last column in Table 2) comprises the dispersed residuals that could be available as fuelwood because it is large enough to be skidded, yet is smaller than contemporary sawlog size limits.

Table 2: Volume summary of dispersed residuals.

Company	Cutblock	Total Volume m^3/ha	Total Volume ODt/ha	Volume of pieces larger than strict minimum size (m^3/ha)	Volume of pieces larger than strict minimum size and smaller than contemporary merchantable size limits (m^3/ha)
A	1	50.7	21.3	2.6	0.0
A	1	71.6	30.1	0.0	0.0
A	1	44.9	18.9	8.8	2.0
A	2	18.7	7.8	0.0	0.0
B	1	20.0	8.4	2.5	0.0
B	2	20.0	8.4	3.4	0.8
B	3	31.0	13.0	0.4	0.0
B	4	26.3	11.0	1.5	0.3
B	4	56.2	23.6	1.2	0.6
C	1	37.2	15.6	4.1	0.0
C	2	51.1	21.5	1.9	1.1
C	3	51.5	21.6	0.0	0.0
D	1	67.9	28.5	7.0	1.8
D	1	47.0	19.7	2.3	0.9
D	1	50.9	21.4	0.0	0.0

Table 2 shows that the dispersed residuals comprise a significant volume, with an average volume of nearly 50 m^3/ha or 20 ODt/ha. Relative to the roadside residuals, especially in cleanly-logged cutblocks (Table 1), the dispersed residuals makes up a large part of the total residual biomass. However, most of the dispersed volume is from pieces that are much too small to be harvested economically; the dispersed residual volumes that are larger than the strict utilization limits ranged from about 1 - 5 m^3/ha (Figure 5). Furthermore, most of the volume that is over the strict utilization limit is also larger than more contemporary utilization limits, and may have been overlooked (intentionally or inadvertently) during skidding. The residual biomass volume that is large enough to be skidded but would also be available after exactly following contemporary sawlog specifications ranged from 0 – 2 m^3/ha. FERIC observed a few sites where the number of unskidded pieces was clearly more than normal (Figure 6). For these areas, FERIC observed that the average diameter was less than 15 cm, and the stems would likely have been left as roadside residue if they had been skidded. This may explain why the buncher and skidder operators did not harvest all the trees from these areas. Such heavy residual loading was atypical.

Figure 5: ***Most of the dispersed residuals are small, widely scattered, and uneconomic to harvest. Some of the dispersed residuals are large enough to make sawlogs, and may have been overlooked during skidding. Only a small fraction of the dispersed residual is sized suitably for skidding as biomass.***

Figure 6: ***Large amounts of dispersed residuals were uncommon in the surveyed areas.***

FERIC concluded that the volume of dispersed residuals that actually represents potential for harvesting as biomass feedstock is very small, and will be omitted from further analysis.

3.2 Standing fuelwood volume calculations

Forest Analysis and Inventory Branch of the MoFOR provided a dataset of the Quesnel TSA forest cover. In addition to standard forest cover attributes, the dataset included attributes for ownership, timber harvesting constraints, biogeoclimatic zones and subzones, and Land Units for each forest cover polygon. Volume summaries and travel-time analyses for the case study were conducted using the Land Units as defined by the MoFOR database.

Several factors, including the actual land base, the suitability of harvesting systems, and the shelf life of the sawlogs and fuelwood, must be considered for calculating the volume of standing fuelwood. These factors will be described.

3.2.1 Case study area chosen using travel times and existing road development

For each of the Land Units in the Quesnel TSA west of the Fraser River, FERIC estimated the haul distance to Quesnel on highway, mainline, branch, and spur roads, then subsequently calculated the hauling time to Quesnel using the average travel speeds shown in Table 3.

Table 3: Travel speeds for log and chip trucks.

Road Class	Travel Speed (km/h)
Highway	80
Main	60
Branch	45
Spur	20

Using the road network from the LRDW database (Ministry of Sustainable Resource Management 2006), FERIC estimated the existing road network density in three classes. Densely-roaded areas had a clearly-visible existing road network that serviced existing cutblocks. In the absence of other constraints, the leave strips between existing cutblocks in these areas could be harvested for fuelwood with a minimum of new road development. Sparse road-development areas lacked a mainline road system, and would require a significant amount of mainline and branch road development before harvesting could be undertaken. The remaining areas, i.e., those with some roads such as nearby mainline roads and only a few cutblocks, comprised the partially-roaded class. These partially-roaded areas would require some mainline road development and a significant amount of branch development before timber harvesting could take place. Partially-roaded areas offer few opportunities to harvest leave strips between existing cutblocks without a significant amount of new road construction.

The existing main road development in the three westernmost Land Units of the Quesnel TSA is intended for travel to destinations other than Quesnel so their round-trip travel time to Quesnel (excluding load, unload, and delay times) averaged more than 8 h. Since these three Land Units also have sparse road development, they were excluded from subsequent analysis. Accordingly, the land base used for the case-study analysis comprised all the Land Units in the Quesnel TSA west of the Fraser River, except for the three westernmost Land Units. The longest round-trip travel time for the included Land Units was almost 5 h. The Quesnel TSA and the case study area are shown in Figure 7.

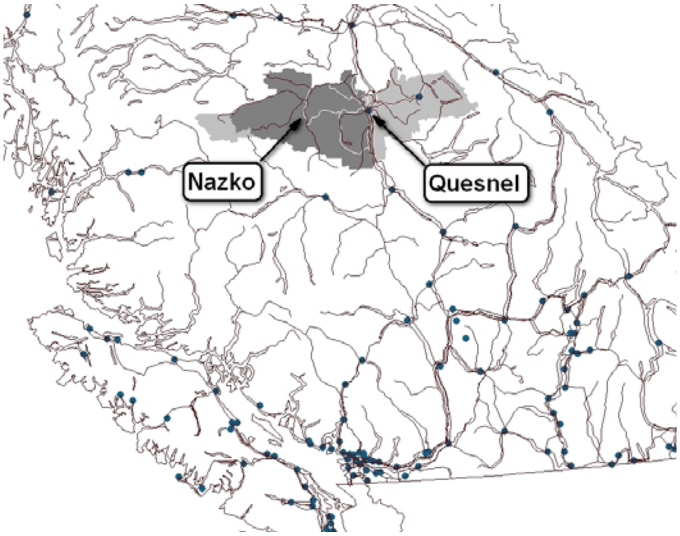

Figure 7: Quesnel TSA with case study area highlighted.

3.2.2 Fuelwood harvesting potential

FERIC's primary objective in this project was to calculate costs, but costs can be influenced by the total harvested volume. Accordingly, it was important to assess the total potential harvesting volume, even at a rudimentary level. FERIC made some assumptions about what stands could be available for harvest, but in practice many stands will need to be retained to provide for other resource values and objectives. Each landscape unit will have differing objectives and would need to be assessed for its acceptance to removal of existing leave strips. Any future analysis must consider all resource values when calculating the available volumes.

Stands within the study area were classified for their fuelwood harvesting potential by excluding all stands that were marked as non-forest cover, non-Crown ownership, or non-harvestable (i.e., had a non-timber harvesting constraint). Further, stands less than 25 years old, with less than 30% pine content, or with less than 75 m^3/ha of merchantable volume were also excluded. The remainder was designated as potential for fuelwood harvest, and the distribution of land within the case study area is shown in Table 4.

The distribution of road density within the "potential fuelwood harvest" area is shown in Table 5.

Table 4: Land distribution within the case study area west of Quesnel.

Fuelwood Harvest Potential	Area within Case Study Area (ha)
Non-forest land	132 125
Non-crown land	51 386
Non-timber harvesting constraint	169 081
Age < 25	111 579
Pine content <= 30%	133 840
Volume < 75 m^3/ha	44 367
Potential fuelwood harvest	589 328

Table 5: Road-density class distribution of the potential fuelwood harvest areas in the case study area.

Road Density Class	Area (ha)
Sparse	259 728
Partially-roaded	127 780
Dense	201 820
Total	589 328

3.2.3 Influence of fuelwood content on the harvesting system

While large-scale harvesting of beetle-killed pine will have similarities with biomass harvesting operations in other jurisdictions, FERIC believes that customized solutions will be required because of the overall volume to be harvested, the mixture of sawlogs and fuelwood within individual stands, the tree size, and unique terrain, climatic, and geographic conditions. As such, the cost and productivity information from other jurisdictions may provide useful starting points for cost analysis, but the only way to reliably determine the cost and productivity is to conduct operational trials under actual operating conditions. Such trials should be the subject of future research.

FERIC believes that the varying proportions of sawlogs and fuelwood within individual stands will have a significant influence on the selection of the harvesting system, and proposes to use different systems depending on the relative proportions of sawlogs and fuelwood.

In current salvage operations (i.e., with sawlogs as the primary focus), the forest industry harvests the beetle-killed stands using conventional roadside harvesting systems in which the trees are felled and bunched, then skidded to roadside where they are processed into sawlogs. The tops, butts, and limbs that are not suitable for sawlogs are left in piles near the roadside, to be burned when weather conditions are appropriate. FERIC believes that this system will continue to be used for as long as the forest companies can extract sufficient value from the stands to cover operational costs, fixed development costs, and administrative costs, and to generate a profit. However, at some point, stands will have deteriorated to a stage when the sawlog volume cannot cover the harvesting costs, and conventional harvesting will not be undertaken. FERIC assumed that this point will occur when 50% of the stand volume is fuelwood as determined by the shelf-life model described later. Some stands in which FERIC measured the residual volume are approaching the 50% residual level. Until the 50% residual level is reached, FERIC assumed that stands will continue to be harvested using conventional systems, and that biomass will be available only as roadside residuals.

A different harvesting system is indicated once the stand contains more than 50% fuelwood. The stand will still contain a significant proportion of sawlogs, and as with conventional harvesting practices, the sawlogs must be separated from the fuelwood at some selected location. Possible locations for the separation to occur are at the stump, at the landing or roadside, at a satellite yard, or at the final destination (mill or power plant).

One factor for deciding the location for the separation to occur is the production rates of the machines used in the harvesting system. The production rate of typical comminution equipment is much higher than the production rate for the bunchers and skidders, so pairing one comminution machine with a typical roadside or landing logging operation would cause it to operate inefficiently through low utilization. Accordingly, FERIC concentrated its analysis on systems where several logging operations were combined with a single comminution site, i.e, in a satellite yard or at the final destination. This is the system FERIC proposes to use for stands in the second level of sawlog-to-fuelwood content.

Once the fuelwood content exceeds some high threshold, it will become uneconomic to separate the sawlogs from the fuelwood, and a third harvesting system will be warranted. Such a harvesting system should use on-site comminution, and haul the comminuted feedstock directly from the cutblocks to the final destination, resulting in significant cost savings compared to processing the volume through a satellite yard. At the same time, value would be lost because sawlogs would be chipped as fuelwood. FERIC assumed that stands with 95% or more fuelwood would be suitable for this harvesting system, but a thorough breakeven analysis would be required to determine the best threshold between the two systems.

Since the current industry practise is to harvest sawlogs, any indication of the thresholds when the industry will transition between these harvesting systems, or even if the systems as described here will be deployed, must be speculation. Depending on market conditions, as-experienced shelf-life, political conditions, regulatory conditions, advances in sawmilling technology, and other factors, the current industry will continue its current practises and stand-selection criteria for some undetermined time period. However, some assumptions were required in order to complete this analysis, but care must be exercised in predicting the path that the industry will take in the future.

In summary, and for the purposes of cost calculations for this report, the choice of harvesting system is governed by the percentage of fuelwood in the stand. Conventional harvesting with comminution of the roadside residuals is indicated for stands with less than 50% fuelwood content, a satellite yard would be used for stands between 50% and 95% fuelwood, and onsite comminution would be used for stands with more than 95% fuelwood.

3.2.4 Shelf-life estimates

As stated previously, the primary objective for this project was to determine harvesting and transportation costs, both for the individual harvesting systems and as an overall average from an example area. The harvesting system is determined by the form of the feedstock which is in turn influenced by the shelf-life of the dead pine. Some assumptions about shelf-life had to be made in order to complete the cost analysis, and it is expected that revisions to shelf-life estimates will be necessary as new information becomes available. Changes to shelf-life estimates will affect the volume estimates for the study area, the distribution of the harvesting systems within the study area, and the weighted cost of all harvesting, but will not affect the estimated harvesting costs for the individual systems.

Using the principles described by Eng *et al* (2005), FERIC created shelf-life models in which the pine volume deteriorated from sawlogs to fuelwood to non-recoverable volume at a rate that depends on the biogeoclimatic zone and subzone (Appendix 1). In principle, the pine in wet subzones deteriorates faster than in dry subzones; the various subzones were grouped into three shelf-life classes (short, medium, and long time periods, based on subzone classification) to calculate the shelf-life of pine sawlogs and fuelwood (Table 6, Appendix 2). For the case study analysis, it was assumed that 100% mortality had already occurred at the time of analysis, and that deterioration of all pine would commence immediately. It was further assumed that the pine would deteriorate from sawlog to fuelwood until 95% of the pine volume was suitable only for fuelwood. The stand would remain at the 95% fuelwood composition for a period of time, and then it would deteriorate until all the fuelwood had deteriorated. The model assumes that a minimum 5% of the pine volume will always be available as sawlogs.

Volumes and costs in subsequent analyses were calculated at 5, 10, 15, and 20 years past mortality (YPM). This model assumes that 100% of the pine volume will be recoverable as sawlogs or fuelwood during the early stages of degradation (e.g., Short class at 5 YPM), but that less than 100% of the pine volume will be recoverable during later stages (e.g., Long class at 20 YPM). The shortfall represents the volume that has degraded beyond the point where any commercial product can be made.

Table 6: ***Pine shelf-life: fuelwood and sawlog content in three classes based on biogeoclimatic subzone at 5, 10, 15, and 20 years past mortality.***[2]

Projected Stand Composition for Various Shelf-life Classes						
	Fuelwood (%)			Sawlog (%)		
Years Past Mortality	Short	Medium	Long	Short	Medium	Long
5	90	75	30	10	25	70
10	10	95	60	5	5	40
15	0	10	95	5	5	5
20	0	0	80	5	5	5

Note the connection between the values used in the shelf-life model and the thresholds for the different harvesting systems. The shelf-life model generates fuelwood to a maximum of 95% of the pine volume, and the full-tree chipping harvesting system is implemented at 95% fuelwood content. If different values were used for these thresholds, the volume calculated for the study area would be impacted significantly.

3.2.5 Case-study area volumes

Using the fuelwood volumes as generated by the shelf-life model and the definition of the stand types that are suitable for the various harvesting systems, the volume of fuelwood and sawlogs that could be available from the case study area was calculated. The merchantable volume within the potential fuelwood harvest area was calculated using a 12.5 cm top diameter merchantability standard (Table 7) from stands with a minimum volume of 75 m^3/ha (at the specified YPM) and a minimum age of 60 (current age at time of analysis). Volume was tallied as pine fuelwood and total sawlogs (i.e., live-pine sawlogs plus other species) at 5, 10, 15, and 20 YPM. The volume was further classified by the stand composition: mixed species (30% < pine <90%) and pure pine (>=90% pine).

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[2] Wet sites have shorter shelf life than moist and dry sites. Warm sites have shorter shelf life than cool and cold sites. The short, medium, and long classes are consolidations of various biogeoclimatic subzones (Appendix 1).

*Table 7: **Volumes of pine fuelwood and sawlog from different harvesting systems at various years past mortality.***

	Volume (m^3)						Area (ha)		
	Pine Fuelwood			Total Sawlog					
YPM	Roadside Residuals	Satellite Yard	Full-tree chip	Roadside Residuals	Satellite Yard	Full-tree chip	Roadside Residuals	Satellite Yard	Full-tree chip
From mixed stands (30% < pine < 90%)									
5	7 059 785	9 622 680		17 796 881	6 963 130		102 281	64 527	
10	7 492 859	15 996 746		10 461 755	7 465 687		74 702	92 095	
15	2 186 513	9 555 872		9 284 223	3 747 976		83 125	59 435	
20	648 323	7 931 340		7 990 697	3 703 562		63 346	57 528	
From pure pine stands (>=90% pine)									
5	11 878 626	30 265 833		28 963 662	11 802 673		202 094	181 140	
10		42 473 329	19 612 862		19 778 002	1 030 159		286 898	96 093
15	256 027	12 645 082	24 973 223	409 616	1 913 405	1 312 175	8 017	64 624	137 444
20		10 305 734	20 448 261	1 140	1 867 626	1 288 623	15	61 567	126 521
Total									
5	18 938 411	39 888 513		46 760 543	18 765 803		304 375	245 667	
10	7 492 859	58 470 075	19 612 862	10 461 755	27 243 689	1 030 159	74 702	378 993	96 093
15	2 442 540	22 200 954	24 973 223	9 693 839	5 661 381	1 312 175	91 142	124 059	137 444
20	648 323	18 237 074	20 448 261	7 991 837	5 571 188	1 288 623	63 361	119 095	126 521

The volume calculations in Table 7 do not include growth of the non-pine or live-pine components in the stands, nor do they include depletions from harvesting. For example, the volume calculations at 20 YPM do not account for the sawlog growth that will occur or volume that will be harvested between 0 and 20 YPM. Since the volume that will be harvested from the study area depends on many factors that are outside the scope of this project, it was decided not to account for either growth or depletion. Any potential power plant development, whether for the study area or elsewhere, must include a more rigorous fibre-supply analysis than was done for this costing analysis.

At 5 YPM, there will be about 7.0 million m^3 of fuelwood that could be available as roadside residual from mixed stands that are suitable for conventional logging operations (i.e., less than 50% fuelwood content). In order to harvest the 7.0 million m^3 of fuelwood, an accompanying volume of 17.8 million m^3 of sawlogs would need to be harvested. Also at 5 YPM, the pure pine stands could generate approximately 11.9 million m^3 of roadside residuals, but would require 28.9 million m^3 of sawlogs to be harvested to achieve that volume.

Mixed stands that are suitable for harvesting via satellite yards (i.e., more than 50% fuelwood content) could generate about 9.6 million m^3 of fuelwood at 5 YPM, plus an accompanying 7.0 million m^3 of sawlogs. Pure pine stands could generate 30.2 million m^3 of fuelwood, while requiring 11.8 million m^3 of sawlogs to be harvested.

These volumes exceed the allowable cut for the entire Quesnel TSA and, depending on the cut allocated to the study area and the distribution of cut within various stand types, significantly less total volume would be expected to be harvested. However, these volume calculations are useful to illustrate the proportion of fuelwood to sawlog volume that could be expected when harvesting in these stands.

In pure pine stands, the volume from roadside residuals drops to zero at 10 YPM. This is because the dead pine will degrade until more than 50% of the stand is fuelwood, and very little non-pine component exists in the stand to generate sawlogs. This means that all the harvesting from pure pine stands should flow through satellite yards by 10 YPM; i.e., there is limited opportunity to harvest biomass from roadside residuals in pure pine stands. On the other hand, the volume of fuelwood generated as roadside residuals from mixed stands will remain high.

A simplification in the shelf-life model creates an apparent contradiction about roadside residuals from pure pine stands in Table 7: the volume drops between 5 YPM and 10 YPM, and then increases again by 15 YPM. To explain this apparent contradiction, recall that any stand with less than 50% of its total volume as fuelwood is classified for roadside residual. Depending on the site, a moderate percentage of pine is considered as fuelwood at 5 YPM, thus generating a roadside residual classification (the average fuelwood volume is less than 50% of the total stand volume). In other stands on other sites, the aggregate fuelwood percentage is greater than 50%, and the stand receives a satellite yard classification. By 10 YPM, almost all of the pine has degraded to fuelwood, thus generating a satellite yard classification (fuelwood comprises more than 50% of the stand volume). At 15 YPM, the pine on some sites has deteriorated beyond fuelwood to a point where it contributes zero volume to the stand, thus the total stand volume has also been reduced. At this point, the live pine and other species comprise more than 50% of the reduced stand volume, thus causing the stand to revert to a roadside residual classification. By 20 YPM the total stand volume has been reduced to less than 75 m^3/ha and the stand is eliminated from the analysis.

Based on the 95% fuelwood threshold and the FERIC's shelf-life model, full-tree-chip stands are non-existent at 5 YPM, but thereafter comprise a significant component of the volume. Note that only pure pine stands are designated for full-tree chipping; any amount of non-pine volume in the stand is sufficient to classify the whole stand for the satellite yard or roadside residual system. By 20 YPM, the full-tree chipping component comprises about 20.4 million m^3, or about 40% of the total volume of 54.1 million m^3.

3.3 Costs

As mentioned, the choice of harvesting system will depend significantly on the ratio of sawlogs to fuelwood in each stand. For stands with less than 50% fuelwood, conventional harvesting with subsequent recovery of the roadside residuals is appropriate. For stands with more than 50% fuelwood content, a harvesting system that involves a satellite yard is indicated. Stands with more than 95% fuelwood should be harvested with full-tree chipping at the cutblock. Each system requires a different complement of equipment (Appendix 3) as described next.

As a by-product of conventional harvesting, residual tops, butts, and limbs are left in piles approximately 10-13 m from the road. In the roadside residuals system, they are moved closer to the road using a hydraulic loader, then chipped directly into a semi-trailer chip van using a mobile chipper situated on the road. Costs for falling, skidding, and processing are excluded from the fuelwood costs because they are allocated to the conventional harvesting. In the satellite systems, costs for part of the falling, skidding, and loading are allocated to the fuelwood depending on its relative volume in the stand. Trees are hauled to a satellite yard where they are separated into streams of sawlogs and fuelwood. Sawlogs are processed using a pull-through delimber and saw, while fuelwood is chipped into B-train chip vans. For the "remote" scenario, trees are hauled full-length using off-highway trucks to a satellite yard situated near the cutblock. For the "in-town" scenario, trees are delimbed and topped before being hauled on highway log trucks to a satellite yard situated near the final destination. In the full-tree chipping system, 100% of the stand volume, including any incidental green trees, is chipped on-site into semi-trailer chip vans. All the direct costs, including falling and skidding are allocated to the fuelwood.

Direct costs for these systems exclude the costs of road development, layout, administration, silviculture, or other overhead costs that occur during all timber-harvesting operation. Costs were calculated using FERIC's standard costing methods (Appendix 4).

Note that the calculated costs do not represent real-world contract costs because they omit contractor profit, supervision, and transportation. Using the same productivities, machine costs, and methodology as described for the chipping systems, FERIC calculated the costs for conventional harvesting operations under similar conditions to provide a comparison with actual costs. In general, the model's conventional harvesting costs are about 15% less than average, as-experienced costs from similar operations. It is assumed that the same proportion would be true for the chipping costs; real-world costs would be about 15% higher than the calculated costs.

3.3.1 Roadside residuals

In roadside logging systems, the phases are separated from one another so that delays in one phase have little impact on the other phases, thus helping to reduce costs. The logging industry is unlikely to abandon roadside systems because of this major benefit, thus the harvesting of residuals must exist within the conditions created by roadside logging.

Transporting the roadside residuals to a central site for comminution is not economically feasible because of their low bulk density. MacDonald (2006) found that the actual payload of unprocessed roadside residuals loaded into a semi-trailer truck was only about 10% of its capacity because of low bulk density. On-site comminution of the residuals is required to increase the bulk density and reduce the trucking costs.

The residual piles from conventional harvesting operations have two characteristics of particular importance in the choice of comminution equipment: the residual piles are situated between 10-13 m from the centreline of the road and they are distributed along the full length of the road. These characteristics imply that the fuelwood harvesting system must be highly mobile (i.e., be able to move quickly between piles) and be able to retrieve the residuals over a distance of about 15 m. Most typical mobile comminution machines of sufficient size to handle the roadside residuals would be impractical to use because they require significant moving and setup time. Furthermore, many of the roads had steep banks or deep ditches that would prohibit most machines from leaving the road (Figure 8).

Figure 8: ***Roadside residuals may be situated across a ditch and away from the road.***

When operating from a stationary location, it is common for comminution machines to load the trucks from the side, but this arrangement will not work on narrow logging roads unless the comminution machine can leave the road. As already mentioned, leaving the road may not be feasible in many sites because of steep terrain or ditches. A more practical arrangement is for the comminution machine and the truck to work in tandem on the road, with the truck being loaded from the end. Grinders are best suited for loading from the side because they discharge the feedstock at low velocity. Chippers discharge the feedstock at high velocity, and can load a van completely from the end, and are therefore more appropriate to use with this tandem arrangement.

Most chippers discharge the chips at an angle to their length, thus making it awkward or time-consuming to position the chipper and truck in tandem on a narrow road. Several manufacturers produce a track-mounted, mobile chipper with a straight-through processing path and rear-discharge, such as shown in Figure 9. This class of machine is a good candidate for processing the roadside residuals.

Figure 9: ***Track-mounted mobile chipper with integral grapple and straight-through processing path.***

One drawback of this type of machine is that the integral grapple can only reach material that is piled close to the road, so a second machine would be required to reach the feedstock from the existing piles. A small excavator could easily move the material within reach of a chipper situated on the road. The excavator could work ahead of or in conjunction with the chipper. FERIC has not observed this class of machine operating in roadside residuals, so the productivity information was adapted from the manufactures specifications and operational results from similar-sized machines in comparable conditions. The critical factor to achieve high productivity and the lowest costs will be to maintain a high utilization level. FERIC calculated the costs by assuming that the density of the roadside residuals will have a significant influence on utilization – widely scattered residual piles will require more moving time thus reducing the utilization. FERIC calculated costs for forwarding the roadside residuals with an excavator, then comminuting and loading with the mobile chipper using three values of residual residuals density (Table 8). An operational trial should be conducted to verify the productivity rates.

Table 8: Productivity and cost for chipping roadside residuals.

Roadside residual loading	Estimated Chipping Productivity (ODt/PMH)	Chipping Cost ($/ODt)
Light	20	21.56
Medium	25	17.25
Heavy	30	14.38

The loading arrangement and the requirement to work on steep, low-class logging roads preclude using B-train chip trucks with this system; semi-trailer trucks are more appropriate. While semi-trailer trucks are less economical for long hauls because of their smaller payload, their mobility will be advantageous, especially on steep logging roads when travelling empty. Cost calculations were based on 13.7 m (45-ft) chip vans with a payload of 13 ODt of chips.

Note that costs do not include any allowance for falling, skidding, or processing. It is assumed that the costs for these phases are borne by the conventional harvesting operations.

3.3.2 Satellite operations

At some point, as the ratio of fuelwood to sawlog in the stand increases, FERIC believes that the forest companies will find that conventional operations are no longer economically viable. At that point, which FERIC has assumed to be 50% fuelwood content, the focus will shift to extracting the fuelwood and producing sawlogs as a by-product. While it may be feasible to conduct such operations at roadside, the increasing amount of fuelwood will make such operations difficult and FERIC believes that efficiency will be gained by moving to a satellite yard. There are two considerations: 1) the space occupied by the large volume of residual material will make it awkward to work from roadside, and 2) the high production rate of the comminution equipment will require more volume than can be supported by a single logging operation. Moving the comminution to a satellite yard allows one machine to service several logging operations.

Two options exist for the location of the satellite yard, each with their own advantages and disadvantages. If the yard is located within a short distance of the cutblocks (“remote satellite yard”), then the stems can be hauled using off-highway log trucks without being processed at the cutblock. On the other hand, if the satellite yard is located near the final destination (“in-town satellite yard”), then the logs must be hauled on the highway, and will require delimbing and topping before they can be hauled. Only a minimal amount of processing would be done in the cutblocks in order to maximize the fuelwood volume, but such processing still represents an extra cost that is not required for the remote satellite yard. While the remote satellite yard system eliminates this extra handling, it also requires that several logging contractors operate in a small geographic location to supply a single satellite yard. This would require additional planning and coordination of harvesting activities. The in-town system would use one permanent yard, instead of several temporary yards. The operating costs for both options will be calculated.

For both satellite system, the stems would be unloaded from the trucks using a wheel loader and taken to a machine for chipping and processing. One appropriate machine for this purpose is the so-called trailer loader (Figure 10), which is rare in western Canada but common in southeast USA. Trailer loaders have a delimber/topping saw built onto the chassis of a hydraulic loader so they can process sawlogs as well as feed the chipper. An alternative to this specialized machine would be a conventional hydraulic loader paired with a pull-through delimber (Figure 11). With pull-through delimbers, the stems are pulled through the delimbing knives using the loader, and the built-in hydraulic chainsaw is used to cut them to length. Both trailer loaders and pull-through delimbers use fixed-length stops to measure the logs to the correct length.

***Figure 10:** Trailer loaders include an integral delimber/topping saw for processing sawlogs. The loader also feeds the chipper.*

***Figure 11:** Pull-through delimber and cut-off saw can be paired with conventional loader for processing sawlogs.*

Trucks can be loaded from the side in a satellite yard, thus either chippers or grinders can be used although FERIC based the costs on chippers for consistency with the previous calculations. The fuelwood is hauled by B-train trucks, and logs are loaded onto conventional log trucks using the wheel loader.

The costs include falling, skidding, and loading because satellite operations are assumed to take place only after conventional harvesting methods have proven to be uneconomic; no other operation exists to provide the falling, skidding, and loading for free to the fuelwood operation as it did with the roadside residuals. In FERIC's costing model, these costs are allocated between the sawlogs and fuelwood in proportion to their volume; volume distributions from the study area were used to prorate the costs. The costs for the in-cutblock processing for the in-town satellite yard are included and prorated between the fuelwood and sawlogs. The hauling cost from the cutblocks to the satellite yard is included, although hauling to the in-town satellite yard is excluded from the direct harvesting costs (hauling from the satellite yard to town is accounted separately in the hauling phase).

Costs in FERIC's model for all phases except skidding are expressed as a function of tree size (Appendix 5). Costs were calculated for average tree sizes of 0.2, 0.3, and 0.4 m^3/tree, an appropriate size range to use for pine trees in the Quesnel area. Skidding costs were based on a simple model that uses skidding distance as its only independent variable, and uses average values for other variables such as slope, soil strength, and terrain condition. All costs shown here were calculated for 200 m average skidding distance. The cost summaries shown in Table 9 represent typical ranges of values; see Appendix 5 for the actual outputs from the cost model.

Table 9: Summarized production costs through remote and in-town satellite yards (excluding haul costs).

	Remote Satellite Yard		In-town Satellite Yard		Conventional Harvesting
Average tree size and stand type	Chips ($/ODt)	Logs ($/m^3)	Chips ($/ODt)	Logs ($/m^3)	Logs ($/m^3)
0.2 m^3/tree					
Mixed stand	35-37	15-17	52-54	22-23	14
Pure pine	38-41	17-18	54-57	23-24	
0.3 m^3/tree					
Mixed stand	29-30	13-14	42-43	18-19	11
Pure pine	31-33	14-15	44-47	19-20	
0.4 m^3/tree					
Mixed stand	26-27	11-12	36-38	15-16	10
Pure pine	28-29	12-13	38-39	16-17	

Costs for the remote satellite yard were less than for the in-town satellite yard because the in-town system requires additional processing to make the logs suitable for on-highway hauling. Logs produced through the satellite yard are more expensive than logs produced via conventional harvesting, again reflecting the additional processing that is required. The difference of cost between the mixed stands and the pure pine stands is a reflection of the different proportion of sawlogs and fuelwood in the different stand types. In principle, the model uses the same productivity and machine cost values for both stand types.

3.3.3 Full-tree chipping

As the proportion of sawlog in the stand is reduced to nearly zero, a breakeven point exists where the extra cost required to sort the sawlogs from the fuelwood exceeds the additional value of the sawlogs. Beyond the breakeven point, stands should be harvested by full-tree chipping all of the volume in each cutblock. FERIC assumed the threshold level to be 95% or more fuelwood in the stand. Volume analysis for the study area showed that no stands were in this category at 5 YPM, but that the volume increased significantly until it comprised about 40% of the volume 20 YPM. According to the assumptions in the shelf-life model and the harvest-system classification, any non-pine volume in a stand will preclude it from being classified for full-tree chipping, and full-tree chipping will be applicable only to pure pine stands. Note that the volume of full-tree chipping stands is dependent entirely on the values selected for the shelf-life model and the harvest-system thresholds. Using values other than 95% of fuelwood for these parameters would result in much different volume results.

Full-tree chipping operations may be conducted at roadside, using equipment similar to the mobile chipper proposed for processing the roadside residuals, or may be done in a landing using a less-mobile chipper. Each equipment type has advantages and disadvantages. Roadside operations allow for separation of the phases, which may improve utilization for the skidders or chipper, but also requires that the logs be decked within easy reach of the chipper (i.e., deep ditches may hinder operations).

Furthermore, an integral lightweight loader on the chipper may have difficulty extracting trees from high roadside piles. An auxiliary loader would alleviate these problems, but would also increase costs. Another way to address these issues is to conduct the chipping operations in a landing.

Costs for chipping were calculated using an integrated loader/chipper as in the roadside residual scenario, or a separate chipper and loader similar to Figure 12. Costs will be about equal for either system. Chipping costs were calculated using higher productivity values than for either of the other systems because no sorting or log-manufacturing will be required.

Figure 12: Full tree chipper situated on a landing, and loading directly into chip van.

Costs for the falling and skidding phases in the full-tree chipping system were calculated using the same productivities as those phases in the satellite systems. In the satellite systems, a portion of the costs for these phases were allocated to the sawlogs that were harvested, but the fuelwood must support the full costs of these phases because there are no sawlogs produced from the system. Also, the costs exclude layout, road development, silviculture, and other overhead activities that would be supported by the sawlogs harvested from the other systems. With full-tree chipping, the entire cost of these activities must be borne by the fuelwood.

As with the satellite systems, costs vary depending on the tree size (Table 10). Since other species would contribute green sawlogs, the costs for this system are applicable only to pure pine stands.

Table 10: Falling, skidding, chipping, and loading costs for full-tree chipping.

Average Tree Size (m^3/tree)	Chips ($/ODt)
0.2	27.11
0.3	23.49
0.4	20.91

3.3.4 Hauling

Costs were based on 13.0 and 21.5 ODt payloads respectively for semi-trailer and B-train trucks. Below a certain moisture content (typically about 50% moisture content, wet basis), chip vans are limited by volume rather than by weight. Once a truck is into the volume-limited condition, the payload expressed in terms of ODt is constant for all values of the moisture content. The truck weight may change as the moisture changes, but the dry-wood-equivalent payload does not change. The average moisture content of the dead pine is assumed to be about 25%, which is far below the threshold where loads become limited by volume. The average load size for off-highway log haul from the cutblocks to the remote satellite yard was set at 80 m^3, as compared to the 60 m^3 that was used for on-highway log trucks.

Loading times were calculated as a function of the chipper productivity, and averaged about 0.4-0.5 h for the semi-trailer trucks and 0.7-0.8 h for the B-train trucks. Unloading times and delay times were added to each trip. FERIC assumed that remote satellite yards will be located on all-weather roads, and will be accessible to B-train trucks.

Figure 13 shows the hauling cost for chips hauled using two truck configurations and logs using a conventional log truck. The B-train trucks will be used for remote satellite operations, while the semi-trailer trucks are suited for the roadside residuals and full-tree chipping. These costs are based on the travel speeds from Table 3 and the distribution of road classes from Table 11.

Table 11: Road class distribution for various total haul distances.

	Haul distance (km one way)						
Highway	10	35	50	65	65	65	65
Mainline	10	10	20	30	40	65	90
Branch	25	25	25	25	40	40	40
Bush	5	5	5	5	5	5	5
Total haul distance	50	75	100	125	150	175	200
Two-way haul time (h)	2.19	2.82	3.53	4.24	5.24	6.07	6.90

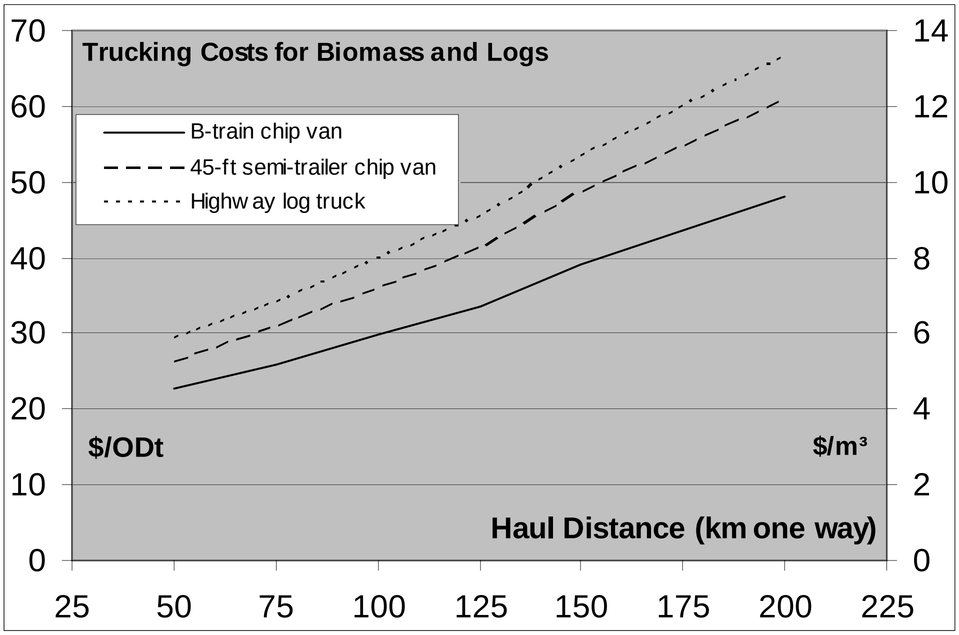

Figure 13: Estimated trucking costs for biomass and logs.

For the remote satellite operation, FERIC assumed that the round-trip, off-highway haul time from the cutblocks to the satellite yard was 0.75 h, and that the haul time from the satellite yard to town would be reduced by the same amount. Costs for the off-highway portion of the haul were included in the processing costs.

For the in-town satellite operation, the round-trip rehaul time from the yard to the mill for both logs and chips was estimated as 0.6 h per trip. Logs were assumed to be hauled by a log truck with 50 m^3 payload, and the chips were hauled with a semi-trailer van with a payload of 13 ODt.

3.3.5 Comminution and hauling costs

Using comminution costs and hauling costs discussed previously, FERIC estimated the total direct cost for harvesting, comminuting, and transporting the biomass over typical haul distances. The costs in Figure 14 were for 10 YPM, medium density of roadside residuals, mixed stands, and 0.3 m^3/tree average tree size. “Residuals” is for biomass generated from the roadside residuals after conventional harvesting, “Remote” is for whole trees hauled via off-highway truck to a remote satellite yard for processing, “In-town” is for delimbed and topped trees hauled via highway truck to an in-town satellite yard, and “Full-tree” is for on-site comminution of 100% of the stand.

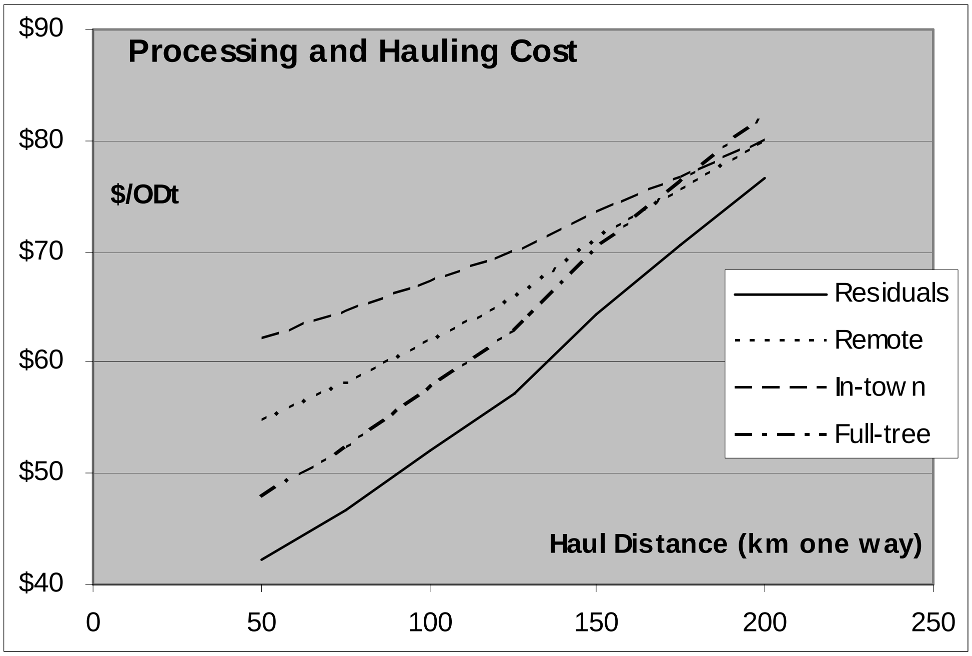

Figure 14: ***Processing and hauling costs under average conditions for four methods of producing biomass.***

Changing the model parameters will change the relative costs of the different systems. Heavier roadside residual density will reduce the cost of the residuals, but will have no effect on the two satellite yard scenarios. For light residual density, the costs for roadside residual and full-tree chipping are almost identical. Conversely, running the model with a larger average tree size will reduce the cost for the two satellite systems and the full-tree chipping, but not affect the cost of roadside residuals.

These direct costs omit several phases that would be required for a complete cost of delivered fibre, but are outside the scope of the project. They are covered in the discussion area.

3.3.6 Case-study area summary

Using the average hauling distance from the various Land Units in the case-study area, FERIC calculated the overall cost of comminuting and hauling the biomass (Appendix 6). As covered in the discussion section, additional phases must be included to estimate the total cost. The different costs for roadside residuals for the different values of YPM result from different average hauling distances; the actual processing costs are the same for each time period.

The cost for roadside residuals averaged about $45-54/ODt for all processing and hauling, depending on the concentration of residuals at the roadside. The costs for fuelwood depend on the average tree size, the stand type, the average haul distance as determined by the YPM, the satellite yard location, and the amount of sawlog in the stand. Costs from pure pine stands with 0.3 m^3 average tree size and processed through a remote satellite yard are estimated at $63-65/ODt. Costs with an in-town yard would be slightly higher, at about $69-70/ODt. The satellite yard operations would also generate sawlogs, although their costs would be higher than sawlogs produced from conventional harvesting operations. Costs for falling, skidding, and hauling to the satellite yard are prorated between the sawlogs and fuelwood depending on their relative concentration in the stand, so the costs for the two products will vary depending on their relative proportions. Table 12 shows the fuelwood percentage at various times past mortality. The values in Table 12 apply only to stands that are designated for satellite operations, i.e., between 50% and 95% fuelwood as determined by the shelf-life model. Chip costs from full-tree chipping in pure pine stands with 0.3 m^3 average tree size were \$53-56/ODt.

Table 12: Average fuelwood proportion from stands designated for satellite operations.

	Percent of stand that is fuelwood Stand Type	
YPM	Mixed	Pure
5	60%	72%
10	65%	82%
15	68%	88%
20	74%	91%

The average haul distance used for each time period was the weighted average of the haul distance from each of the included Land Units in the case-study area. The average round-trip haul time varied between 4.1 and 4.5 h during each of the YPM periods. Using the values from Table 11, these times correspond to a one-way haul distance of about 125 km.

4 Discussion

The lowest-cost source for fuelwood is from the roadside residuals generated by conventional harvesting operations. The volume of roadside residuals is related directly to the harvest level of sawlogs, which is determined by the allowable annual cut and the licencees' cut allocation within the TSA. In response to the beetle outbreak, the historic AAC of 2.3 million m^3 in the Quesnel TSA was revised to 3.2 million m^3 on a temporary basis in 2001 (Ministry of Forests 2001), then again to 5.3 million m^3. Tree Farm Licence 52, which is also near Quesnel, has an allowable cut of 0.5 million m^3 (Ministry of Forests 1996), therefore, the current AAC in the Quesnel vicinity is 5.8 million m^3.

The roadside residual volume is also related to the utilization standard used by the company. The target top diameter for some cutblocks where FERIC conducted measurements was 5 cm; about 15%-20% (30 ODt/ha) of the original biomass of these cutblocks remained as roadside residuals. The roadside residuals in other cutblocks where the target top diameter was more than 10 cm comprised 40-45% (90 ODt/ha) of the original stand biomass. For these calculations, the residual percentage equals the residual volume divided by the sum of residual volume plus harvested volume. Harvested volume equals the merchantable inventory volume plus 5%.

Using an average of 60 ODt/ha, 6 700 ha would need to be harvested each year to generate 400 000 ODt of roadside residuals, the approximate volume of feedstock required to supply a 60 MW facility (McCloy 2006). At an average merchantable volume of 250 m^3/ha, this area represents an annual timber harvest of about 1.7 million m^3, less than 30% of the current AAC in the Quesnel vicinity, and about 60% of the historic AAC.

Although it appears that sufficient area is harvested each year near Quesnel to generate 400 000 ODt of roadside residuals, some additional factors must be considered:

- There is no assurance that the allowable annual cut will remain at its current level; the AAC may be reduced below its historic level after the salvage operations are completed. Some scenarios of future cut level indicate that the AAC may be reduced to 0.4 - 1.1 million m^3 (COFI 2006) after 20 years.
- If the licencees harvest from stands where pine is not the leading species such as in many stands east of Quesnel that are not pine-leading stands, the volume of roadside residuals may be less than indicated. FERIC measured residual volumes only from areas west of Quesnel, where the highest concentrations of pine occur.
- The biogeoclimatic zones east of Quesnel are wetter than in the west, which will likely result in shorter shelf-life for sawlogs and fuelwood.

This study considered two stand types that generate roadside residuals from harvesting sawlogs: mixed-species stands and pure pine stands up to 5 years past mortality. After 5 years past mortality, most of the volume of pure pine stands is forecast to degrade into fuelwood, and the sawlog content will decrease significantly. Without sufficient sawlog volume to justify the expense of layout, road development, silviculture, and other overhead costs, the licencees are unlikely to target these very-high-fuelwood stands for harvesting. FERIC assumed that stands containing more than 50% fuelwood will be avoided for harvesting sawlogs, and should no longer be considered as sources for roadside residuals. A more appropriate system for such stands would be to haul the logs to a satellite yard, where the fuelwood could be comminuted and the sawlogs sorted and processed more efficiently. Combining the production from several operations at a single satellite yard would allow for higher utilization of the comminution equipment, and reduce costs. A high level of planning and coordination would be required to ensure adequate volume from several operations would flow through the satellite yard to make it economically viable.

On-site full-tree chipping is the most appropriate system for stands with very high fuelwood content; FERIC used 95% fuelwood content as the threshold for full-tree chipping. No stands were classified for full-tree chipping at 5 YPM, but full-tree chipping stands comprised 40% of the volume by 20 YPM. Only pure pine stands were classified for full-tree chipping; any amount of non-pine volume caused the model to classify mixed stands as suitable for satellite yard operations. The direct costs for this system are about equal to the direct costs for roadside residuals, but some costs were omitted from the calculations, and the two costs are not directly comparable.

The costs that were omitted from the satellite and full-tree chipping operations include planning, layout, road development, road maintenance, silviculture, and overhead. These costs do not apply to the roadside residual scenario because they are included in the sawlog harvesting that occurs prior to salvaging. FERIC estimated that the additional costs are about $30/ODt for the satellite operations and about $41/ODt for the full-tree chipping scenario (Appendix 7). Stumpage is not included in any of the cost estimates.

More stands in the study area are suited to satellite operations than to either roadside residuals or full-tree chipping. However, satellite operations also have the highest cost of the three systems because they require the most equipment and handling.

The choice of harvesting system will affect the constant flow of feedstock to the power plant because poor hauling conditions will curtail in-block operations for several months each year. Storage will be required to ensure year-round flow, and the different systems have different suitability for storage. Satellite yards provide the best opportunity for storage because the biomass could be stored as logs. The roadside residual and full-tree chipping systems are poorly suited for storage because such storage would occur after comminution, and the comminuted material would deteriorate from inclement weather. Satellite yards would need to be constructed near all-weather roads to allow for year-round hauling.

Harvesting costs for the satellite and full-tree chipping systems were based on clearcut operations, although it may be feasible to harvest the dead pine in some stands and leave the live understorey for future growth. FERIC is conducting trials to document the additional costs associated with such harvesting systems, but no results are available yet. Sauder and MacIsaac (2004) found that falling and skidding costs increased by 20-30% when using conventional equipment to harvest the overstorey and protect the understorey in boreal mixedwood stands. Similar increases may be expected in the pine stands.

FERIC's cost calculations are intended for comparison of two or more harvesting systems, and are not meant to represent contractors' costs. In particular, they omit items such as supervision, transportation, overhead, and contractor's profit. When compared to industry averages, the costs generated by FERIC's model were about 15% low. A spreadsheet with the cost model is available upon request to FERIC member companies.

5 Conclusions

FERIC conducted a study to estimate the costs of harvesting, comminuting, and transporting beetle-killed pine to supply feedstock for a potential power plant. Three harvesting systems were examined, as determined by the ratio of fuelwood volume to sawlog volume in the stand. Costs were developed for the generic harvesting systems, then applied to the Quesnel/Nazko corridor in central Interior of British Columbia as a case study.

The cost models were based on the assumption that the beetle-killed pine will deteriorate from sawlog quality to fuelwood quality, and then to non-commercial quality at a rate determined by each stand's biogeoclimatic zone. Three shelf-life classes were used to predict the proportion of fuelwood and sawlogs in each stand as a function of years past mortality. The model assumed that a minimum of 5% of the pine volume would remain as sawlog at all times.

For stands with less than 50% fuelwood, costs were calculated using the existing roadside harvesting system, followed by a separate operation to comminute the roadside residuals into feedstock. The system comprised a log loader to move the residuals closer to the road, a mobile, track-mounted machine on the road to chip the residuals, and semi-trailer chip vans to haul the feedstock to the plant. FERIC calculated that the direct costs were $45-54/ODt.

For stands with 50%-95% fuelwood, the entire volume was processed through a satellite yard to facilitate sorting the sawlogs from the fuelwood. Two satellite scenarios were considered: in the "remote" system, whole trees were hauled via off-highway trucks to satellite yards situated near the cutblocks, while the "in-town" satellite scenario used a satellite yard situated near the power plant. Since this latter scenario involves hauling trees on public roads, they were assumed to be delimbed and topped before hauling, which increased the cost compared to the remote satellite scenario. Costs for both satellite systems were substantially higher than with the residual system, due largely to the falling and skidding costs that were included with these systems. For example, costs for trees from pure pine stands with an average tree size of 0.3 m^3 and processed through a remote satellite yard, were estimated at $63-65/ODt. Costs for the in-town scenario were $69-70/ODt. The model prorated the cost for falling and skidding between the sawlogs and fuelwood depending on their relative volume in the stand; larger volumes of fuelwood caused the cost of fuelwood to increase and the cost of sawlogs to decrease by a corresponding amount.

On-site, full-tree chipping was used for stands with 95% fuelwood, at a cost of \$53-56/ODt in stands with 0.3 m^3 average tree size. Only stands comprising 100% pine can generate a full-tree chipping classification because of the way the shelf-life model was defined.

The direct cost does not provide a complete comparison because the latter two systems omit some costs that are covered by the existing licencee in the roadside residual system (e.g., road development and silviculture), and are assumed to be provided for free to the biomass operation. These costs are estimated to add \$30-41/ODt onto the direct costs of the satellite and full-tree chipping systems.

Based on FERIC's assumptions for shelf-life and harvest-system selection criteria, "pure" pine stands (i.e., with more than 90% pine content) will be a significant source of sawlogs, and thus of roadside residuals, until 5 YPM. Beyond that time, these stands will generate more than 50% fuelwood, and the volume would be more appropriately harvested through satellite yards (where sufficient sawlog volume exists to justify the expense of sorting) or by full-tree chipping (where the sawlog component is insignificant).

Based on FERIC's assumptions for shelf-life and harvest-system selection criteria, mixed stands will be a significant source of sawlogs and fuelwood using the roadside residuals system for most of the analysis time period. By 20 YPM, the roadside residuals volume from mixed stands will be reduced significantly. The pure pine stands are impacted more quickly; roadside residuals from these stands are a significant source of fuelwood only until 5 YPM, after which point their volume is reduced to zero. At 10 YPM, the majority of volume from pure pine stands is suitable for satellite yard operations, but full-tree chipping comprises more volume at 15 and 20 YPM.

FERIC conducted measurements of the volume of roadside residuals that remain after conventional roadside harvesting. Depending on the utilization specifications for sawlogs, there was 22-145 ODt/ha of roadside residual, representing from about 15% to over 50% of the original stand biomass. There was an additional 8-30 ODt/ha of residuals dispersed across the cutblocks, but almost all of that volume was in pieces too small to be harvested with existing equipment. When compiled to more contemporary utilization standards, the dispersed residuals represented less than 2 ODt/ha, and were omitted from any further consideration.

6 Recommendations for further work

The volume and extent of the damage caused by the mountain pine beetle will cause changes to harvesting systems that are unprecedented in British Columbia. As such, the costs and productivities in this report are from the best available information, but they are adapted from other locations and conditions that may not be directly comparable. Operational trials should be undertaken to:

- Verify the productivity of the mobile chipper while working in tandem with a log loader for forwarding the residuals to roadside. Trials should be undertaken on a variety of road conditions (e.g., road grade, sideslope, ditch configuration, etc.) and roadside residual pile arrangements (e.g., distribution along the length of the road, distance from road centreline, volume per pile, distribution of tops and butts within each pile, etc.).
- Verify the gradability of semi-trailer chip vans on steep logging roads.
- Verify the productivity of full-tree chippers and chipper/processor combinations.
- Verify payloads of dry pine for off-highway log trucks and B-train and semi-trailer chip trucks operating from satellite chip yards.

In addition to these operational trials, further work is required to:

- Improve the characterization of the roadside residuals, especially as result of different utilization levels (e.g., bulk density of piles, volumes, piece size distribution, etc.).
- Verify the shelf-life characteristics for sawlogs and fuelwood.

7 Bibliography

Badger, P.C. 2002. Processing cost analysis for biomass feedstocks. ORNL/TM-2002/199 Oak Ridge national Laboratory, Oak Ridge Tennesee. 52 p.

Blair, C.W. 1998. Using a chip storage bin to improve in-woods chipper efficiency and reduce chip van cycle times. Technical Note TN-274. Forest Engineering Research Institute of Canada, Vancouver, BC. 8 p

Bolding, M.C., Lanford, B.L. 2005. Wildfire fuel harvesting and resultant biomass utilization using a cut-to-length/small chipper system. Forest Products Journal 55(12):181-189

COFI 2006. Timber supply analysis: mountain pine beetle impact on Interior timber supply areas. Council of Forest Industries. Vancouver BC. 105 p.

Eng, M., Fall, A., Hughes, J., Shore, T., Riel, B, Hall, P., Walton, A. 2005. Provincial-Level Projection of the Current Mountain Pine Beetle Outbreak: an Overview of the Model (BCMPB v2) and Results of Year 2 of the Project. Working Paper 2005-20. Natural Resources Canada, Canadian Forest Service, Victoria BC. 56 p.

Forest Products Society 2006. PowerPoint Presentations in PDF from Smallwood 2006 URL: www.forestprod.org/smallwood06powerpoints.html

Forrester, P.D., Sauder, E.A., Lerochers, L., Ryans, M. 2006. Cost structure of hog fuel transport in Canada. Advantage Report AD-7-14. Forest Engineering Research Institute of Canada, Vancouver, BC. 20 p

Hamelinck, C.N., Suurs, R.A.A., Faaij, A.P.C. 2003. International bioenergy transport costs and energy balance. Universiteit Utrecht, Copernicus Institute, Science Technology Society, Utrecht, The Netherlands. http://www.senternovem.nl/mmfiles/149993_tcm24-124375.pdf

Hardy, C.C. 1996. Guidelines for estimating volume, biomass, and smoke production for pile slash. Gen. Tech. Rep. PNW-GTR-364. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. Portland, OR. 17 p.

Kumar, A., Flynn, P.C., Sokhansanj, S. 2005 Feedstock Availability and Power Costs Associated with Using BC's Beetle-Infested Pine. BioCAP Canada Foundation, Kingston, ON. 4

Lewis, K.J., Hartley, I.D. 2006. Rate of deterioration, degrade, and fall of trees killed by mountain pine beetle. BC Journal of Ecosystems and Management 7(2):11-19.

Loeffler, D., Calkin, D.E., Silverstein, R.P. 2006. Estimating volums and cost of forest biomass in Western Montana using forest inventory and geospatial data. Forest Products Journal 56(6):31-37

MacDonald, A.J. 2004. Volumes and costs of forest residue collection. Contract Report CR-3235-1. Forest Engineering Research Institute of Canada, Vancouver, BC. 33 p

MacDonald, A.J. 2006. A template for demonstrating the economic feasibility for generating electricity from woody biomass. Contract Report CR-3212-1. Forest Engineering Research Institute of Canada, Vancouver, BC. 22 p.

McCloy, B. 2006. The business case for BC Wood Energy. In publication. Forintek Canada Corp. Vancouver, BC.

Ministry of Forests 1996. Tree Farm Licence 52 rationale for allowable annual cut determination. www.for.gov.bc.ca/hts/tsr1/ration/tfl/t52/httoc.htm

Ministry of Forests 2001. Quesnel allowable annual cut increased. www.for.gov.bc.ca/pscripts/pab/newsrel/mofnews.asp?refnum=2001%3A069

Ministry of Forests 2004. Interior appraisal manual. www.for.gov.bc.ca/hva/manuals/interior/InteriorNovMaster2004.pdf

Ministry of Sustainable Resource Management 2006. Land and Resource Data Warehouse https://srmapps.gov.bc.ca/apps/dwds/login.do

Oregon Department of Energy 2006. Oregon’s biomass energy resources. http://www.oregon.gov/ENERGY/RENEW/Biomass/resource.shtml

Pottie, M.A., Guimier, D.Y. 1985 Preparation for forest biomass for optimal conversion. SR-32 Forest Engineering Research Institute of Canada, Vancouver, BC. 112 p.

Sauder, E.A., MacIsaac, D.A. 2004. Using alternative harvesting techniques to protect the boreal mixedwood understorey: evaluation of harvesting productivity and costs. Advantage Report AD-5-12. Forest Engineering Research Institute of Canada, Vancouver, BC. 43 p

Sutherland, B.J. 1986. Standard assessment procedures for evaluating silvicultural equipment: a handbook. Ministry of Supply and Services Canada Catalogue No Fo42-92/1986E 96 p.

WoodEnergy.ie 2006. Ireland’s natural and renewable energy source . http://www.woodenergy.ie/biomass_fuel/biomass2.asp

Appendices

Appendix 1: Shelf-life class by biogeoclimatic zone and subzone.

Zone	Subzone	Subzone Description	Shelf Life Class
BAFA	unp	Undifferentiated and Parkland	Long
BG	xh	Very Dry Hot	Long
ESSF	dc	Dry Cold	Long
ESSF	dcp	Dry Cold Parkland	Long
ESSF	dcw	Dry Cold Woodland	Long
ESSF	dk	Dry Cool	Long
ESSF	mk	Moist Cool	Medium
ESSF	mv	Moist Very Cold	Long
ESSF	mw	Moist Warm	Short
ESSF	vc	Very Wet Cold	Short
ESSF	vcp	Very Wet Cold Parkland	Short
ESSF	vcw	Very Wet Cold Woodland	Short
ESSF	wc	Wet Cold	Short
ESSF	wcp	Wet Cold Parkland	Short
ESSF	wcw	Wet Cold Woodland	Short
ESSF	wk	Wet Cool	Short
ESSF	xc	Very Dry Cold	Long
ESSF	xcp	Very Dry Cold Parkland	Long
ESSF	xcw	Very Dry Cold Woodland	Long
ESSF	xv	Very Dry Very Cold	Long
ICH	dk	Dry Cool	Medium
ICH	mk	Moist Cool	Medium
ICH	mw	Moist Warm	Medium
ICH	vc	Very Wet Cold	Short
ICH	vk	Very Wet Cool	Short
ICH	wk	Wet Cool	Short
IDF	dk	Dry Cool	Long
IDF	dm	Dry Mild	Long
IDF	mw	Moist Warm	Medium
IDF	xh	Very Dry Hot	Long
IDF	xm	Very Dry Mild	Medium

Zone	Subzone	Subzone Description	Shelf Life Class
IMA	un	Undifferentiated	Medium
IMA	unp	Undifferentiated and Parkland	Long
MS	dc	Dry Cold	Long
MS	dk	Dry Cool	Long
MS	dm	Dry Mild	Long
MS	xk	Very Dry Cool	Long
MS	xv	Very Dry Very Cold	Long
PP	xh	Very Dry Hot	Long
SBPS	dc	Dry Cold	Long
SBPS	mc	Moist Cold	Medium
SBPS	mk	Moist Cool	Medium
SBPS	xc	Very Dry Cold	Long
SBS	dk	Dry Cool	Long
SBS	dw	Dry Warm	Medium
SBS	mc	Moist Cold	Medium
SBS	mh	Moist Hot	Short
SBS	mw	Moist Warm	Medium
SBS	wk	Wet Cool	Short

Appendix 2: Pine shelf-life: fuelwood and sawlog content in three classes by biogeoclimatic subzone at various years past mortality.

	Fuelwood Content (%)			Sawlog Content (%)		
Years Past Mortality	Short	Medium	Long	Short	Medium	Long
0	10	10	10	90	90	90
1	20	15	15	80	85	85
2	30	30	30	70	70	70
3	50	45	30	50	55	70
4	70	60	30	30	40	70
5	95	75	30	5	25	70
6	95	90	30	5	10	70
7	70	90	30	5	10	70
8	50	95	40	5	5	60
9	30	95	50	5	5	50
10	10	95	60	5	5	40
11	10	74	70	5	5	30
12	10	58	80	5	5	20
13	10	42	90	5	5	10
14	10	26	90	5	5	10
15	0	10	95	5	5	5
16	0	10	95	5	5	5
17	0	10	95	5	5	5
18	0	10	95	5	5	5
19	0	10	90	5	5	5
20	0	0	80	5	5	5

Appendix 3: Machines used in each chip-harvesting system.

Direct costs for these systems exclude the costs of road development, layout, administration, silviculture, or other overhead costs that occur during all timber-harvesting operation.

	Chip-harvesting System				Hourly cost	Productivity or Payload	
Machine name	Roadside Residuals[3]	Remote Satellite[4]	In-town Satellite[5]	Full-tree Chipping[6]	$/SMH[7]	Amount	Units
Feller-buncher		X	X	X	155	50-70	m³/PMH[8]
Grapple skidder		X	X	X	105	58-65	m³/PMH
Butt 'n top loader		X	X		125	120-170	m³/PMH
Log loader	X	X			115	limited by companion machine	
Wheel loader (unloading)		X	X		105	250-320	m³/PMH
Wheel loader (loading)		X	X		105	110-160	m³/PMH
Dangle-head processor			X		130	27-45	m³/PMH
Chipper - no operator		X	X		130	20-30	ODt/PMH
CTR Delimber		X	X		25	limited by companion machine	

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[3] As a by-product of conventional harvesting, residual tops, butts, and limbs are left in piles approximately 10-13 m from the road. In the roadside residuals system, residuals are moved closer to the road using a hydraulic loader, then chipped directly into a semi-trailer chip van using a mobile chipper situated on the road. Costs for falling, skidding, and processing are excluded from the fuelwood costs because they are allocated to the conventional harvesting.

[4] In the satellite systems, costs for part of the falling, skidding, and loading are allocated to the fuelwood depending on its relative volume in the stand. Trees are hauled to a satellite yard where they are separated into streams of sawlogs and fuelwood. Sawlogs are processed using a pull-through delimber and saw, while fuelwood is chipped into B-train chip vans. For the "remote" scenario, trees are hauled full-length using off-highway trucks to a satellite yard situated near the cutblock.

[5] For the "in-town" scenario, trees are delimbed and topped before being hauled on highway log trucks to a satellite yard situated near the final destination.

[6] In the full-tree chipping system, 100% of the stand volume, including any incidental green trees, is chipped on-site into semi-trailer chip vans. All the direct costs, including falling and skidding are allocated to the fuelwood.

7 SMH: Scheduled machine hour

[8] PMH: Productive machine hour

& log loader							
Mountain goat chipper	X				230	20-30	ODt/PMH
Off-highway truck		X			110	80	m^3
On-highway log truck		X	X		95	60	m^3
In-town rehaul			X		85	50	m^3
B-train chip van (highway)		X			116	21.5	ODt
Semi-trailer chip van (bush)	X			X	95	13	ODt

Appendix 4: Cost components for selected machines.

Machine description	20-tonne Excavator/Loader	Wheel-mounted chipper	Pull-through delimber	Track-mounted mobile chipper
Make and model	Komatsu PC200	Trelan 23	CTR 426	Morbark 50/48 Mountain Goat
Total purchase price ($)	370 000	450 000	45 000	675 000
Expected life (h)	16 000	10 000	8 000	9 000
Residual value, % of purchase (%)	20	20	15	20
Labour wages ($/h)	22.00			22.00
Fuel consumption per PMH (l/h)	26.0	75.0	15.0	100.0
Lube & oil as % of fuel (%)	15	15	25	15
Repair & mtce ($/h)	21.00	25.00	8.00	30.00
Annual repair and maintenance ($)		15 000		20 000
Hourly rate ($/SMH)	98.75	135.60	25.76	224.68

Item	Value used for all machines
Scheduled hours per year (h)	2 400
Interest rate (%)	6.0
Insurance rate (%)	4.0
Wage benefit loading (%)	35
Utilization (%)	80
Fuel cost ($/l)	0.90

Appendix 5: Chip and log costs from stands harvested primarily for fuelwood (excluding haul costs[9]).

Stand Description and Years Past Mortality	Remote Satellite Yard		In-town Satellite Yard		Conventional Harvesting	Full-tree chipping
Average tree size and stand type	Chips ($/ODt)	Logs ($/$m^3$)	Chips ($/ODt)	Logs ($/$m^3$)	Logs ($/$m^3$)	Chips ($/ODt)
0.2 m^3/tree Mixed stand						
5	34.50	15.34	51.40	21.76	13.78	27.11
10	35.52	15.85	52.43	22.27	13.78	27.11
15	36.15	16.16	53.05	22.58	13.78	27.11
20	37.44	16.77	54.34	23.19	13.78	27.11
0.2 m^3/tree Pure pine						
5	37.00	16.57	53.91	22.99	13.78	27.11
10	39.19	17.59	56.09	24.01	13.78	27.11
15	40.52	18.21	57.42	24.62	13.78	27.11
20	41.20	18.51	58.10	24.93	13.78	27.11
0.3 m^3/tree Mixed stand						
5	28.82	12.73	41.90	17.54	11.23	23.49
10	29.65	13.13	42.73	17.95	11.23	23.49
15	30.16	13.38	43.24	18.20	11.23	23.49
20	31.20	13.87	44.28	18.69	11.23	23.49
0.3 m^3/tree Pure pine						
5	30.85	13.71	43.93	18.52	11.23	23.49
10	32.61	14.53	45.69	19.34	11.23	23.49
15	33.69	15.02	46.77	19.83	11.23	23.49
20	34.23	15.26	47.31	20.08	11.23	23.49
0.4 m^3/tree Mixed stand						
5	25.52	11.30	36.31	15.16	9.75	20.91
10	26.20	11.64	36.99	15.50	9.75	20.91
15	26.62	11.85	37.41	15.70	9.75	20.91
20	27.47	12.26	38.26	16.11	9.75	20.91
0.4 m^3/tree Pure pine						
5	27.18	12.12	37.97	15.97	9.75	20.91
10	28.63	12.80	39.42	16.66	9.75	20.91
15	29.52	13.21	40.31	17.07	9.75	20.91
20	29.97	13.42	40.76	17.27	9.75	20.91

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[9] Haul cost from cutblock to remote satellite yard using off-highway log trucks is included.

Appendix 6: Processing and hauling costs for the case study area west of Quesnel.

Fuelwood from Roadside Residuals			
Stand Description and Years Past Mortality	Chips ($/ODt)		
Mixed stand	Light Residual Loading	Medium Residual Loading	Heavy Residual Loading
5	51.48	46.22	42.71
10	51.80	46.54	43.03
15	56.71	51.44	47.93
20	56.71	51.44	47.94
Pure pine			
5	52.42	47.15	43.64
10	54.84	49.58	46.07
15	56.41	51.14	47.63
20	55.77	50.51	47.00

Stands Harvested for Fuelwood						
Stand Description and Years Past Mortality	Remote Satellite Yard		In-town Satellite Yard		Conventional Harvesting	Full-tree chipping
	Chips ($/ODt)	Logs ($/m^3)	Chips ($/ODt)	Logs ($/m^3)	Logs ($/m^3)	Chips ($/ODt)
0.2 m^3/tree Mixed stand						
5	64.77	24.02	73.61	30.41	20.19	56.09
10	66.03	24.61	74.80	30.99	20.26	56.41
15	70.28	25.97	77.96	32.36	21.32	61.31
20	71.56	26.59	79.24	32.97	21.32	61.31
0.2 m^3/tree Pure pine						
5	67.96	25.45	76.59	31.84	20.39	57.02
10	71.93	27.00	80.03	33.39	20.91	59.44
15	74.42	27.96	82.17	34.34	21.25	61.01
20	74.63	28.13	82.52	34.51	21.12	60.37
0.3 m^3 Mixed stand						
5	56.76	20.74	63.35	25.60	17.43	51.83
10	57.83	21.21	64.35	26.08	17.50	52.15
15	61.96	22.52	67.38	27.38	18.56	57.05
20	63.00	23.01	68.42	27.87	18.56	57.05
0.3 m^3/tree Pure pine						

Stands Harvested for Fuelwood

Stand Description and Years Past Mortality	Remote Satellite Yard		In-town Satellite Yard		Conventional Harvesting	Full-tree chipping
	Chips ($/ODt)	Logs ($/m^3)	Chips ($/ODt)	Logs ($/m^3)	Logs ($/m^3)	Chips ($/ODt)
5	59.48	21.92	65.86	26.78	17.63	52.76
10	63.03	23.27	68.88	28.13	18.16	55.19
15	65.27	24.10	70.76	28.96	18.50	56.75
20	65.34	24.20	70.97	29.06	18.36	56.12
0.4 m^3/tree Mixed stand						
5	52.32	19.18	57.60	23.10	15.92	48.79
10	53.23	19.59	58.45	23.51	15.99	49.11
15	57.27	20.86	61.39	24.77	17.05	54.01
20	58.12	21.27	62.24	25.18	17.05	54.01
0.4 m^3/tree Pure pine						
5	54.66	20.20	59.74	24.12	16.12	49.72
10	57.90	21.41	62.44	25.33	16.65	52.15
15	59.95	22.16	64.14	26.07	16.98	53.71
20	59.93	22.23	64.26	26.14	16.85	53.08

Appendix 7: Estimated costs for items not included with direct harvesting cost.

The BC Interior Appraisal Manual (Ministry of Forests 2004) recognizes costs for road management (maintenance), administration, and silviculture. FERIC used values of \$1.75/m^3, \$9.00/m^3, and \$1200/ha respectively for these costs. Using conversion rates of 0.42 ODt/m^3 and 250 m^3/ha, the total of these costs is \$37/ODt.

FERIC developed estimates of road development costs based on three road-construction classes and three classes of existing road density. Using map measurements from the case-study area, FERIC estimated that 45 km of mainline is required to service an area 60 km by 30 km. Within that area, FERIC estimated that 66% of the land base was merchantable, and that the mainline would be written off over 20% of the volume (to account for periodic reconstruction over its lifetime). The resulting amortization rate for mainlines at a construction cost of \$100 000/km is \$0.75/m^3.

Estimated costs for branch roads were based on developing an area 18 km by 6 km with 10 km of branch road. If the road cost is amortized over one-third of the merchantable volume within that area, the branch road amortization cost is \$0.33/m^3 using a construction cost of \$30 000/km.

Costs for on-block roads were estimated using a net developed area of 25 ha per km of road (250 m net skid width). On-block road costs are \$1.28/m^3 if on-block roads are estimated to cost \$8 000/km for construction.

For each of the road-development classes, FERIC assumed a proportion of the three construction classes that would be required. In areas with more existing road development, some of the volume can be harvested from areas of leave strips between existing cutblocks. The resulting road-development costs are shown in Table 13.

Table 13: Estimated road development costs by existing road development class.

	Amount of Construction Required (%)			Weighted Road Development Cost		Proportion of potential fuelwood harvest area
Existing road development class	Mainline	Branch	Spur	\$/m^3	\$/ODt	%
Sparse	100	100	100	2.36	5.60	44
Partially-roaded	10	90	100	1.52	3.60	22
Dense	0	33	75	1.07	2.50	34

Approximately 44% of the land base within the case-study area is in the sparse road-density class (Table 5). To see how the distribution changed with time, the volume of fuelwood in the sparse road-development class was tallied and expressed as a percentage of the total fuelwood that is available for each of the time periods (Table 14).

Table 14: Percentage of fuelwood in the sparse road-development class at selected time periods.

Stand Type	Years Past Mortality	Roadside Residual	Satellite Yard
Mixed stands	5	42%	35%
	10	46%	35%
	15	36%	50%
	20	46%	50%
Pure pine stands			
	5	42%	35%
	10	n/a	41%
	15	39%	45%
	20	n/a	42%

While there was some variation around the 44% overall average, the volume of fuelwood in the sparse road-development class generally remains between 40% and 50% for all analysis periods.

Using the area distribution from Table 5 and Table 13, the weighted average of road development costs is $4.10/ODt. If the sparse road development class is omitted, the average cost of the remaining two classes is $2.92/ODt.

The total for costs that must be added to the direct harvesting costs is $41.10/ODt. The full amount is applicable to any volume harvested via the full-tree chipping system, and part of the cost is applicable to the fuelwood for the satellite yard systems. The cost should be allocated in proportion to the amount of fuelwood in the stand, which varies with YPM and the stand type. The average fuelwood content of satellite-yard type stands in the study area was 75% of the volume, therefore, the costs for processing chips through satellite yards should be increased by about $30/ODt.