Wood Based Biomass in British Columbia and its Potential for New Electricity Generation

Prepared for

BC Hydro's Long Term Planning Process

Industrial Forestry Service Ltd.

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EXECUTIVE SUMMARY

This report was completed in support of BC Hydro's Long-Term Planning Process. The report is an update to a similar analysis report completed by the authors for BC Hydro in May 2013. The analysis forecasts the availability of biomass fuels, with estimated cost, that might be used for new electricity generation projects from the year 2016 until 2040. The analysis was completed using the BC Fibre Model that links existing and forecast regional fibre supplies (i.e., logs, roadside logging waste and sawmill residues) throughout the Province, with historic and forecast fibre demands by the existing forest industry.[1] Provincial fibre supplies that are surplus to the demands of the forest industry were presumed to be available as potential biomass fuel for energy production. However, it should be noted that there can be other future competing use for this biomass potential that are of higher value than electricity generation (e.g., wood pellets, biodiesel, biogas, combined heat and power), making the fibre availability for electricity production uncertain.

Tree mortality as a result of the mountain pine beetle epidemic, the flow of fibre between regions, the operating capacity of the forest industry (e.g., sawmills, plywood plants, pulp mills, pellet mills, bioenergy plants, etc.), the economic drivers that determine mill operating rates and the supply of residual fibre that results from the processing of timber were all quantified as part of this analysis. Forecasting regional fibre supply was facilitated with technical input from the Forest Analysis and Inventory Branch of the Ministry of Forests, Lands and Natural Resource Operations.

Potential biomass supplies are reported for a 10-year period (2016 to 2025) and a 15-year period (2026 to 2040). The first period corresponds to the progressive decline in BC Interior timber harvest levels in the aftermath of the Mountain Pine Beetle epidemic. The second period represents the subsequent time when a stable mid-term harvest is forecast to occur. Potential biomass supply was forecast for 13 regions throughout BC and collated to derive potential biomass volume for the Province as-a-whole.

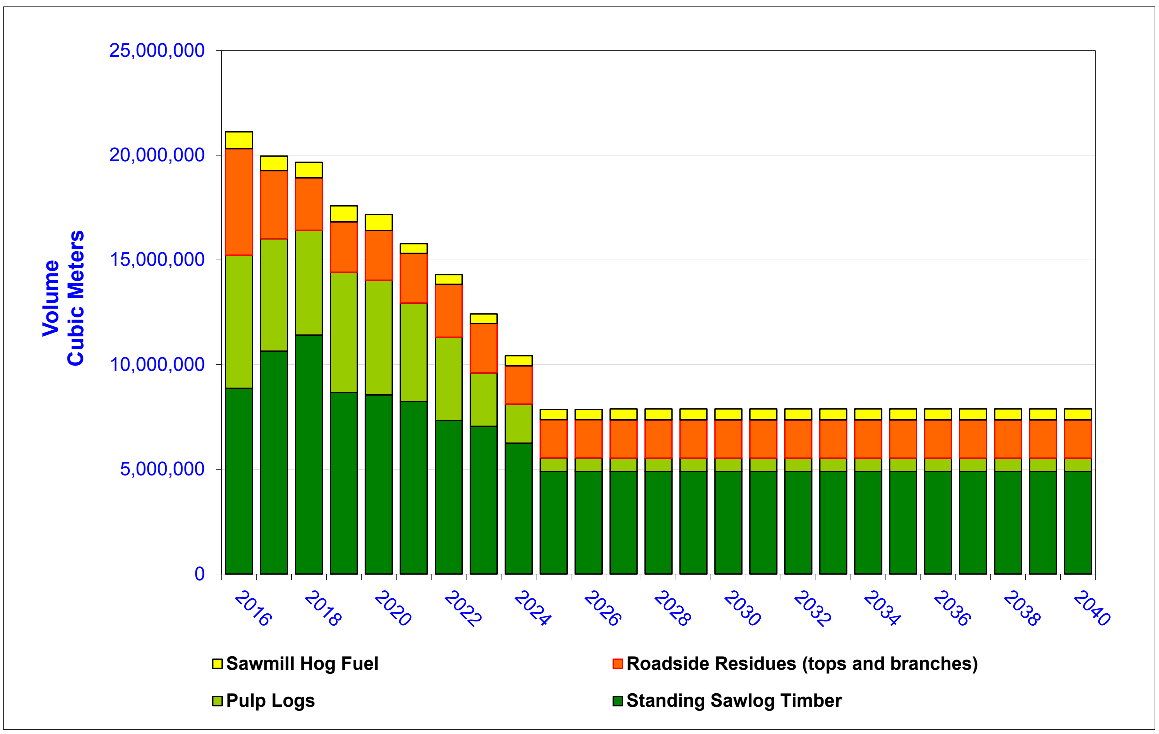
Four sources of woodwaste biomass were examined in this analysis: sawmill woodwaste, roadside woodwaste, pulp logs and standing timber. Surplus supplies of

[1] The BC Fibre Model is used by most of the BC pulp mills and integrated forest products companies for strategic planning purposes.

municipal solid waste, as well as woodwaste from demolition and construction etc., were not reviewed and may exist as future potential for energy production.[2]

The analysis demonstrates that the volume of wood biomass potentially available for bioenergy production and surplus to the demands of the existing forest industry is about 21 million cubic metres. However, as a result of forecast reductions to the annual allowable cut and resultant changes in sawmilling activity, the volume of biomass potentially available for energy production is forecast to decline rapidly to about 7.9 million cubic metres by 2025. The volume of surplus biomass is forecast to remain at about 7.9 million cubic metres thereafter. To understand the potential for using this surplus biomass, an examination of the quantity, type and duration of availability is necessary and is provided in this report at a regional level. Exhibit 1 forecasts the surplus wood biomass by type over a 25-year horizon.

Exhibit 1. Forecast of Annual Available Biomass by Type throughout BC



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[2] Though refuse-based biomass from the Metro-Vancouver Region that is currently used by the Pulp and Paper Industry for existing bioenergy production (~250,000 tonnes) is included as a fibre supply in the BC Fibre Model, surplus volumes were not examined.

Based on this forecast, an estimated 6.4 TWh/year of energy equivalent is available for the 10-year period (2016 to 2024) and about 4.5 TWh/year thereafter (2025-2040). Exhibit 2 summarizes the energy and capacity potential, subdivided by fuel category, for BC. The availability of low-cost sawmill woodwaste (“hog fuel”) provincially, is relatively minor. It is also concentrated in only 3 of the 13 regions examined. Whether this biomass type alone can sustain a reasonably-sized bioenergy plant at a particular location in the province requires a regional analysis.

The cost of energy/electricity generation is the sum of two components: project cost and the delivered fibre/fuel cost. Note that the cost of energy/electricity generation or unit energy cost shown in this report is quoted as the cost up to plant gate.

Project cost: Cost of electricity generation from greenfield bioenergy plants is estimated to be (in May 2015 dollars) $80/MWh at 5% real weighted-average cost of capital (WACC), $85/MWh at 6%, $90/MWh at 7% and $96/MWh at 8% (details of the derivation of this number are included in Appendix 1). The project cost shown in this report (i.e. $90/MWh) is based on 7% WACC and assumes a 20-year amortization period. The amortization period for bioenergy projects is influenced by fibre availability. Any micro-level projects trying to take advantage of near-term fibre availability which is forecasted to progressively declining over the next 10 years could have a shorter amortization period, thus resulting in a higher unit energy cost. As the development lead time for BC bioenergy projects is typically 4 years, it may be uneconomical for a new project to capture near-term elevated fibre availability.

Delivered fuel cost includes: (1) commodity cost, which varies between regions, fuel categories and the existing competition for fuel; (2) delivery cost, which varies based on average regional transportation distance; and (3) cost for conversion to feedstock suitable for power generation. To estimate delivery cost, current average commodity costs by type and the average delivery cost to hypothetical plant locations were assumed for each region (these locations are identified in Map 2 on Page 16).

Exhibit 2 shows the cost of electricity by fuel type categories (i.e., weighted-average across all regions). In the current period, the cost of electricity generation using standing timber is $214/MWh as compared to $115/MWh when sawmill woodwaste (i.e., hog fuel) is used.

The determination of available unused biomass fuel within the province was calculated on a regional level, to ensure the fibre supply demands of the existing forest industry were recognized, localized and forecast in consideration for changes to the annual allowable cut. Exhibit 3 summarizes the estimated potential volume (in GWh/year by fuel type) of sustainable bioenergy that currently exists within each planning region, as well as the corresponding delivered fuel cost. Note that $90/MWh needs to be added to the delivered fibre cost to get the cost of energy.

Exhibit 3 demonstrates that the majority of the electricity potential lies in existing unused standing timber (4.6 TWh/year). Excluding sawlog timber from the analysis, the forecast biomass electricity potential for the first 10-year period would drop from 6.4 TWh/year to 1.76 TWh/year.

Exhibit 2 Potential Biomass and Cost of Energy by Fuel Category and by Period

Biomass Type	Potential Capacity (MW)		Annual Energy (GWh/year)		Cost of Energy ($/MWh)	
Forecast Period	2016 - 2024	2025 - 2040	2016 - 2024	2025 - 2040	2016 - 2024	2025 - 2040
Standing sawlog timber	530	317	4,643	2,774	$214	$219
Standing pulp logs	58	42	512	364	$177	$176
Road side logging residues	115	118	1,007	1,035	$146	$146
Sawmill hog fuel	28	34	245	297	$115	$114
Total	731	510	6,407	4,470		

* Capacity (MW) quoted here are gross values and do not reflect capacity factor assumptions

The analysis resulted in five primary conclusions.

1. Significant volumes of wood-based biomass that are surplus to the demand of forest industry exist. When all fibre categories are considered this volume equates to approximately 6.41 TWh of annual electricity potential during the first period and 4.5 TWh annually thereafter.
2. Most of the available biomass is in the form of standing timber that exists in the far north of the Province where it is currently uneconomic to harvest this timber even for lumber production.
3. Pulp logs are less costly but their availability is forecast to decrease significantly after 10 years.
4. There are significant volumes of lower-cost fibre (sawmill woodwaste and roadside woodwaste) surplus to the current demand of existing industries. About 1,300 GWh/year worth province-wide thru to 2040. The fibre is scattered and the highest potential regions are the BC coast, and the West Kootenays.
5. Although there is currently a 9-year surplus of total biomass, after this time surplus biomass availability is forecasted to become scarce in several BC interior regions.
6. Cost of electricity from wood-based biomass can vary substantially, depending on the fibre types (fuel profile) that are utilized over the life of a plant.

Exhibit 3. Potential Biomass Energy and Delivered Fibre Cost by Fuel Category, Region and Period

Period	2016 - 2025								2026 - 2040							
Biomass Type	Sawmill Waste		Roadside Residues		Pulplogs		Standing Timber		Sawmill Waste		Roadside Residues		Pulplogs		Standing Timber	
Region	Energy (GWh/Yr)	Delivered Fibre Cost ($/MWh)	Energy (GWh/Yr)	Delivered Fibre Cost ($/MWh)	Energy (GWh/Yr)	Delivered Fibre Cost ($/MWh)	Energy (GWh/Yr)	Delivered Fibre Cost ($/MWh)	Energy (GWh/Yr)	Delivered Fibre Cost ($/MWh)	Energy (GWh/Yr)	Delivered Fibre Cost ($/MWh)	Energy (GWh/Yr)	Delivered Fibre Cost ($/MWh)	Energy (GWh/Yr)	Delivered Fibre Cost ($/MWh)
Coast	4	$25	499	$55	0	n/a	147	$143	37	$25	523	$55	0	n/a	0	n/a
East Kootenay	0	n/a	97	$58	0	n/a	0	n/a	0	n/a	97	$58	0	n/a	0	n/a
West Kootenay	211	$25	184	$58	0	n/a	0	n/a	220	$25	187	$58	0	n/a	0	n/a
Kamloops/Okanagan	0	n/a	0	n/a	0	n/a	79	$117	0	n/a	0	n/a	0	n/a	0	n/a
Cariboo	0	n/a	17	$52	0	n/a	178	$117	0	n/a	17	$52	0	n/a	0	n/a
Prince George	0	n/a	0	n/a	102	$90	925	$117	0	n/a	0	n/a	0	n/a	0	n/a
Mackenzie	0	n/a	30	$63	47	$84	281	$108	0	n/a	29	$63	0	n/a	0	n/a
South Peace	9	$32	163	$54	99	$84	0	n/a	9	$32	163	$54	99	$84	0	n/a
North-east	0	n/a	0	n/a	0	n/a	921	$134	0	n/a	0	n/a	0	n/a	921	$134
East Prince Rupert	0	n/a	1	$55	198	$84	275	$108	9	$20	1	$55	199	$84	49	$108
West Prince Rupert	21	$18	17	$54	65	$97	1728	$125	21	$18	17	$54	65	$97	1718	$125
North-west	0	n/a	0	n/a	0	n/a	109	$134	0	n/a	0	n/a	0	n/a	86	$134
Total GWh per year and weighted-average cost	245	$25	1,007	$56	512	$87	4,643	$124	297	$25	1,035	$56	364	$86	2,774	$128

This analysis and report is an update to similar reports completed in 2010 and 2013 for BC Hydro. Since these two reports, the primary changes have been a marked decline in the forecast availability of biomass fibre for energy production and an increase in cost for pulp logs. The cost for pulp logs has increased to reflect the observation that most forest licensees would rather burn pulp logs at road side, than provide them to a biomass consumer at anything less than a fair market value. As for the decline in biomass availability, there are four primary reasons:

a. The closure of many sawmills (18 mills since 2010) has resulted in a reduction sawmill residues. Existing biomass consumers (pulp and pellet plants) have compensated by salvaging more roadside residues and standing pulp logs.
b. Construction of several more pellet plants has reduced surplus availability.
c. Optimistic sawmill operating regimes resulted in temporal impacts on the availability of pulp logs and sawmill resides.
d. The timing of allowable annual cut (AAC) reductions in several management units occurred sooner than previously forecast.
e. Biomass supply reductions have been made in consideration for BC Hydro’s Integrated Customer Solutions program directed to sawmills interested in near-term electrical load displacement projects.

List of Acronyms

AAC	Allowable Annual Cut
Biomass	An energy resource fuelled by the combustion of organic materials
BC	British Columbia
BCTMP	Bleached Chemi Thermo Mechanical Pulp
BCTS	British Columbia Timber Sales
Canfor	Canadian Forest Products Ltd.
Category B	Fuel type category used by BC Hydro in the Biomass Call for Power to describe sawmill residues
Category C	Fuel type category used by BC Hydro in the Biomass Call for Power to describe logging residues
Category D	Fuel type category used by BC Hydro in the Biomass Call for Power to describe standing timber
GIS	Geographic Information Systems
GJ	Giga Joule
GW	Giga Watt
ha	Hectare
Hog	Bark and Waste wood. Used to describe wood that has been processed through a "hogger" and ground into chunks.
BCH	British Columbia Hydro
IFS	Industrial Forestry Service Ltd.
IPP	Independent Power Producer
LP Canada	Louisiana Pacific Canada
m3	Cubic metre of wood.
MDF	Medium Density Fibreboard (panels used in house construction)
MFBM	Thousand Foot Board Measure (used to quantify lumber production)
MOF	Ministry of Forests, (Lands and Natural Resource Operations)
FLNRO	Ministry of Forests, Lands and Natural Resource Operations
MPB	Mountain Pine Beetle
MS	Microsoft
MSW	Municipal Solid Waste
MW	Mega Watt
MWh	Mega Watt hour
NBSK	Northern Bleached Softwood Kraft pulp
ODT	Oven Dry Tonne
OSB	Oriented Strand Board (in sheets similar to plywood)
Partition	Mechanism used by the FLNRO to split an AAC
SPF	Spruce, pine, Douglas fir
TFL	Tree Farm License
TSA	Timber Supply Area
TWh	Terawatt hour (equal to 1000 Gigawatt hours)

Energy Conversion Assumptions and

Key Assumptions for a Hypothetical Bioenergy Plant

1) 2.45 cubic metres of wood = 1 oven dry tonnes of wood at 0% moisture. This conversion recognizes that the majority of biomass projected to be available in the Province comes from standing timber with a specific gravity that is much higher than road-side residues. Road-side residues typically have a high bark component and consequently a lower conversion.

2) 1 MWh electricity requires 0.72 oven dry tonnes of wood biomass.

3) A Greenfield bioenergy plant costs $5 million per MW of capacity in June 2015$.

4) Annual cost to operate a biomass plant is estimated at $120/kW-year fixed cost and $7/MWh variable cost.

5) Plant amortization period was assumed to be 20 years.

6) Electric capacity factor is normally about 91%. Capacity values provided in this report do not reflect this capacity factor, they are gross values.

7) 7 percent was used as a discount rate and real cost of capital.

8) Annual operating hours were assumed to be 8,760 hours per year.

9) Project lead time was assumed at 2 years (construction and major capital spending). Project development time (another 2 years) prior to construction is not assumed to incur major capital spending.

10) Selling price of electrical power to BC Hydro was assumed to be $90/MWh + delivered fuel cost. (See Appendix 1 for more details)

11) Annual allowable cuts, dead pine shelf life and harvest partitions were estimated in consultation with the Ministry of Forests, Lands & Natural Resource Operations

12) Existing and future lumber industry demand, pulp mill demand, pellet mill demand, board plant demand was forecast using a proprietary “BC Fibre Model”.

13) Fuel demand from projects resulting from the BC Hydro Biomass Phase 1 and Phase 2 Calls for Power, the Integrated Power Offer, Community Based Biomass and the Open Power offer were incorporated in current and future demand. Fibre requirements for load displacement projects included in BC Hydro’s demand side management program have also been accounted for as those projects are expected to be more economical.

14) Forecasts of the annual supply of available biomass were converted to a single sustainable volume by fuel (by fuel type category for each period studied) as follows:
    a. Sawmill hog fuel was estimated as the minimum amount available over the first 10-year period and the minimum amount over the subsequent 15-year period.
    b. Pulp logs and road side residues were calculated as the average over every 3-year period and the lowest 3-year running average in the 10-year and 15-year period was used.
    c. Standing Timber was estimated as the average amount available over each of the 10 and 15 year periods.

15) Surplus urban and refuse-based biomass fuels were not quantified for this report, although ~250,000 tonnes of refuse-based biomass from the Metro Vancouver Region currently used by the Pulp and Paper industry for existing bioenergy production is included as a fibre supply in the BC Fibre Model.

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Wood Biomass in British Columbia and its Potential for Electricity Generation

1.0 Introduction

This report is an updated version of two previous papers completed for BC Hydro in support of its Integrated Resource Planning process. It provides background information on surplus biomass resources that could be considered to meet future electrical energy demands. Biomass, in the context of this report, is defined as the quantity of wood that can be obtained directly or indirectly from the forest and that could be converted to electricity *after* consideration is given to the current and future supply and demand for wood fibre by the existing forest industry.[3] Although other future competing use for this surplus biomass may exist and be of higher value than electricity generation, these other uses were not considered in this review.

The biomass supply forecasts were completed using data outputs from the proprietary "BC Fibre Model". This Model was designed to provide regional assessments of log, chip, sawmill residual fibre and biomass availability at a strategic level over a 25-year planning horizon. The theoretical construct and underlying database of the BC Fibre Model provides a representative snapshot of the BC forest industry. The Model and associated database have been extensively reviewed and acknowledged by all significant forest companies in BC, as well as BC Hydro and the Ministry of Forests, Lands & Natural Resource Operations. The Model is used on an ongoing basis by several of these companies to facilitate near-term strategic planning.

[3] Surplus biomass available as solid waste and biogas generated from landfills in Metro Vancouver (and other municipalities) exists, but quantifying the amount was outside the scope of this analysis.

2.0 Assignment Scope

The assignment scope was the determination of long-term biomass electricity potential within BC for the next 25-year period. The process involved updating a 2013 version of this report produced as part of BC Hydro's Integrated Resource Planning process. All of the graphs and tables have been updated since 2013 to incorporate changes that have occurred across all regions. These changes include:

- Changes in Crown land harvest forecasts based upon new government and industry analyses.
- Changes in private land harvest forecasts based upon actual harvests experienced over the past 5 years.
- Updates on sawmill closures.
- Updates on new bioenergy plants and pellet plants.
- All mid-term sawmill operating rates were adjusted to reflect the forecast availability of sawlogs in each region in the mid-term. Where deemed appropriate, future sawmill closures were forecast to balance sawlog supply with demand.
- All regional fibre transfers and fibre imports from outside BC (logs, chips, sawdust, shavings and hog fuel) were updated based upon known purchase/sale agreements.
- Biomass fibre demands resulting from BC Hydro's Phase 1 and Phase 2 Biomass Calls for Power, Integrated Power Offer, Community Based Biomass Call, and the Open Power Offer have been incorporated into the future fibre demands of the industry. Fibre requirements for future load displacement projects included in BC Hydro's demand side management program have also been accounted for.
- All estimates of delivered fibre costs were updated based upon the authors' industry knowledge of current regional rates paid by wood pellet manufacturers and pulp and paper companies, coupled with feedback from BC Hydro's bioenergy stakeholder engagement. As a result of this engagement the commodity price of hog fuel has been doubled in some regions, to reflect a price

increase that would occur, where biomass fuel demand and competition is greatest.

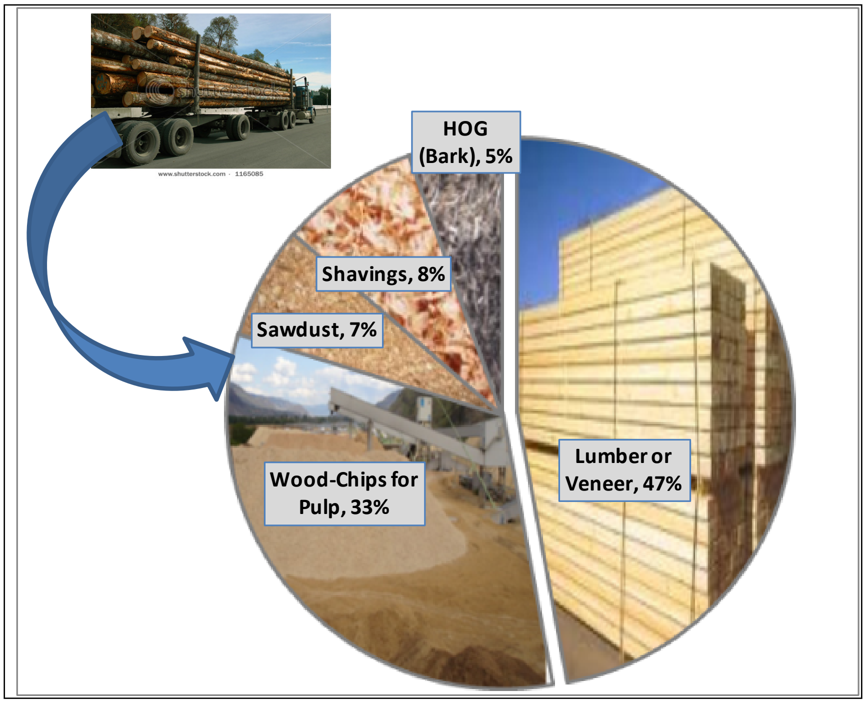
To predict biomass energy potential, the assignment required a review of Provincial timber supplies (by region), demands on this supply by the existing BC forest industry and identification of surplus biomass potential. Short and long-term energy potential from the conversion of surplus biomass into electricity was quantified in terms of potential supply and cost. The uncertainty to this potential supply if sawmills re-direct waste biomass to internal uses is discussed in Section 18.1, as well as the opportunity to acquire additional biomass supplies from lumber re-manufacturing facilities (Section 18.2).

A second report was also prepared that examined the variables that independent power producers (IPP) might consider when developing business plans centered on the construction of a green-field biomass-to-electricity project. That report serves as the basis for calculating the cost of energy (see Appendix 1).

3.0 B.C. Forest Industry - Sector Overview

Trees in British Columbia are generally older and slower growing than those found in the USA. As a result, BC trees possess physical characteristics that are highly desired in the production of both pulp (for paper manufacturing) and lumber (for house construction). The age and characteristics of older trees result in shapes that are far from a perfect cylinder. Trees are often prone to defects such as cracks, stain, rot, decay, and geometric irregularities. Production of lumber from these imperfect shapes result in considerable waste. Only about 45 percent of the volume in every log that reaches a sawmill is converted into saleable lumber. The rest of the log is waste material that a sawmill must dispose of. Wood waste material exists in several forms. *Bark* is removed from the log prior to it entering a sawmill. The *slabs* that comprise the outer sides of a log are converted into *wood chips*. *Sawdust* is created by cutting a square or rectangular ‘cant’ into dimensional lumber. *Shavings* are created after the lumber has been dried and is planed to provide a smooth finish. Figure 1 shows the average proportional distribution of products and by-products from an average sawlog entering and exiting a primary breakdown mill (e.g., sawmill).

Figure 1. The Component Parts of an Average Sawlog



Disposal of lumber or veneer processing facility by-products (comprising roughly 55% of every log) has led to the creation of several synergetic industries. The pulp and paper industry in BC developed decades ago as an outlet for the **Wood Chips** that are used in the production of market pulp. This industry pays a premium price for a secure chip supply. In many cases, pulp mills have developed long-term exclusive control over the wood chips produced by regional sawmills. These chip supply agreements have greatly benefited sawmills, providing a steady source of revenue that in poor lumber markets may approach 20 percent of a sawmill's gross revenue.

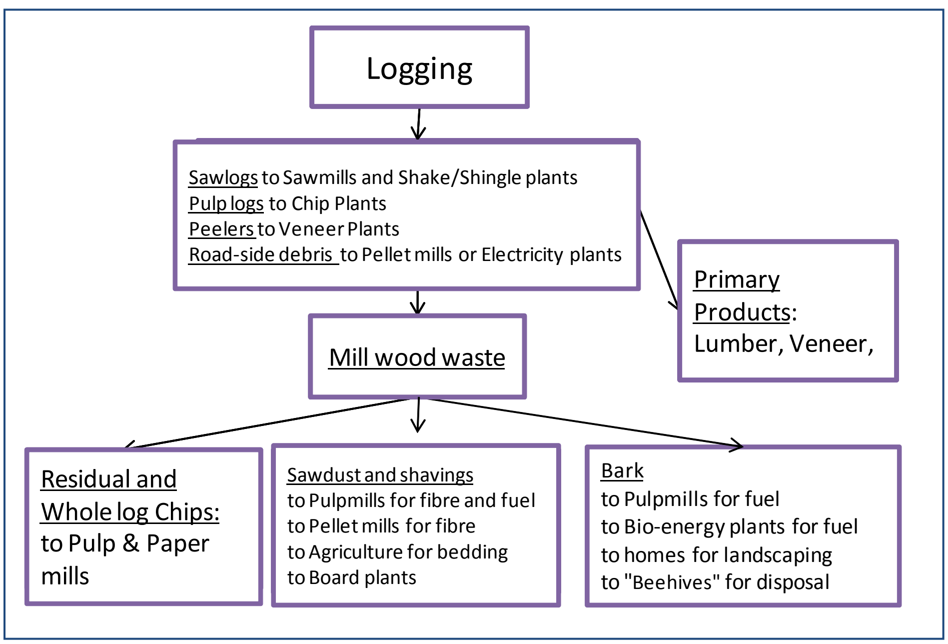
Historically, the disposal of minor residual wood supplies (sawdust, shavings and bark) has been a challenge due to lack of demand for these by-products and the environmental issues around storage or disposal. Until the late 1990's incineration of these sawmills by-products in 'bee-hive' burners was the primary means of disposal. Alternative, innovative uses have since developed.

In 2014 only one BC pulp mill continued to produce Sawdust Pulp, using a mixture of **sawdust and shavings,** and wood chips. In so doing it consumes about 6% of the provincial sawdust supply.

Pellet manufacturers have cropped up virtually everywhere in BC over the past 20 years to supply the demand for 'green energy' in Europe. In 2014 there were 10 pellet plants in operation in the BC interior consuming about 61 percent of the Provincial sawdust and shavings supply. Three more pellet plants are currently under construction. Although sawdust and shavings are the preferred fibre for pellets, shortages in sawmill residues during the 2009 and 2010 forest industry slowdown caused pellet mills to begin using bark and begin collecting and grinding roadside logging waste that remained after a sawlog harvesting operation. These initiatives to offset regional shortfalls in sawdust and shaving supplies continue today.

Other smaller users of sawdust and shavings include particle board plants, agriculture (for bedding, soil manufacture and hothouses) and sawmill kiln-heat systems.[4] **Bark** produced by the sawmill and chip plant debarking process is typically used by four industries – Pulp and Paper Mills (to fuel their power boilers), Biomass Power Plants (to fuel stand-alone power or co-generation), Sawmill Power Plants, and most recently Pellet Plants. Agriculture and Landscaping also use small amounts of bark. As a result of these initiatives, very few BC sawmills utilize beehive burners today as a means of disposing sawmill residues[5]. The basic flow of fibre in the forest industry follows the pattern shown in Figure 2.

Figure 2. Basic Fibre flow Diagram



[4] Part of the lumber manufacturing process requires that the moisture in lumber be removed so that it does not warp. Lumber is dried in sheds called "kilns". About 1/3 of the sawmills in the BC interior have small "Konis style" energy systems that use their own dry shavings to fire boilers for kiln heat.

[5] At the time of writing, the West Fraser Chetwynd bee-hive was still operating, but a permanent shut-down was scheduled for June 2015, The West Chilcotin sawmill bee-hive in Anahim Lake operates intermittently and the BC Timber bee-hive east of Vanderhoof operates intermittently.

3.1 The Mountain Pine Beetle and Lumber Economics

The mountain pine beetle (MPB) epidemic continues to impact the BC Interior forest industry in several ways:

- Harvest levels were initially increased significantly to promote the salvage of dead pine trees. Harvest levels have since begun to decline in several BC interior forest management units, reflecting the reduced availability of both sawlogs and pulp logs. More declines will occur, with most BC interior mid-term AAC's forecast to be lower than the levels set by government prior to the MPB epidemic.
- Manufacturing lumber from dead pine trees results in both a reduction in the volume and the value of lumber sold into the market place. The rate that this occurs is dependent on both physical and economic factors. Non-lumber grade trees are used by the "residual" forest industry (i.e., pulp and paper) when the industry is willing to pay the proportional cost to extract these trees.
- The residual industry (with the exception of pulp mills and to a very small extent some pellet mills) cannot (yet) afford the full cost of logging and delivering trees to their facilities. A few new green-field biomass to electricity facilities are currently being constructed that may utilize standing dead pine to supplement feedstock deliveries from other sources. Haul distance from these dead stands to the plant will be a major factor in determining availability.
- As the volume of poor-quality logs in MPB-killed stands increase over time, the unit cost to extract the remaining merchantable (lumber-grade) logs rises. The impact to lumber companies is a reduction in the amount of merchantable wood that they can economically access.
- Dead pine trees will not remain standing forever. After about 15 years dead, nearly 50 percent of them will have fallen over and they will begin to decay rapidly.
- Across the BC interior generally, the supply of dead pine is expected to be largely extinguished in about 10 years' time, if not sooner.

In 2008, the collapse of the US housing market resulted in a substantial drop in lumber selling-prices. In most instances, prices were below the cost of production. North American log processing mills reacted by curtailing production. Curtailments were accomplished through combination of reduced number of operating shifts, increased down-time, or by permanent or indefinite mill closure. A significant consequence was the reductions in the supply of sawmill by-products. The price of wood-chips rose considerably, and the price for sawdust, shavings and bark, (which in 2000 could be had for next to nothing) skyrocketed. Manufacturing plants that developed between 1998 and 2006 to utilize the large supply of sawmill residues were confronted with both a large increase in cost and reduction in supply of their raw materials. Other fibre supply sources needed to be explored. The collection of roadside logging residues (tops and branches) and/or whole-log grinding of dead pine trees were the only logical options. The salvage of roadside logging residues from operations closest to manufacturing centers has proven to be economical. Grinding and/or chipping logs at any significant distance from a manufacturing plant is not currently economical for industries other than pulp and paper. A large scale chip and biomass processing plant commenced operation in Quesnel in fall 2014. The plants ability to merchandize all logs salvaged from dead pine stands has resulted in a marked improvement in sawlog recovery as well as the salvage of considerably more biomass volume as a result of integrating sawlog harvesting with biomass recovery.

These regional initiatives to salvage more biomass directly from the forest clearly demonstrate that there is very little in the way of sawmill residuals remaining in the BC Interior that have not already been allocated to a consumer.

3.2 Bioenergy Policy

The economic drivers of the forest industry that existed in BC fifteen years ago were insufficient to utilize all of the volume in dead pine trees created as a result of the MPB epidemic. The BC Liberal Government recognized this early on and incorporated a partial solution into their 2007 BC Energy Plan. The government's plan was to expand opportunities to generate electrical power by using alternative fuels such as mountain pine beetle wood. Initiatives resulted in the implementation of a Bioenergy Strategy, the creation of a BC Bioenergy Network, the application of an Innovative Clean Energy (ICE) Fund to support investment of new projects (eight of which have been bioenergy), and the initiation of the BC Hydro Phase 1 and Phase 2 Bioenergy Call for Power. BC Hydro also worked with pulp and paper customers to identify biomass power projects that would result in customers securing funding under the federal government's Green Transformation Program.

3.3 Bioenergy Fibre Supply Complications

In the development of a business plan for any bioenergy or fibre processing facility in BC, **access to fibre** is a key consideration. BC land ownership is about 1% federal, 3% private and 96% provincial – so options are limited. An IPP can really only access Crown biomass fuel in one of two ways: (1) by acquiring a forest license to harvest/collect biomass from Crown Land or, (2) by developing a relationship with a licensed tenure holder who already has access to wood.

Independent power producers that are already established in BC with some form of wood processing facility have two significant advantages over newcomers proposing a green-field facility – they likely have a long-term fibre supply and their existing facility enables them to amortize the cost of generators or capital upgrades to the facility over a shorter time period. The fact that existing major licensees (i.e., Tolko Industries Inc.) and pulp mills (i.e., Canfor Pulp, Mercer International, Domtar Corp.) have been the first to move forward on the utilization of forest biomass for electricity production is indicative of this advantage.

Greenfield bioenergy plants typically require 20 to 30 years to amortize the cost of new construction. They face the following complications:

- The Annual Allowable Cut (AAC) for each of the Province's timber supply areas and tree farms is determined by the Provincial Chief Forester. A re-determination is made every five to ten years. The rate at which timber is made available for harvesting is in response to social, economic, environmental and biological considerations. The Minister then apportions the AAC to applicants using various forms of agreement that grant rights to harvest Crown timber for varying terms. Most of the AAC in forest management units is already allocated to established forest companies under long-term tenure. Any new harvest rights under consideration are being funneled to First Nations.
- Uplifts to the traditional AAC were significant as a result of the beetle. However, the harvesting rights tied to these uplifts were non-replaceable and were typically for less than 15 years. Many of these uplifts have since expired. Those remaining are scheduled to terminate in the next 1 to 4 years and are unlikely to be replaced.
- Dead pine trees are unlikely to remain standing much longer than 20 to 25 years after they have been killed. Many stands have already been dead for over 15 years.
- The surge in sawmill residual value over the past decade in most regions across of BC has made this a commodity that is no longer the low-cost waste-wood it was once perceived to be.
- Considerable roadside logging waste exists in harvested dead-pine stands. Under Section 7 of the Wildfire Act, this waste material must be disposed of within 6 to 12 months after it is determined that a fire hazard exists. Therefore, this waste is not something that can be logistically stockpiled.
- The 2008-2010 drop in the price of lumber forced all sawmill operators to minimize delivered wood costs. In reaction, harvesting operations during this period were concentrated in forests close to existing sawmills. Very few forestry-based communities in the BC Interior have significant volume of dead-pine trees close to potential points of consumption. As a result, the delivered log cost for all forest companies will increase in the near future and the corresponding transportation distance for roadside residues will increase.

Compounding these problems is uncertainty surrounding the amount of biomass that is available now and into the future. Although the Ministry of Forests, Lands & Natural Resource Operations has considerable information on the area impacted by the mountain pine beetle, forecasts on actual long-term availability for bioenergy is unclear, because future availability is limited by:

1. The regulated, forest management unit based AAC and future changes to the AAC.
2. The demands of existing forest tenure license holders (predominately sawmills) on the AAC for certain grades of log.
3. The varying technological ability of sawmills to process lower grades of MPB-killed trees.
4. The business-to-business agreements that existing biomass users have in place with forest licensees.
5. The rate of change in log-quality coming from MPB-killed stands.
6. The rate that trees blow-down as the time since death increases.
7. The increased volume losses to forest fire.
8. The distance an IPP is willing to go acquire biomass fuel (or the maximum delivered wood cost that an IPP can accept).
9. Uncertainties inherent in the quality of the forest inventory
10. Difficulties in using the inventory to spatially identify the location of potential “biomass” stands.

As a result of these issues, the establishment of green-field bioenergy facilities focused on the utilization of dead-pine in the BC Interior has been fraught with hurdles. Notwithstanding these factors, two new large green-field bioenergy facilities were being constructed in 2015. Supported by BC Hydro Electricity Purchase Agreements, one plant is being constructed in Merritt, the other in Fort St. James.

This project reviews biomass availability in the context of bioenergy while considering all of the uncertainties identified above.

4.0 Analysis Methodology

This analysis utilized the proprietary BC Fibre Model that forecasts timber quantity and biomass availability for 25 years, across forest management units encompassing all of BC. In addition, the model considers and tracks all of the major wood processing facilities in British Columbia (sawmills, pulp mills, veneer plants, pellet plants, shake and shingle mills, etc.) and matches their forecast fibre demand in consideration of the available wood supply. The Model is used by industrial clients in the BC Pulp and Paper, solid wood and bio-energy sectors to provide strategic guidance in determining the potential impact of numerous 'what if' statements. As a result, their input into the industrial drivers used in the model (i.e., manufacturing plant capacities, mill operational efficiencies, sawlog recovery from MPB-killed stands) provides some of the best localized knowledge of the BC forest industry that exists in 2015.

The assumptions used in this analysis were evaluated and discussed with experts at BC Hydro, the Ministry of Forests, Lands and Natural Resource Operations and other bioenergy stakeholders in meetings held in March and June 2015. Discussions with these stakeholders resulted in some modification to the assumptions made in the 2013 report.

Future global and regional economics play an important role in forecasting long-term demand for solid wood products. Sources from which input is received and utilized to help drive the future demand portion of the model include International WOOD MARKETS Group, RBC Capital Markets Equity Research, RISI, and the National Association of Home Builders. There are numerous economic scenarios that may develop over the next three decades. What is presented herein is a single forecast based upon the best information available in June 2015.

This analysis examines the bioenergy capability of the Province of BC as-a-whole. It also examines capabilities within 13 geographic regions that comprise the Province. These geographic regions constitute the timber supply regions from which the Forest Industry typically operates. Timber transfers across regions occur (and have been accounted for in the Model). Transfers across regions are typically small and impeded somewhat by terrain, infrastructure, timber type and delivered wood cost constraints. The fibre regions analyzed are shown in Map 1.

The availability of forest-based, woody biomass is framed within the context of the Annual Allowable Cut (AAC). Actual harvest levels within any single forest management unit (FMU) may exceed the prescribed AAC in any one year. However, for the purposes of this forecast and given its strategic nature, the AAC is the best available framework from which available biomass can be forecast.

In order to derive a forecast of available biomass by region, the Model was used to:

- Provide an AAC forecast for each forest management unit; Timber Supply Area (TSA), Tree Farm License (TFL) and a regionally aggregated forecast for woodlots, community forests and private harvests.
- Provided a coniferous sawlog availability forecast based on:
  - An average sawlog component in the annual harvest for all non-MPB forest management units; and

    - Application of shelf-life assumptions to all MPB impacted forest management units.
- Forecast demand from all coniferous log-using mills (lumber/veneer) and their resultant production of residual chips, sawdust and hog fuel.
- Forecast demand from all coniferous wood chip and biomass consuming mills.
- Compare, using tabular summaries and charts, the regional relationship by region between:
    - Sawlog supply and mill demand;
    - Residual chip supply and demand;
    - Sawdust and shavings supply and demand; and
    - Hog fuel supply and demand.
- Forecast annually available biomass with accumulation over the planning horizon.
- Forecast available biomass (to support new electrical generation) which includes all woody fibre not forecast to be consumed by the current forest industry today or in the future.

For purposes of this report, "available biomass" includes four categories of fuel types. The volumes associated with these fuel categories are not forecast to be consumed by the existing forest industry over the next 25 years.

- ***Sawmill woodwaste*** *includes residual wood chips, sawdust, planer shavings and bark, much of which is sometimes grouped together and referred to as "hog fuel",*
- ***Roadside residues*** *are comprised of tree tops and branches that are left at roadside as a result of timber harvesting (and is not part of the merchantable timber included in the AAC). These residues are typically burned on site by forest companies within eight months after harvesting.*
- ***Pulp Logs*** are primarily dead trees or mountain pine beetle killed trees that are no longer suitable for the production of lumber. These logs *result from the harvest of sawlogs and are either burned at road side or delivered to pulp mills.*
- ***Standing timber*** *not harvested over the planning horizon due to lumber economics, lack of existing industry or lack of demand.*

As a result of the significant size of the BC pulp and paper sector and in the face of reduced sawmill activity because of the MPB, it was assumed that all residual wood chips would be consumed by the pulp and paper sector over the planning horizon and that none would be available to support new electrical generation capacity.

The forecast covers a planning horizon of 25 years from 2016 to 2040. In each year, a forecast of available biomass has been made, net of all other users, within the framework of the AAC. Available forest-based biomass over the 25-year planning horizon was then summarized into the following two periods:

- **2016–2025:** This is the period when forest management unit AACs, which were elevated as a consequence of the MPB-epidemic, have begun a gradual decline to the mid-term sustainable harvest level. Though significant excess volumes of MPB-killed pine trees remain, these volumes are declining rapidly as a consequence of sawlog and pulp log harvests, stem rot, blow down and wild-fire.

- **2026-2040**: In this period it is assumed that all management units are at a mid-term sustainable level. The remaining forest industry is expected to operate in balance with the available fibre supply. As a result, available biomass within the framework of the legislated allowable cut will be relatively constant on an annual basis.

Within each period, a sustainable level of biomass availability has been estimated, based upon the forecast of annual biomass availability within each period. This approach will ensure that electrical generation capacity developed within the period will operate without fibre shortfalls in any single year. Where appropriate and feasible, surplus biomass forecast to accumulate in any one year will be carried forward into subsequent years in order to smooth the overall fibre flow.

The cost to deliver all available biomass to a potential location (within each Region) where a biomass generation plant might be located was estimated. Cost included both the market cost of fibre (fuel cost) together with the expected average regional transportation cost (delivery cost, with allowance for conversion) assuming current technology and infrastructure.

Map 1. BC Fibre Supply Regions

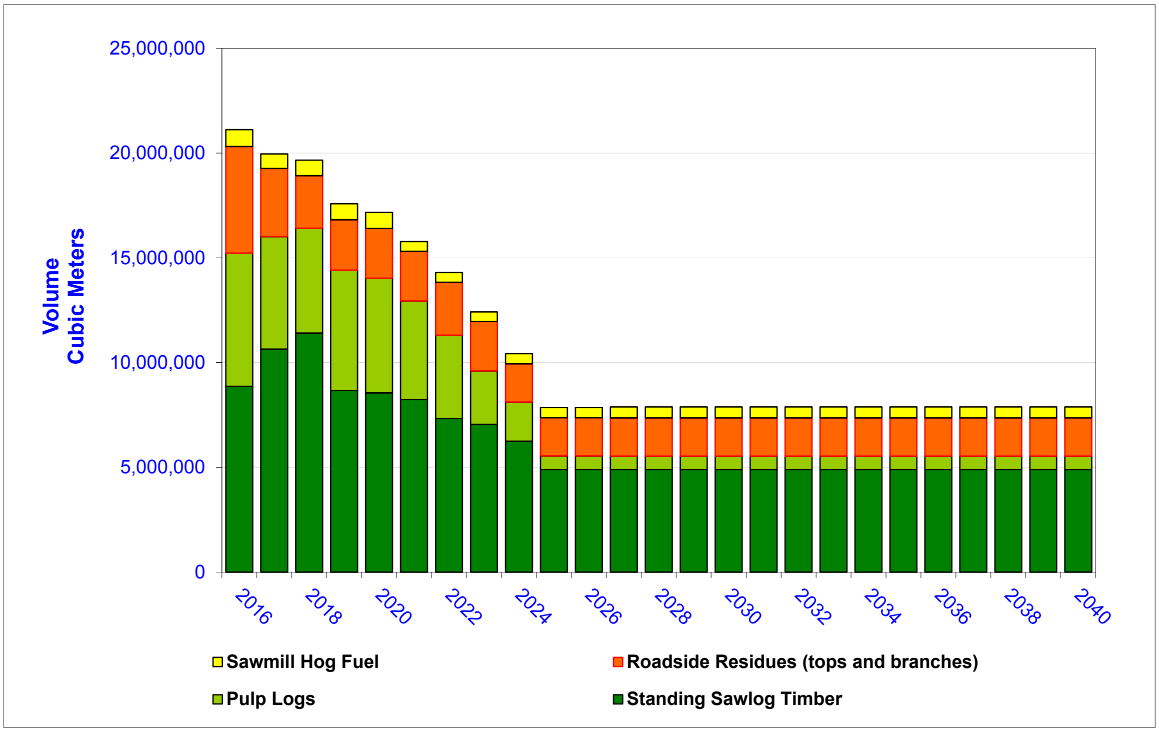
5.0 Provincial Bioenergy Summary

This report examines the Provincial bioenergy capacity of the Province of BC under the key assumption that all biomass within the framework of the annual allowable cut and not required by the existing forest industry is potentially available for electrical generation. In December 2014 the Province of BC had an annual allowable cut of about 80.5 million cubic metres when considering all forest management units and contributions from private forest lands. This AAC exceeded the 2014 demand for logs by the existing forest industry by a considerable margin – primarily as a result of: (1) uplifted AACs to address the MPB-epidemic, (2) lack of demand for sawlogs existing in certain regions of the Province due to the high cost of delivery (3) the continued uplift AAC above the regional capacity of the existing sawlog industry and (4) the increasing proportion of pulp logs in what are/were predominately saw log stands. As a result, there are significant, albeit declining amounts of biomass available to support electrical generation capacity until about 2023. However after this period the AAC is forecasted have stabilized at a 'mid-term' sustainable level and any future biomass salvage opportunities will likely be very limited and will exist outside of the AAC.

Figure 3 shows the amount of biomass that is forecast to be available over a 25-year time horizon, while operating within the framework of the Provincial Annual Allowable Cut. As can be seen by Figure 3, a considerable amount of biomass fuel, now and in the future, exists in the form of standing timber. This volume declines in the short-term (next 10 years) as demand for lumber and veneer products continues to recover. The majority of the standing timber shown in Figure 3 exists in northern parts of the Province. The availability of surplus pulp logs is expected to disappear by 2022. This fuel comprises predominately MPB-killed pine trees. A forecast reduction in sawmilling activity (as a result of fewer sawlog-quality trees) will reduce the supply of wood chips and other sawmill residues. Over the next decade this should increase demand for dead trees by the pulp and paper industry and consequently remove the surplus pulp log supply. Roadside woodwaste supplies are forecast to remain surplus to the existing forest industries needs for the next 25 years. As shown in Figure 3, sawmill woodwaste occurs as sawmill residues that are not currently demanded by the existing forest industry. Most of this biomass supply currently exists on the BC Coast and in the West Kootenays.

To estimate delivered fibre costs in the various fibre supply regions of BC, potential fibre delivery points were required for delivered fuel cost calculation purposes. These locations were selected based upon the assumption that a biomass plant would need to be located proximal to the transmission grid and in a location close to the existing forest industry where synergies could be gained through the coordinated salvage and delivery of fibre to a central location. Map 2 shows the potential fibre delivery points used in this analysis.

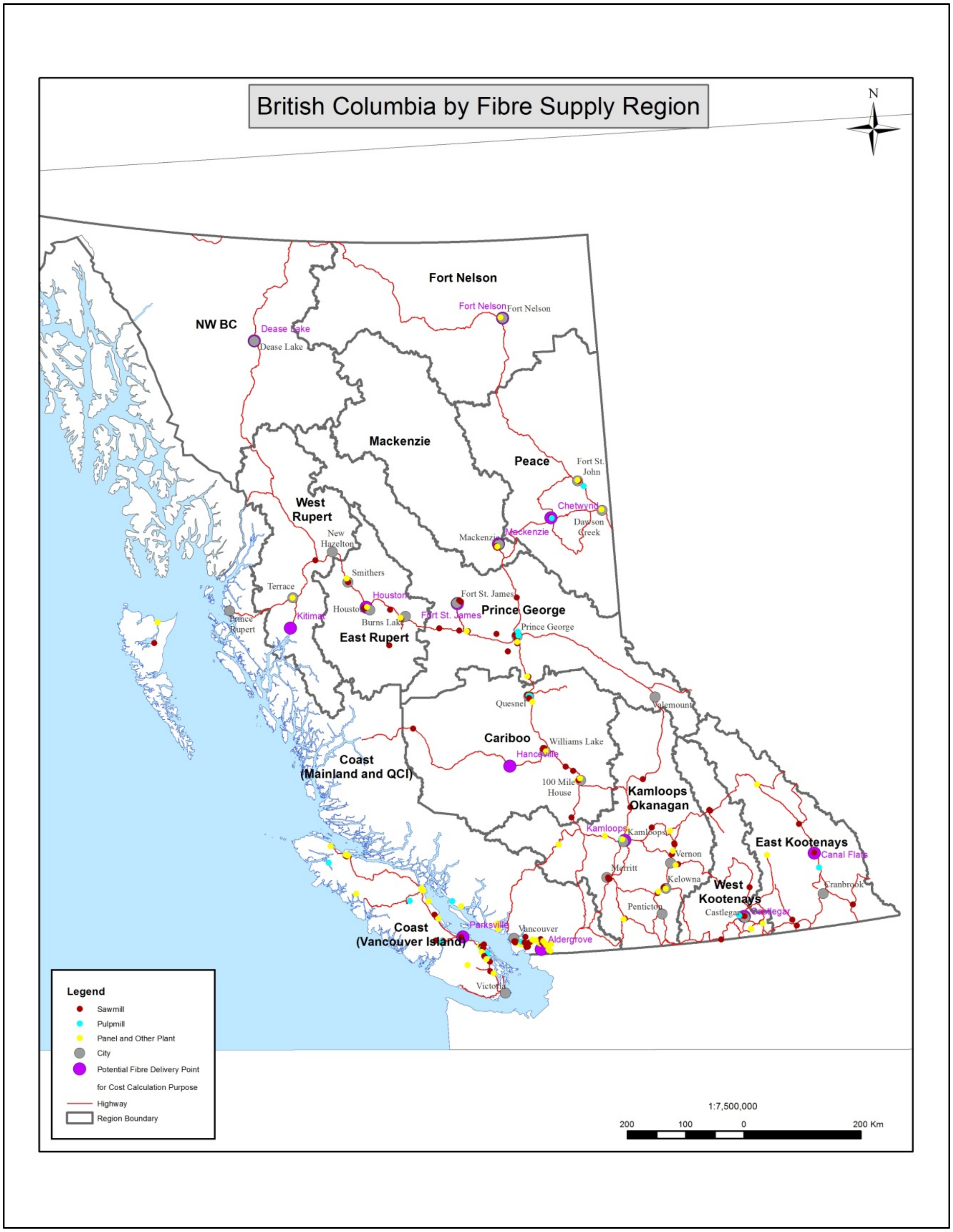
Figure 3. Province of BC Forecast Biomass Supply by Fuel Type



Due to the size, and diversity of terrain within BC, potential biomass fuel supply is dependent on regional supply/demand influences; hence Table 1 offers a Provincial summary of biomass electricity potential and cost for 13 regions. This table shows that, surplus to the needs of the existing forest industry, BC has sufficient biomass to generate an additional 6,408 GWh/yr of electricity for the next 10-year period. The weighted-average cost of this electricity is estimated at $197/MWh (weighted across all fibre categories and regions). In the long-term this capacity is forecast to decline in concert with a reduction in annual allowable cuts. For the next period commencing in 2026, forecast capacity is expected to drop to 4,469 GWh/yr at a cost of $194/MWh.

The cost of biomass-generated electricity depends largely on a bioenergy plants fuel profile and delivered fibre cost. Standing timber is generally the most expensive and results in a much higher electricity generation cost than if a plant managed a fuel profile skewed towards sawmill or roadside residue fuels. Table 2 shows the weighted-average cost of electricity in BC by fuel type. Table 3 provides additional detailed information on delivered fuel by supply region.

Map 2. Potential Fibre Delivery Points



Sensitivity analysis was completed that analyzed the change in generating capacity and cost if standing timber and/or pulp log fuels were removed from consideration. The results shown in Table 4 demonstrate a significant reduction in biomass fuel generating capacity and cost when certain categories of fuel are excluded from the Provincial fuel profile.

Table 5 provides a detailed summary of the estimated potential and cost for electricity generated by biomass from each of the supply regions identified in this analysis.

Table 1. Biomass Generating Energy Potential and Associated Cost for BC

Region	2016 - 2025		2026 - 2040	
	Potential Energy (GWh/year)	Estimated Energy Cost ($/MWh)	Potential Energy (GWh/year)	Cost of Energy ($/MWh)
Coast Mainland	649	$165	561	$144
Coast Vancouver Island		$165		$143
East Kootenay	98	$148	97	$148
West Kootenay	395	$131	407	$130
Kamloops / Okanagan	79	$207	0	$90
Cariboo	195	$201	17	$142
Prince George	1,028	$204	0	$90
Mackenzie	358	$191	29	$153
South Peace	272	$154	272	$163
North-east	921	$225	921	$225
East Prince Rupert	474	$188	257	$195
West Prince Rupert	1,831	$213	1,822	$214
North-west	109	$225	86	$225
Total BC	**6,408**	**$197**	**4,469**	**$194**
Total BC Interior	**2,897**	**$183**	**1,079**	**$148**

Table 2. Electricity Cost by Fuel Type

Biomass Type / Forecast Period	Potential Capacity (MW)		Annual Energy (GWh/year)		Cost of Energy ($/MWh)	
	2016 - 2024	2025 - 2040	2016 - 2024	2025 - 2040	2016 - 2024	2025 - 2040
Standing sawlog timber	530	317	4,643	2,774	$214	$219
Standing pulp logs	58	42	512	364	$177	$176
Road side logging residues	115	118	1,007	1,035	$146	$146
Sawmill hog fuel	28	34	245	297	$115	$114
Total	731	510	6,407	4,470		

Table 3. Estimated Delivered Fibre Costs

Region	Hypothetical Fibre Delivery Location	Estimated Delivered Fibre Costs ($/MWh)			
		Sawmill waste	Roadside logging residues	Pulp logs	Standing Timber
Coast (Vancouver Island)	Parksville	$20	$55	$97	$143
Coast (mainland)	Aldergrove	$25	$55	$97	$143
East Kootenay	Canal Flats	$18	$58	$90	$117
West Kootenay	Castlegar	$25	$58	$97	$125
Kamloops/Okanagan	Kamloops	$35	$60	$90	$117
Cariboo	Hanceville	$28	$52	$90	$117
Prince George	Ft St. James	$30	$55	$90	$117
Mackenzie	Mackenzie	$11	$63	$84	$108
South Peace	Chetwynd	$32	$54	$84	$108
North-east	Fort Nelson	$4	$48	$103	$134
East Prince Rupert	Houston	$20	$55	$84	$108
West Prince Rupert	Kitimat	$18	$54	$97	$125
North-west	Dease Lake	$18	$54	$103	$134

Table 4. Sensitivity to Fuel Type

Scenario	2016 - 2025		2026-2040	
	Energy (GWh/year)	Cost of Energy ($/MWh)	Energy (GWh/year)	Cost of Energy ($/MWh)
Base Case	6,408	$197	4,469	$194
Remove standing sawtimber as fuel	1,765	$142	1,695	$141
Remove standing sawtimber and pulp logs fuels	1,253	$140	1,331	$139

Table 5. Biomass Potential and Cost – by Region, Period and Fuel Type

Period	2016 - 2025								2026 - 2040							
Biomass Type	Sawmill Waste		Roadside Residues		Pulplogs		Standing Timber		Sawmill Waste		Roadside Residues		Pulplogs		Standing Timber	
Region	Energy (GWh/Yr)	Delivered Fibre Cost ($/MWh)	Energy (GWh/Yr)	Delivered Fibre Cost ($/MWh)	Energy (GWh/Yr)	Delivered Fibre Cost ($/MWh)	Energy (GWh/Yr)	Delivered Fibre Cost ($/MWh)	Energy (GWh/Yr)	Delivered Fibre Cost ($/MWh)	Energy (GWh/Yr)	Delivered Fibre Cost ($/MWh)	Energy (GWh/Yr)	Delivered Fibre Cost ($/MWh)	Energy (GWh/Yr)	Delivered Fibre Cost ($/MWh)
Coast	4	$25	499	$55	0	n/a	147	$143	37	$25	523	$55	0	n/a	0	n/a
East Kootenay	0	n/a	97	$58	0	n/a	0	n/a	0	n/a	97	$58	0	n/a	0	n/a
West Kootenay	211	$25	184	$58	0	n/a	0	n/a	220	$25	187	$58	0	n/a	0	n/a
Kamloops/Okanagan	0	n/a	0	n/a	0	n/a	79	$117	0	n/a	0	n/a	0	n/a	0	n/a
Cariboo	0	n/a	17	$52	0	n/a	178	$117	0	n/a	17	$52	0	n/a	0	n/a
Prince George	0	n/a	0	n/a	102	$90	925	$117	0	n/a	0	n/a	0	n/a	0	n/a
Mackenzie	0	n/a	30	$63	47	$84	281	$108	0	n/a	29	$63	0	n/a	0	n/a
South Peace	9	$32	163	$54	99	$84	0	n/a	9	$32	163	$54	99	$84	0	n/a
North-east	0	n/a	0	n/a	0	n/a	921	$134	0	n/a	0	n/a	0	n/a	921	$134
East Prince Rupert	0	n/a	1	$55	198	$84	275	$108	9	$20	1	$55	199	$84	49	$108
West Prince Rupert	21	$18	17	$54	65	$97	1728	$125	21	$18	17	$54	65	$97	1718	$125
North-west	0	n/a	0	n/a	0	n/a	109	$134	0	n/a	0	n/a	0	n/a	86	$134
Total GWh per year and weighted-average cost	245	$25	1,007	$56	512	$87	4,643	$124	297	$25	1,035	$56	364	$86	2,774	$128

6.0 Coast

Due to transmission and distribution considerations BC Hydro classifies the BC Coast according to two regions; Vancouver Island and the Coastal Mainland. To maintain some consistency with this practice, the coastal bioenergy opportunity is reported for both the Island and Mainland. However, the delivered cost of wood or biomass fuel and the availability of this fuel are similar, regardless of location.

The predominate feature of BC's Coast is presence of the Pacific Ocean. Most wood manufacturing facilities on the coast utilize the ocean as a transportation conduit. Logs, chips, sawdust, shavings and hog fuel move by barge and trade routinely from the Lower Mainland / Lower Coast to Vancouver Island and vice versa. The majority of coastal pulping capacity is located on Vancouver Island and over half of the fibre required by the three remaining Vancouver Island pulp and paper mills comes from sources other than Vancouver Island. Sawmilling capacity within the region is split roughly equally between the Lower Mainland and *Vancouver Island.* Thus the ocean exists not as a limiting factor, but as a means for the forest industry to access wood fibre over the entire region at comparable costs. Log dumps and barging are the key components to this transportation system. Once a tree is delivered to a coastal log dump, the cost to delivering the wood anywhere along the BC Coast is relatively static. Transport companies adjust the size of their barges to accommodate a short or long haul (on the south coast) while keeping unit costs about the same.

The integration of island and mainland, with regard to wood supply, is also evident through governments' establishment of coastal timber supply areas and tree farm licenses - the boundaries often extending across the Strait of Georgia. Fibre processing mills in Campbell River, Nanaimo, Powel River and Vancouver procure their wood supplies from both the mainland and the island based on wood quality, logging cost and supply agreements. Transportation cost is seldom a limiting factor. As a result, this analysis regarding potential biomass supply for a possible IPP on Vancouver Island or on the Lower mainland is based on the entire Coastal biomass supply, with barging cost incorporated into delivered fuel cost estimates.

6.1 Background Information

Map 3 shows the location of the Coast in relation to the Province of BC. The forest industry on the Coast has largely recovered from the 2009 industry downturn and is forecast to remain fairly static into the future. Current and future harvest levels stem from a demand for sawlogs, veneer logs, shake and shingle, pulp logs and log exports.

BC Coastal forests have a preponderance of lower-quality hemlock and balsam trees for which there is marginal demand. As a result, harvesting on the Coast is typically below the AAC. This lack of demand may provide high-cost opportunity for bio-energy fuel procurement.

The log supply on the Coast is currently dominated by four companies: Western Forest Products, Island Timberlands, Interfor and Timber West. The coastal log supply is currently furnishing about twenty-five sawmills, twenty one shake and shingle mills, three plywood plants and five pulp & paper mills. Cumulative AAC is about 22.4 million cubic metres. There are very few pine stands, hence the MPB-epidemic is not a concern and the forecast annual allowable cut is quite stable. Sawlog and pulp log demand from this AAC is currently forecast to remain fairly constant at about 9.4 million cubic metres. Thus a sizeable inventory of surplus standing timber exists.

Map 3. Coastal Region

6.2 Demand for Residual Fibre

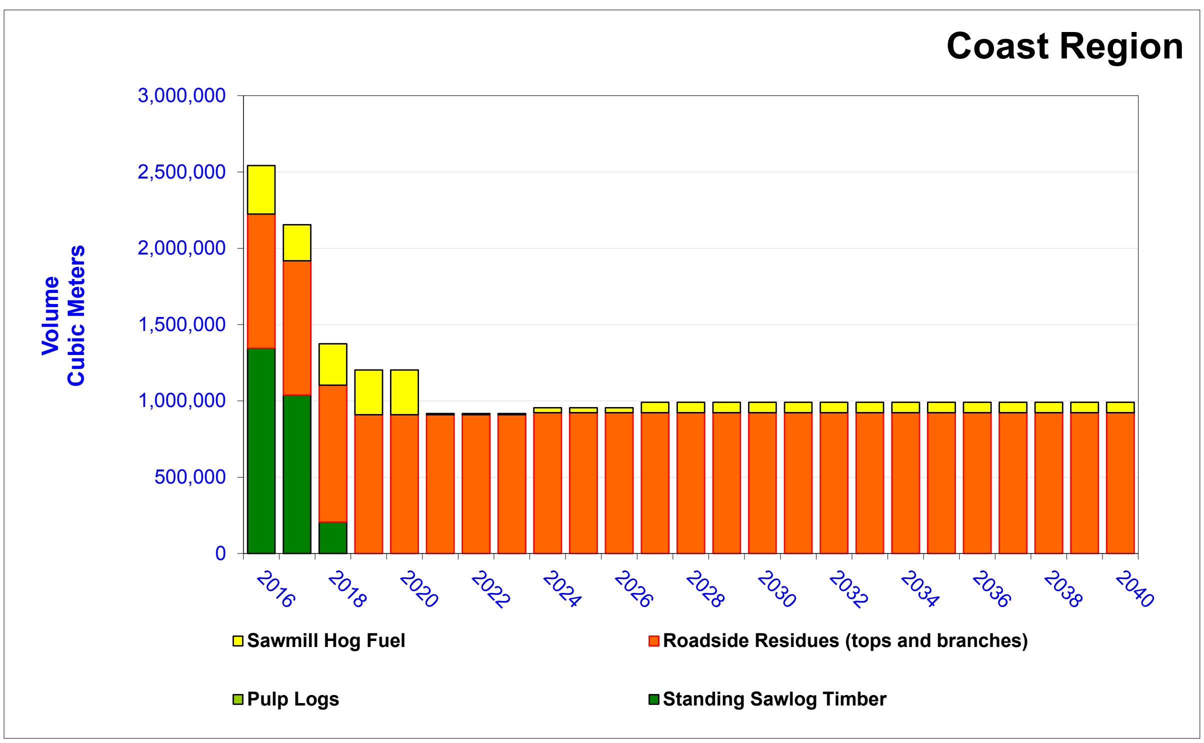
The demand for residual fibre on the coast has changed significantly in the last few years as a result of the closure of the Elk Falls pulp and paper mill and most recently the closure of the Neucel Port Alice mill. While residual wood chips remain in short supply (resulting in significant volumes of chips to be imported from the Interior), sawdust, shavings and hog fuel are currently surplus to industry needs.

Almost all minor residual fibre is consumed by either regional pulp and paper power boilers or in the case of sawdust and shavings, by the significant animal bedding and agricultural markets.

6.3 Coastal Biomass Fuel Availability Forecast

Figure 4 shows the availability of biomass fibre by type over the 25-year forecast given the assumptions described previously. The majority of available fibre for use as biomass exists in the form of un-harvested AAC, with some current surpluses of hog fuel. Available volumes have declined since completion of our 2013 analysis as a result of several factors. A recently announced greenfield pellet plant in Nanaimo has reduced our projected availability of sawmill residues; though likelihood of this plant being constructed remains questionable. Our modeling logic has changed whereby pulp log shortfalls are now assumed to come from standing timber. The resurgence in US housing has resulted in an increase in operating rates for coastal log processing facilities; and lastly the coast has experienced a dramatic increase in log exports. As a consequence of these changes the magnitude of surplus coastal biomass, though still considerable, has declined.

Figure 4. Net Available Biomass by Type – Coast



6.4 Biomass Energy Potential – Vancouver Island

Table 6 describes the biomass electrical generation potential for this region assuming the electrical generation facility is located centrally on Vancouver Island in the Parksville area. A maximum 74 megawatt capacity biomass power plant could generate 649 GWh annually at a forecast cost of $165/MWh over the next 10 years. In the second 15-year period this potential supply drops slightly to 64 MW capacity, producing 561 GWh/year at a cost of $143/MWh.

Table 6. Vancouver Island Biomass Fuel Supply and Price Forecast

	Biomass Fuel Quantities and Costs	Forecast Years	
		2016 - 2025	2026 - 2040
Surplus Biomass Fuel (GWh per year)	Standing sawlog timber	147	0
	Pulp logs	0	0
	Road-side logging residues	499	523
	Sawmill hog fuel	4	37
	Estimated Sustainable Biomass Supply (GWh/yr)	**649**	**561**
Estimated Biomass Electricity Generation Cost	Biomass Generation Potential (megawatts)	74	64
	Estimated Delivered Cost of Biomass ($/m3)	$43	$30
	Estimated Delivered Cost of Biomass ($/megawatt-hr)	$75	$53
	Assumed Capital and Operating Cost ($/megawatt-hr)	$90	$90
	Total Estimated Energy Cost ($/megawatt-hour)	**$165**	**$143**

6.5 Biomass Energy Potential – Coastal Mainland

Table 7 summarizes the biomass potential for an electrical generation facility assumed to be located on the Coastal Mainland. The same maximum biomass power plant capacity of 74 megawatts could generate 649 GWh/year electricity at a forecast cost of $165/MWh over the next 10 years. The potential supply decreases slightly to a maximum of 64 megawatts capacity over the next 15-year period, at a cost of $144/MWh. The small improvement in cost is a result of less available high-cost standing timber and slightly more available low-cost residual fibre when sawmills are forecast to improve operating rates.

Table 7. Coastal Mainland Biomass Fuel Supply and Price Forecast

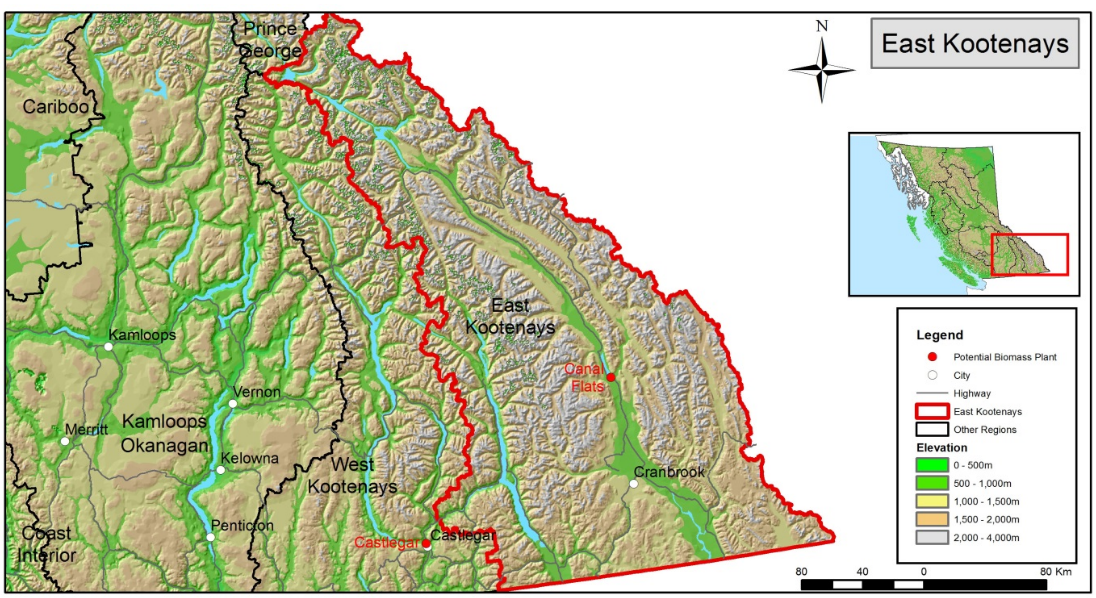
	Biomass Fuel Quantities and Costs	Forecast Years	
		2016 - 2025	2026 - 2040
Surplus Biomass Fuel (GWh per year)	Standing sawlog timber	147	0
	Pulp logs	0	0
	Road-side logging residues	499	523
	Sawmill hog fuel	4	37
	Estimated Sustainable Biomass Supply (GWh/yr)	**649**	**561**
Estimated Biomass Electricity Generation Cost	Biomass Generation Potential (megawatts)	74	64
	Estimated Delivered Cost of Biomass ($/m3)	$43	$30
	Estimated Delivered Cost of Biomass ($/megawatt-hr)	$75	$53
	Assumed Capital and Operating Cost ($/megawatt-hr)	$90	$90
	Total Estimated Energy Cost ($/megawatt-hour)	**$165**	**$144**

7.0 East Kootenay

7.1 Background Information

Map 4 shows the location of the East Kootenay Region in relation to the Province of BC. Rocky Mountains and wide valleys in the region are covered in forests that comprise about 40 percent lodgepole pine. Other principle species include Douglas fir, spruce, balsam fir and larch. The MPB epidemic has had a comparatively minor impact in the area to-date. By 2014, about 15 percent of pine trees are estimated to have been killed. Current AAC for the region is approximately 3.1 million cubic metres. The long-term post MPB-epidemic AAC is expected to drop slightly, to about 2.75 million cubic metres.

Map 4. East Kootenay Region



7.2 Existing Industry

Eight sawmills, a plywood plant and a pulp mill comprises the forest industry in the East Kootenay Region. Residual biomass is directed primarily to the Skookumchuck pulp mill which is now owned by Paper Excellence (2013) and which has since been upgraded with a rebuilt recovery boiler. Aside from pulp, the mill has been producing incremental electricity for a number of years. Surplus lower grade sawmill residuals are also often sold to Avista Corp. (a 46-MW biomass power plant in Kettle Falls USA). The transfer of biomass across the border is cost-effective since wood chips coming from the USA by truck can return on the back-haul with sawdust, shavings and hog fuel.

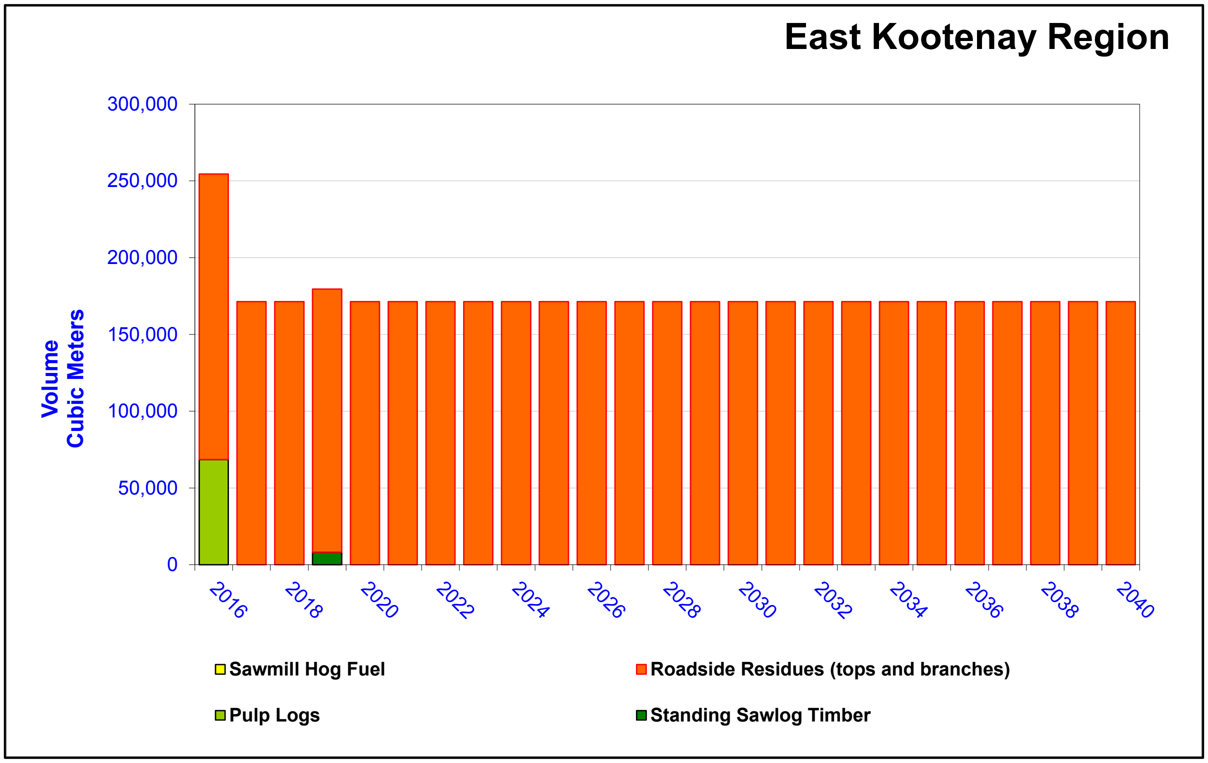
7.3 Demand for Residual Fibre

Within the East Kootenay Region, significant demand for residual sawmill fibre already exists to support power boilers, electrical generation facilities at the regional pulp mill and other mill energy systems. In the face of reduced sawmill activity that has been forecast for the region, with a corresponding decline in available residual fibre, all of these consumers will either resort to using roadside residual fibre to meet their needs, harvest and consume pulp logs, or potentially switch to alternative sources of energy (such as natural gas in some power boilers).

7.4 East Kootenay Biomass Fuel Availability Forecast

Figure 5 shows forecast biomass fibre availability by type over the planning horizon. The majority of the opportunity lies with roadside residues. The standing timber and pulp logs that become available and then lost in the future are a consequence of the rationalization of sawlog demand to sawlog supply. As indicated in Section 7.1, if harvests are incrementally reduced by 350,000 cubic metres, the closure of a regional sawmill is a possibility.

Figure 5. Net Available Biomass by Type – East Kootenay



7.5 Biomass Energy Potential – East Kootenay

Table 8 summarizes the biomass potential for the region, assuming an electrical generation facility is located central to the available fibre supply in the Canal Flats area. A maximum of 11 MW capacity biomass power plant could provide 97 GWh of annual energy at a forecast cost of $148/MWh over the next 25-year period.

Table 8. East Kootenay Biomass Fuel Supply and Price Forecast

	Biomass Fuel Quantities and Costs	Forecast Years	
		2016 - 2025	2026 - 2040
Surplus Biomass Fuel (GWh per year)	Standing sawlog timber	0	0
	Pulp logs	0	0
	Road-side logging residues	97	97
	Sawmill hog fuel	0	0
	Estimated Sustainable Biomass Supply (GWh/yr)	**98**	**97**
Estimated Biomass Electricity Generation Cost	Biomass Generation Potential (megawatts)	11	11
	Estimated Delivered Cost of Biomass ($/m3)	$33	$33
	Estimated Delivered Cost of Biomass ($/megawatt-hr)	$58	$58
	Assumed Capital and Operating Cost ($/megawatt-hr)	$90	$90
	Total Estimated Energy Cost ($/megawatt-hour)	**$148**	**$148**

8.0 West Kootenay

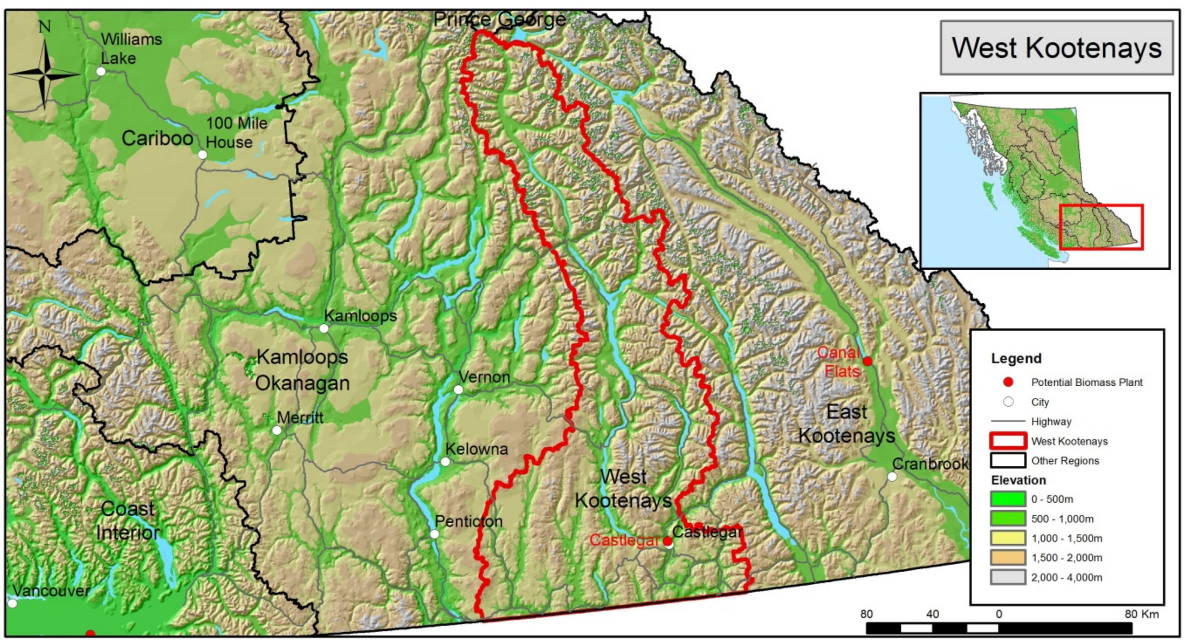
8.1 Background Information

Map 5 shows the location of the West Kootenay Region in relation to the Province. The region is extremely rugged with steep mountains and valleys running predominately north/south. Arrow Lake is a dominate feature that provides water transportation for logs harvested in the northern parts of the region, south to Castlegar. This in turn drives up delivered wood costs relative to other areas. The wetness of the climate results in both very good growing sites and a wide diversity of tree species.

Only about 21 percent of the trees in this region are pine. As a result, the MPB-epidemic has only had a minor impact on the area. Of the roughly 23 million cubic metres of pine within the region, an estimated 3.6 million cubic metres of pine have been killed by the beetle. The epidemic peaked in 2006. An estimated 5.8 million cubic metres of pine is forecast to be killed by 2024 (considerably less than that which was assumed in 2013).

The current AAC for the region is about 2.8 million cubic metres. There has not been in increase in the AAC as a result of the MPB-epidemic, nor is the long-term AAC likely to be significantly impacted by pine mortality.

Map 5. West Kootenay Region



8.2 Existing Industry

The existing regional forest industry is dominated by eight medium-sized sawmills and several many small independently-owned sawmills and one large, modern and very efficient pulp mill (Celgar) which also sells excess electricity to BC Hydro. Through a network of supply agreements with the regional sawmills, the pulp mill acquires its wood chip supply. Since this is insufficient to meet their fibre demand, the mill also has a very large whole log chipping program and imports a significant volume of chips from the USA. Currently, the Celgar mill's production of bio-electricity is accomplished through the consumption of 'black liquor', a byproduct of the pulp production process. Celgar's demand for hog fuel is minimal.

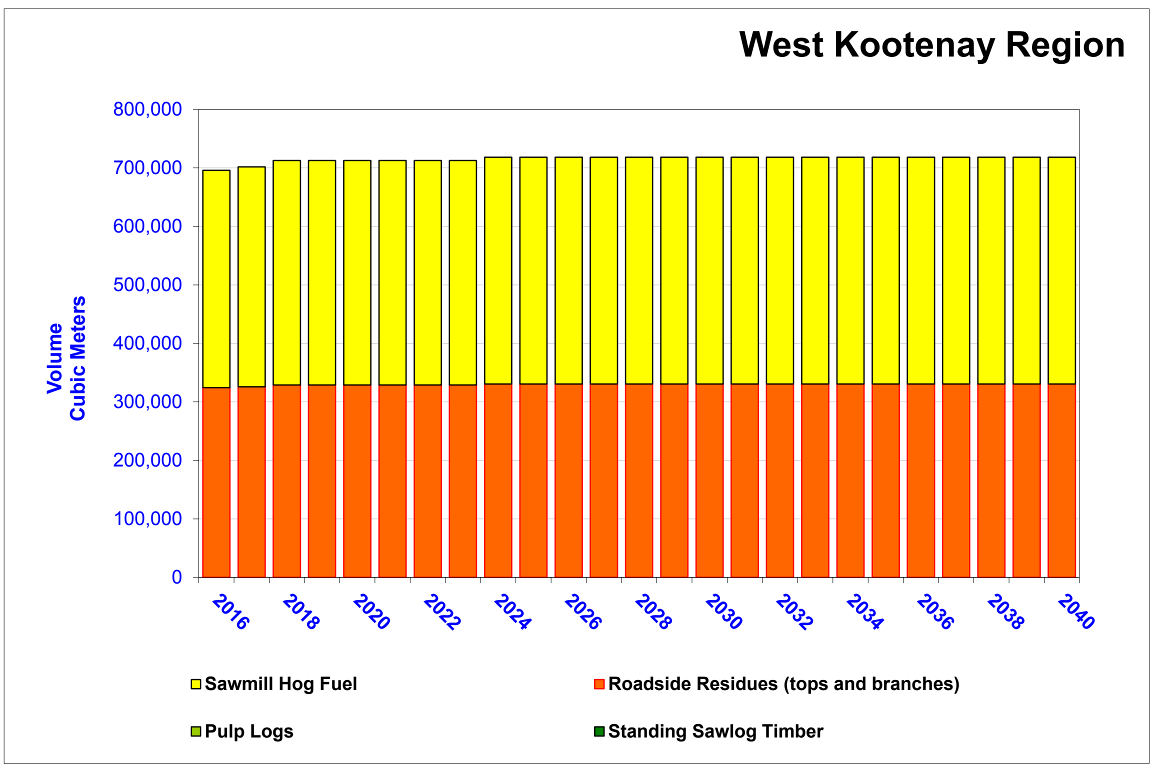
8.3 Demand for Residual Fibre

At the present time only the Downie Timber – Revelstoke community energy system and Celgar utilize residual sawmill fibre. As the combined total demand is less than 75,000 ODTs, there is a surplus of both residual hog fuel and sawdust within the region. This surplus is forecast to persist over the planning horizon. The cost of forest-based residual fibre is high and access is difficult as a result of steep terrain and lake transportation.

8.4 Potential Fibre Sources for Energy

Figure 6 shows the availability of biomass fibre by type over the planning horizon, given the assumptions made. The surplus available biomass fibre over the entire planning horizon is a combination of roadside residues and surplus hog fuel.

Figure 6. Net Available Biomass by Type – West Kootenay



8.5 Biomass Energy Potential- West Kootenay

Table 9 summarizes biomass electrical generation potential for this region assuming an electrical generation facility is located in Castlegar. A maximum 45 MWs of power plant capacity could produce approximately 395 GWh of annual energy at a forecast cost of $131/MWh over the planning horizon.

Table 9. West Kootenay Biomass Fuel Supply and Price Forecast

	Biomass Fuel Quantities and Costs	Forecast Years	
		2016 - 2025	2026 - 2040
Surplus Biomass Fuel (GWh per year)	Standing sawlog timber	0	0
	Pulp logs	0	0
	Road-side logging residues	184	187
	Sawmill hog fuel	211	220
	Estimated Sustainable Biomass Supply (GWh/yr)	**395**	**407**
Estimated Biomass Electricity Generation Cost	Biomass Generation Potential (megawatts)	45	46
	Estimated Delivered Cost of Biomass ($/m3)	$23	$23
	Estimated Delivered Cost of Biomass ($/megawatt-hr)	$40	$40
	Assumed Capital and Operating Cost ($/megawatt-hr)	$90	$90
	Total Estimated Energy Cost ($/megawatt-hour)	**$131**	**$130**

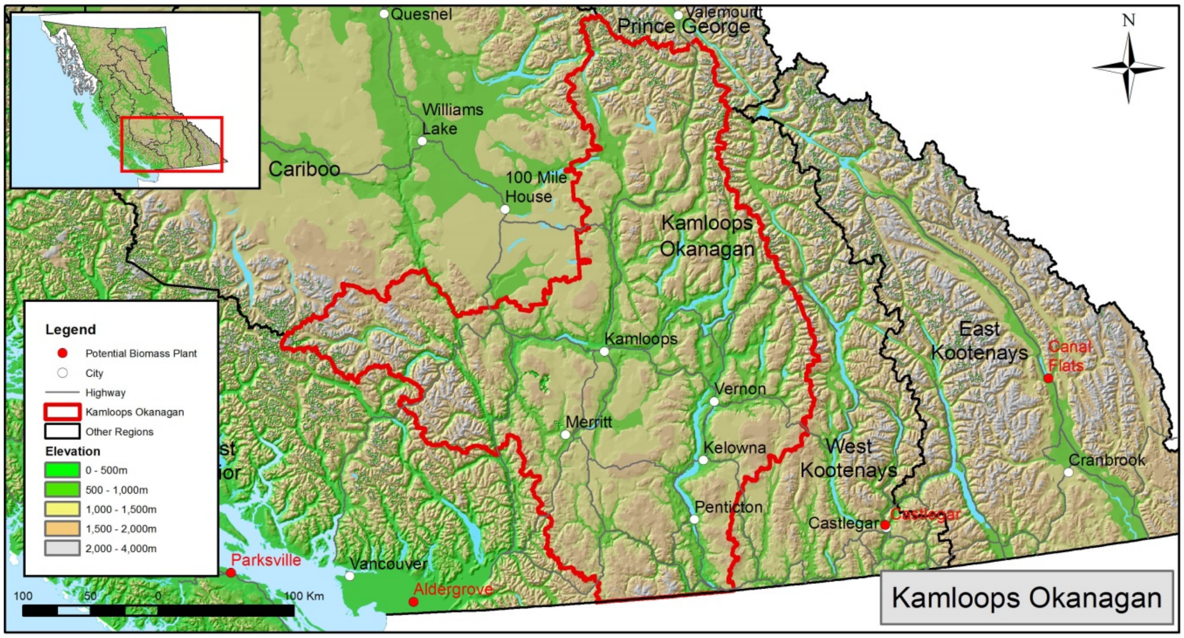
9.0 Kamloops / Okanagan

9.1 Background Information

Map 6 shows the location of the Kamloops/Okanagan Region in relation to the Province. The region's size and diversity includes dry, hot, semi-arid grass lands in the south that transition to wet areas and rugged mountains in the north. The Thompson River, Okanagan and Shuswap Lakes are principle features in the region. A large forest industry competes with the demands of a diverse tourism and recreation industry. The region has an estimated 200 million cubic metres of pine. By 2014, an estimated 62 million cubic metres of pine had been killed by the Mountain Pine Beetle. This is about 98% of the estimated 63 million that is expected to die from the epidemic that peaked in 2007.

The historic AAC for the region was approximately 9 million cubic metres. It was increased to 13 million cubic metres to support salvage of logs from both fire and beetle mortality, and currently sits at about 10.3 million cubic metres. A future long-term sustainable AAC of about 8 million cubic metres is forecast by 2024.

Map 6. Kamloops/Okanagan Region



9.2 Existing Industry

Eleven medium-sized sawmills, five veneer/plywood plants, one independent power plant (Armstrong), three pellet mills and one large pulp mill comprise the existing forest industry in this region. Since 2005, several sawlog consuming mills have closed, including mills in Lytton, Kamloops, Okanogan Falls, Kelowna, Canoe and Merritt. Mill closures were due in part to the difficult operating economics seen during the global recession, short-falls in sawlog supply as a result of the MPB epidemic and corporate decisions to consolidate or shut down assets.

The remaining sawlog consuming mills have a regional annual combined demand capacity of 9.3 million cubic metres.

9.3 Demand for Residual Fibre

The Domtar pulp mill in Kamloops is the largest regional consumer of wood chips and hog fuel. Merritt Green Energy Limited Partnership, which was awarded an EPA with BC Hydro for a biomass-fired power plant under the Phase 2 Power Call, announced closure of financing for a 40-MW plant in 2014. This plant will consume 200,000 ODTs of biomass when in production. Pinnacle Pellet also announced in 2015 the development of a new pellet plant in Lavington BC (utilizing sawmill residues from regional Tolko mills). Regional roadside residuals continue to be in significant demand as they support biomass power production at Howe Sound Pulp and Paper. Approximately 200,000

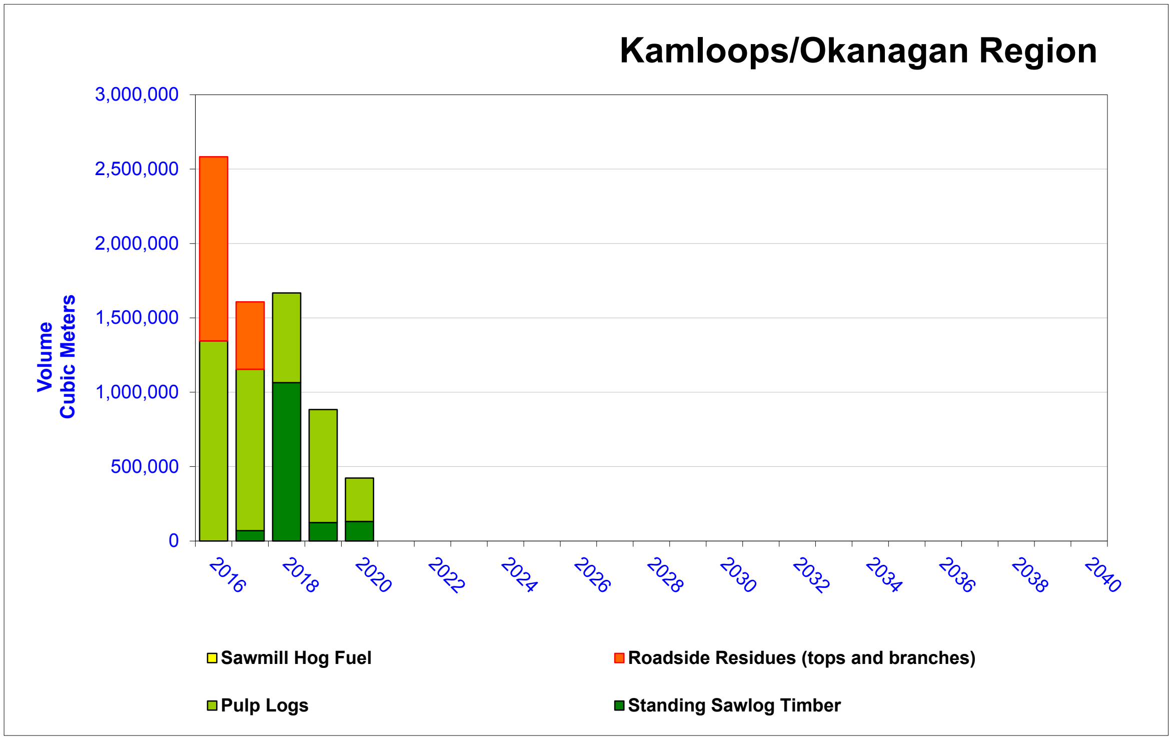
ODTs of roadside material are transferred from the Kamloops/Okanagan region for power generation on the BC coast each year.

There are multiple users of minor residual sawmill fibre within the region, resulting in considerable historic demand and competition between companies. During the forecast period, a short term surplus of sawdust, shavings and hog fuel exist as a result of the closure to the Domtar sawdust digester. It is assumed that existing pellet producers or the proposed Western Bioenergy power plant would secure this volume in the near term.

9.4 Potential Fibre Sources for Energy

Figure 7 shows the availability of biomass fibre by type over the planning horizon. Over the next 6 years the surplus in biomass availability is forecast to decline significantly. Beyond 2023 the opportunity for new bioenergy develop is nil.

Figure 7. Net Available Biomass by Type – Kamloops/Okanagan Region



9.5 Biomass Energy Potential

Table 10 quantifies the surplus biomass potential for the region, assuming an electrical generation facility is centrally located to available fibre supply in Kamloops. Based on a 20-year amortization, new bioenergy development does not appear to be feasible.

Table 10. Kamloops/Okanagan Biomass Fuel Supply and Price Forecast

	Biomass Fuel Quantities and Costs	Forecast Years	
		2016 - 2025	2026 - 2040
Surplus Biomass Fuel (GWh per year)	Standing sawlog timber	79	0
	Pulp logs	0	0
	Road-side logging residues	0	0
	Sawmill hog fuel	0	0
	Estimated Sustainable Biomass Supply (GWh/yr)	**79**	**0**
Estimated Biomass Electricity Generation Cost	Biomass Generation Potential (megawatts)	9	0
	Estimated Delivered Cost of Biomass ($/m3)	$66	$0
	Estimated Delivered Cost of Biomass ($/megawatt-hr)	$117	$0
	Assumed Capital and Operating Cost ($/megawatt-hr)	$90	$90
	Total Estimated Energy Cost ($/megawatt-hour)	**$207**	**n/a**

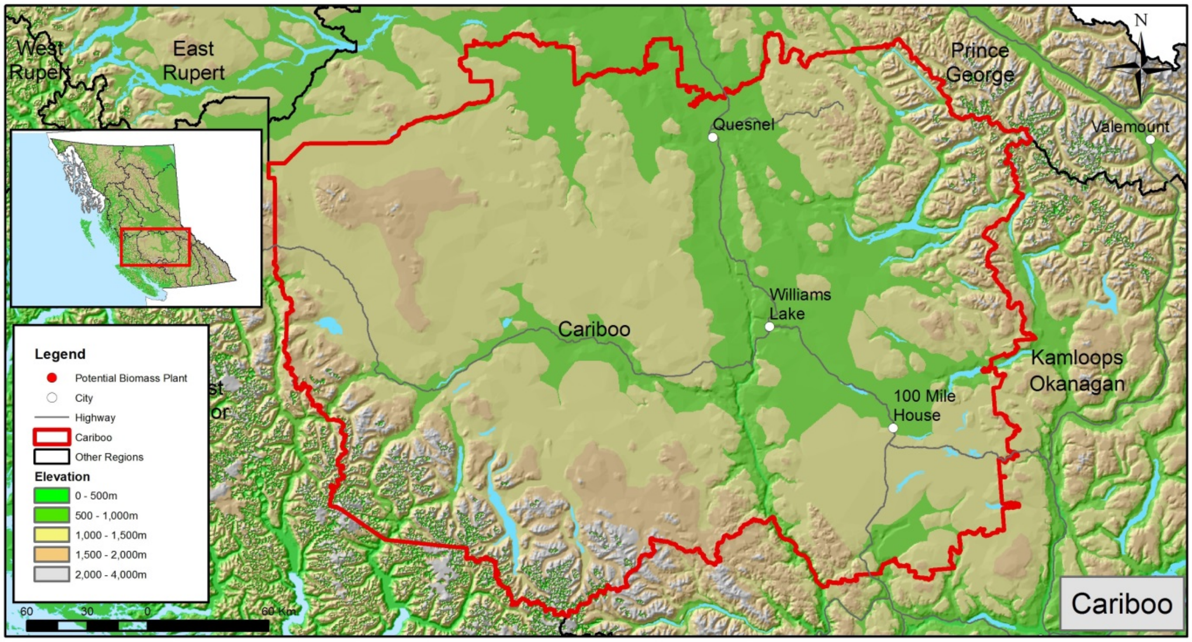
10.0 Cariboo

10.1 Background Information

Map 7 shows the location of the Cariboo Region in relation to the Province. Situated in the central interior, the relatively flat dry terrain is home to roughly 312 million cubic metres of Lodgepole pine. Pine trees comprise about 65 percent of the forests and 70 percent of these trees had been forecast to be killed by the beetle epidemic, The epidemic peaked in 2005 and in 2013 an estimated 219 million cubic metres of pine volume have been killed. Further mortality is not expected.

The traditional AAC for the region was 8.5 million cubic metres. It was at 13.2 million in 2013 and has declined to 10.9 million in 2015. The AAC is forecast to fall to 4.9 million by 2025. At this reduced harvest level not all of the existing log processing facilities will be able to operate. In 2012 Tolko announced the permanent closure of its Creekside sawmill in Williams Lake. In 2014 Canfor permanently closed its Quesnel sawmill.

Map 7. Cariboo Region



10.2 Existing Industry

The existing forest industry is very large. There are ten major sawmills, two veneer plants, one OSB plant, two pulp mills, two pellet plants, a board plant and a large biomass-fired powerplant in the Region. West Fraser Timber Ltd. is the largest operating company followed by Tolko Industries Ltd. The latest development in regards to the existing industry is the completion of a whole log chipping/grinding plant in Quesnel in late 2014. Created through a partnership between Tolko and Pacific Bioenergy, the plant has significantly improved the utilization of fibre salvaged from dead pine stands. This improvement comes in the form of both increased recovery of sawlogs and through the creation of additional supplies of pulp chips and hog fuel.

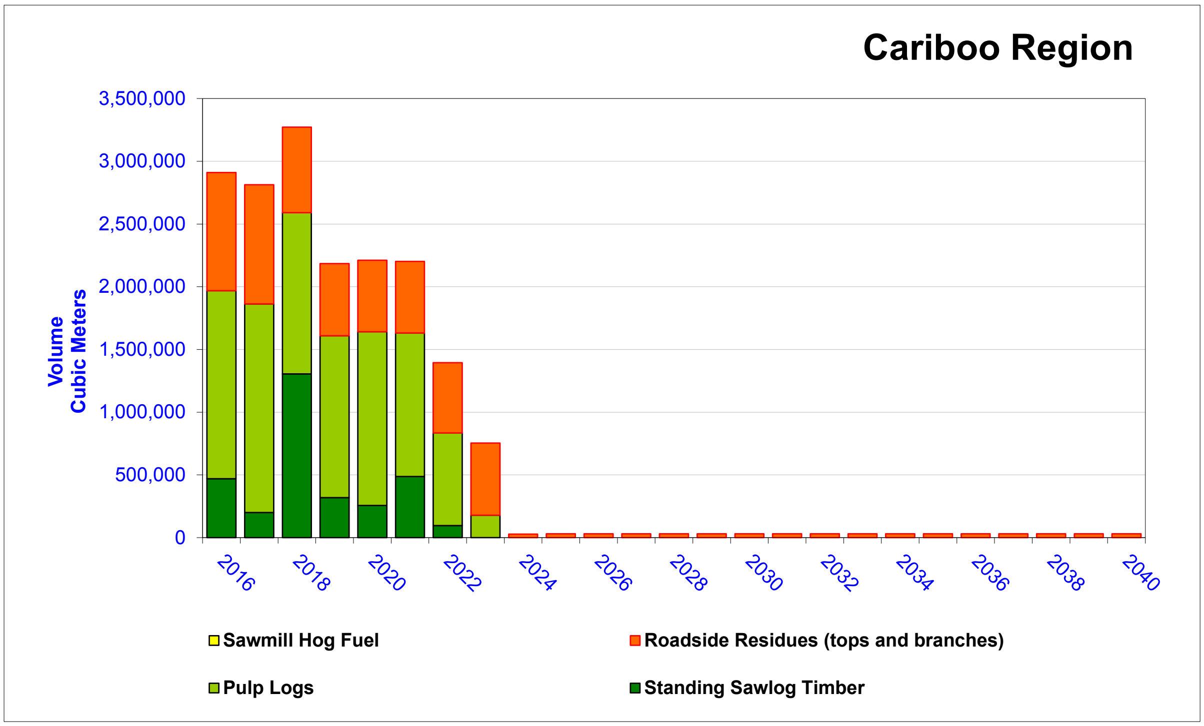
10.3 Demand for Residual Fibre

Given the diversity of the residual products industry that exists within the region, there is already more demand for residual sawmill fibre than meets demand. In the face of reduced sawmill activity forecast for the region and consequently the decline in the availability of residual fibre, all of the residual fibre consumers will either resort to roadside residual fibre to meet their needs, harvest and consume pulp logs, potentially switch to alternative sources of energy (such as natural gas in some power boilers) or curtail operations.

10.4 Potential Fibre Sources for Energy

Figure 8 shows biomass fibre availability by type over the planning horizon. For the next 10 years there is a declining surplus of unused sawlogs, pulp logs and roadside debris. After this time, new opportunities are not apparent and even the existing industry may need to reduce operating rates, or consider closure due to shortfalls in fibre supplies.

Figure 8. Net Available Biomass by Type – Cariboo Region



10.5 Biomass Energy Potential

Table 11 summarizes the biomass potential for this region. In this analysis we assumed that the existing bioenergy plant in Williams Lake would operate into the future at 75 percent of capacity (which has been their operating level for the past several years). A maximum 2 megawatts of additional capacity generating 17 GWh annually could do so at a forecast cost of $142/MWh over the next 25 years.

Table 11. Cariboo Biomass Fuel Supply and Price Forecast

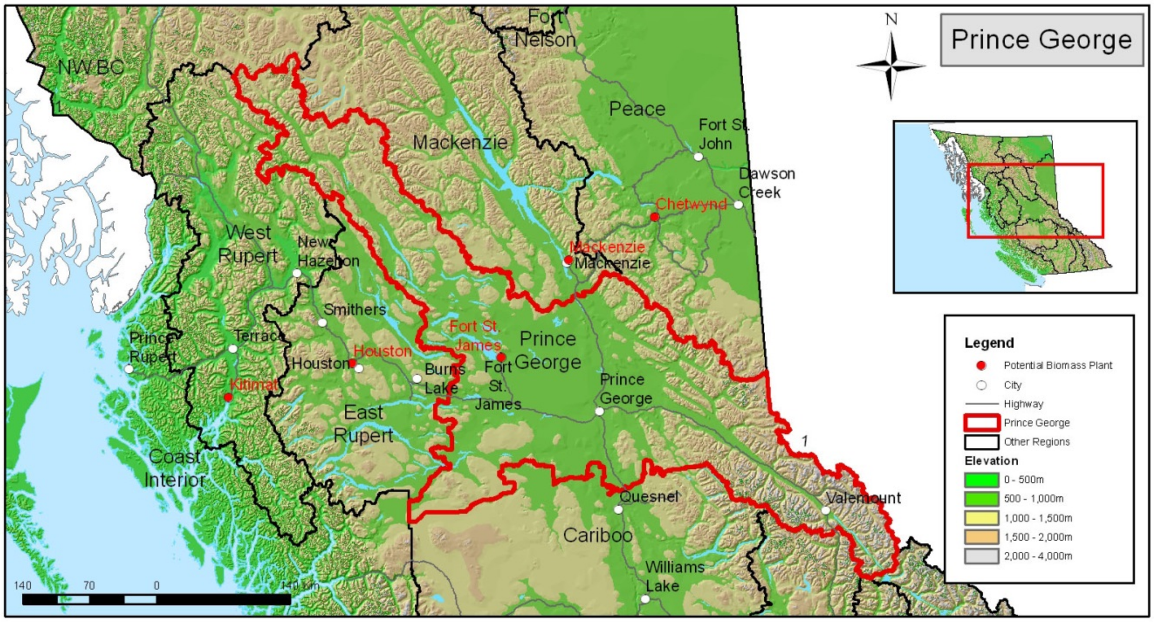
	Biomass Fuel Quantities and Costs	Forecast Years	
		2016 - 2025	2026 - 2040
Surplus Biomass Fuel (GWh per year)	Standing sawlog timber	178	0
	Pulp logs	0	0
	Road-side logging residues	17	17
	Sawmill hog fuel	0	0
	Estimated Sustainable Biomass Supply (GWh/yr)	**195**	**17**
Estimated Biomass Electricity Generation Cost	Biomass Generation Potential (megawatts)	22	2
	Estimated Delivered Cost of Biomass ($/m3)	$63	$29
	Estimated Delivered Cost of Biomass ($/megawatt-hr)	$111	$52
	Assumed Capital and Operating Cost ($/megawatt-hr)	$90	$90
	Total Estimated Energy Cost ($/megawatt-hour)	**$201**	**$142**

11.0 Prince George

11.1 Background information

Map 8 shows the location of the Prince George Region in relation to the Province. Though Lodgepole pine is heavily concentrated in certain areas, the size and diversity of the region includes extensive area where pine is a minor component of forest stands. Forests are composed predominately of pine, spruce and balsam fir at 47 percent, 31 percent and 19 percent respectively. The MPB-epidemic has had a significant effect on the roughly 293 million cubic metres of pine. Within the region the epidemic began in about 1999 and peak mortality occurred in 2005. By 2015 about 200 million cubic metres of pine are presumed killed and the epidemic is largely over. The historic AAC for the Region was about 11 million cubic metres. Due to the MPB-epidemic, the AAC increased to almost 18 million by 2006 and is currently about 14.5 million cubic metres. The long-term AAC is estimated to fall to 9.6 million cubic metres by 2025.

Map 8. Prince George Region



11.2 Existing Industry

Ten large sawmills, three pulp mills and three pellet mills currently operate within the region. Another seven sawmills, a finger joint plant and a plywood plant have in the past four years been closed indefinitely. The Lakeland mill that was destroyed by fire in 2012 has been re-built and commenced operations in 2014. The forest industry is dominated by Canadian Forest Products Ltd (Canfor) which operates four sawmills in the region and maintains controlling interest in the three pulp mills. Lumber producing competitors include the Sinclair Group, Carrier Lumber, Conifex, West Fraser and Dunkley. Sawmill residues from these solid-wood processing facilities are directed to the pulp mills for the production of pulp, paper and electricity, to Pacific Bioenergy, Premium Pellet and Pinnacle Pellet for the production of wood pellets and some residues moved north to Mackenzie or south to Quesnel.

In late 2013 the Fort St. James Green Energy biomass-fired power plant closed its debt financing. Construction of the 40 MW-plant is underway with an expected 2016 start date.

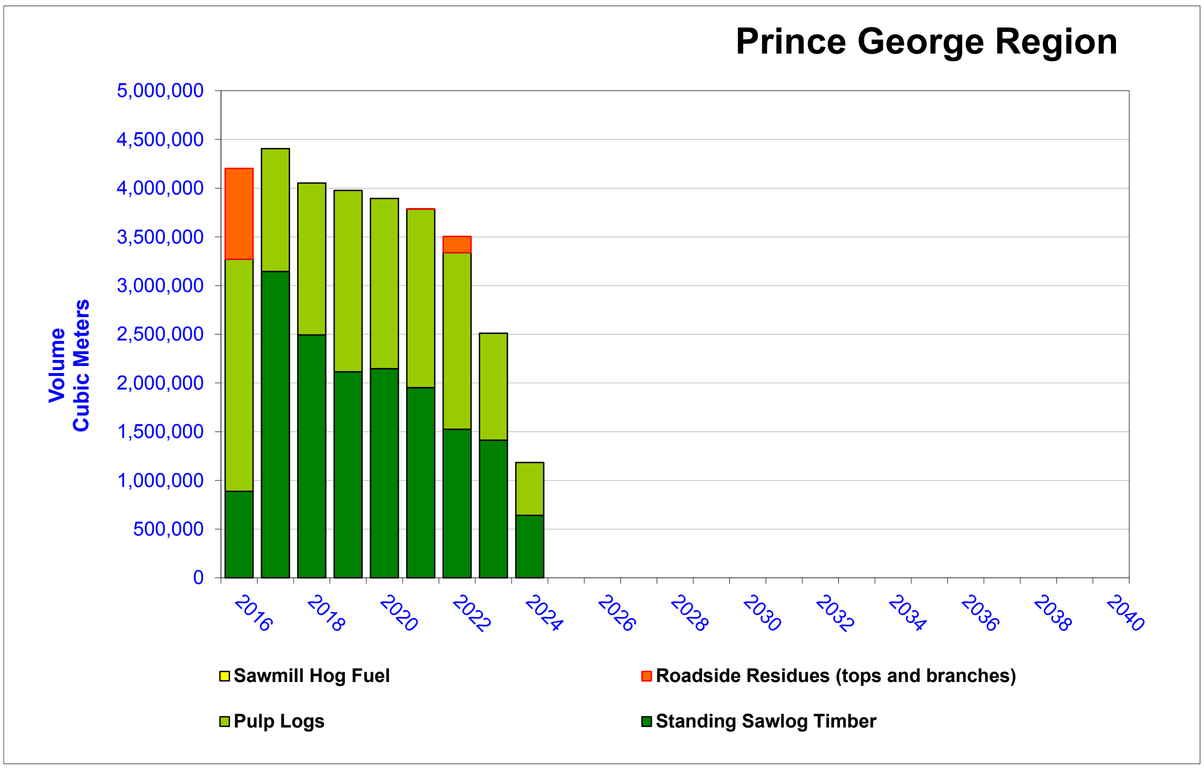
11.3 Demand for Residual Fibre

Given the size of the forest industry that exists within the region, there is significant demand for residual sawmill fibre to support power boilers, pellet plants and other mill energy systems. In the face of reduced sawmill activity forecast for the region with the corresponding decline in availability of residual fibre, all of these consumers will either resort to roadside residual fibre to meet their needs, harvest and grind pulp logs or potentially switch to alternative sources of energy (such as natural gas in some power boilers). By way of example, Canfor Pulp, which operates three pulp mills in Prince George, historically (i.e., pre-2007) acquired all of its chip supplies from sawmill residues. By 2017, 25 percent of their chip demand will need to come either from new sawmill sources, or from the salvage and chipping of pulp-logs.

11.4 Potential Fibre Sources for Energy

Figure 9 shows the forecast availability of biomass fibre by type over the planning horizon. For the next 9 years, standing timber and pulp logs are surplus to the existing industry's needs. After this time, roadside waste provides a very small long-term source of potential biomass fuel. Additional opportunities for bioenergy will have effectively ceased to exist.

Figure 9. Net Available biomass by Type – Prince George Region



11.5 Biomass Energy Potential

Table 12 summarizes the biomass potential for this region. Development of the Fort St James Green Energy biomass plant effectively consumes all biomass that was previously forecasted to be surplus in this region. Opportunities for new bioenergy capacity do not exist under the projected AAC for the region.

Table 12. Prince George Biomass Fuel Supply and Price Forecast

	Biomass Fuel Quantities and Costs	Forecast Years	
		2016 - 2025	2026 - 2040
Surplus Biomass Fuel (GWh per year)	Standing sawlog timber	925	0
	Pulp logs	102	0
	Road-side logging residues	0	0
	Sawmill hog fuel	0	0
	Estimated Sustainable Biomass Supply (GWh/yr)	**1,028**	**0**
Estimated Biomass Electricity Generation Cost	Biomass Generation Potential (megawatts)	117	0
	Estimated Delivered Cost of Biomass ($/m3)	$65	$0
	Estimated Delivered Cost of Biomass ($/megawatt-hr)	$114	$0
	Assumed Capital and Operating Cost ($/megawatt-hr)	$90	$90
	Total Estimated Energy Cost ($/megawatt-hour)	**$204**	**n/a**

12.0 Mackenzie

12.1 Forest and topography

Map 9 shows the location of the Mackenzie region in relation to the Province. The major topographic feature for the Region is the Williston Reservoir, which is bounded on either side by mountains with a preponderance of spruce and balsam on the slopes, and with pine on the flats and in the valley bottoms. The reservoir is critical in the transportation of fibre from the northern parts of the Region to the mills located in the southern end of the fibre supply area. Mountains and lake transport also add considerably to delivered fibre costs.

About 38 percent of the volume in the Region is Lodgepole pine, which comprises 117 million cubic metres. The MPB-epidemic in the Region peaked in 2009 and an estimated 71 million cubic metres have been killed to 2012. The epidemic is forecast to kill 75 million cubic metres.

The AAC for the Region was recently increased from 3.1 million to 5.1 million. The post MPB-epidemic AAC is forecast to return to 3.1 million cubic metres.

Map 9. Mackenzie Region

12.2 Existing Industry

The forest industry in the Mackenzie Region (4 sawmills and 2 pulp mills) collapsed during the period 2008 to 2010 due to a combination of financial difficulties and the availability of lower cost fibre in other regions of the Interior. At present, two sawmills and one pulp mill are operating. The second pulp mill was permanently shut. Canfor operates one sawmill, Conifex a second sawmill and Mackenzie Pulp (a division of Paper Excellence) operates the pulp mill. Conifex was awarded and electricity purchase agreement with BC Hydro and is using infrastructure at the shuttered pulp mill to construct a 36 MW power plant. That power plant is now operational.

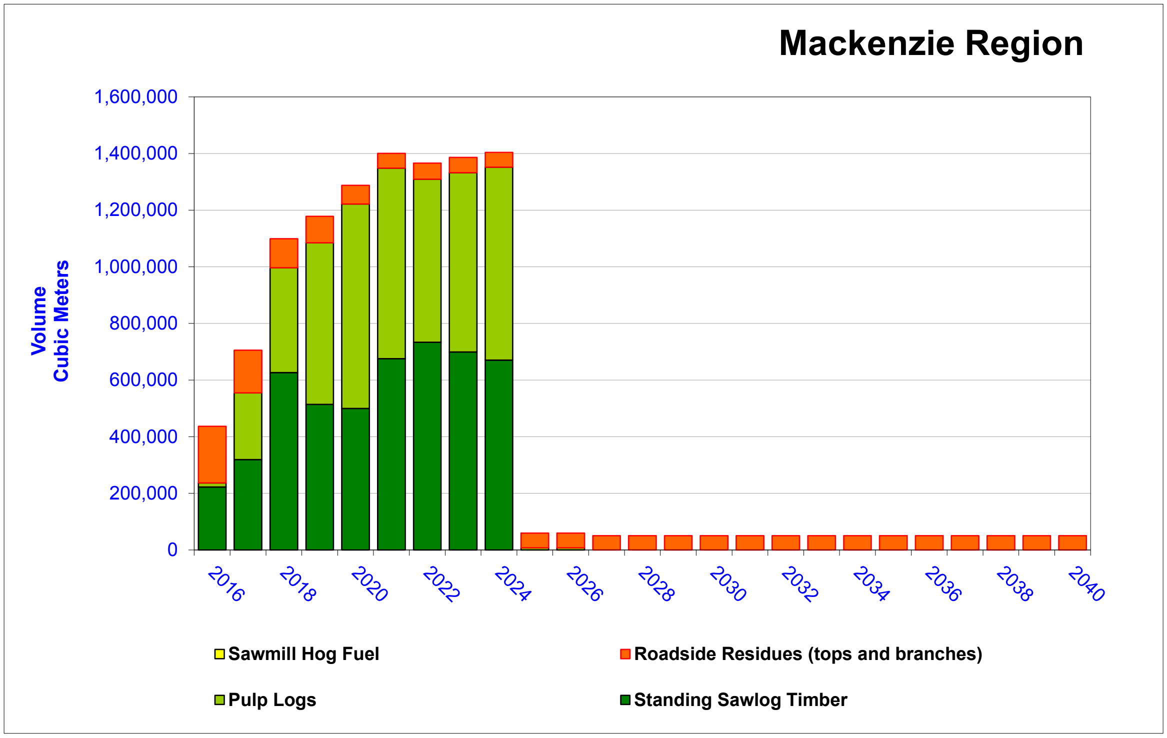
12.3 Demand for Residual Fibre

The Mackenzie Pulp mill is the last remaining pulp mill in BC to utilize sawdust and shavings for the production of pulp. It also utilizes the regional hog fuel produced at Canfor and Conifex and imports hog fuel from Chetwynd. The start-up of the Conifex biomass-fired power plant in 2015 should result in improved efficiencies with respect to the salvage of pulp logs, tops and branches currently incinerated in roadside piles upon completion of Conifex's logging operations in Mackenzie.

12.4 Potential Fibre Sources for Energy

Figure 10 shows the availability of biomass fibre over the planning horizon. The majority of the available fibre in the near term is standing timber that is not forecast to be harvested by the existing industry. The surplus pulp logs and standing timber is a result of the recent increase in the Mackenzie AAC, above the capacity of the existing regional forest industry. The increased AAC is expected to return to its pre-uplift level by 2025.

Figure 10. Net Available Biomass by Type – Mackenzie Region



12.5 Biomass Energy Potential

Table 13 quantifies the biomass potential for this region assuming an electrical generation facility is located in Mackenzie. Under the assumptions modeled, surplus biomass exists over a 20 year amortization period to support a 3 MW capacity power plant generating 29 GWh/year of electricity at a cost of $153 per MWh. This is in addition to the current demands of the industry and future demands of the Conifex power plant which commenced commercial operation in April 2015. The surplus standing timber available in the short-term is the result of a recent government AAC increase to support the salvage of MPB-killed timber. It is possible that this timber will support a short-term increase in sawmilling capacity at either the Conifex Mackenzie sawmill, Canfor Mackenzie sawmill or both.

Table 13. Mackenzie Biomass Fuel Supply and Price Forecast

	Biomass Fuel Quantities and Costs	Forecast Years	
		2016 - 2025	2026 - 2040
Surplus Biomass Fuel (GWh per year)	Standing sawlog timber	281	0
	Pulp logs	47	0
	Road-side logging residues	30	29
	Sawmill hog fuel	0	0
	Estimated Sustainable Biomass Supply (GWh/yr)	**358**	**29**
Estimated Biomass Electricity Generation Cost	Biomass Generation Potential (megawatts)	41	3
	Estimated Delivered Cost of Biomass ($/m3)	$57	$36
	Estimated Delivered Cost of Biomass ($/megawatt-hr)	$101	$63
	Assumed Capital and Operating Cost ($/megawatt-hr)	$90	$90
	Total Estimated Energy Cost ($/megawatt-hour)	**$191**	**$153**

13.0 Peace

13.1 Background Information

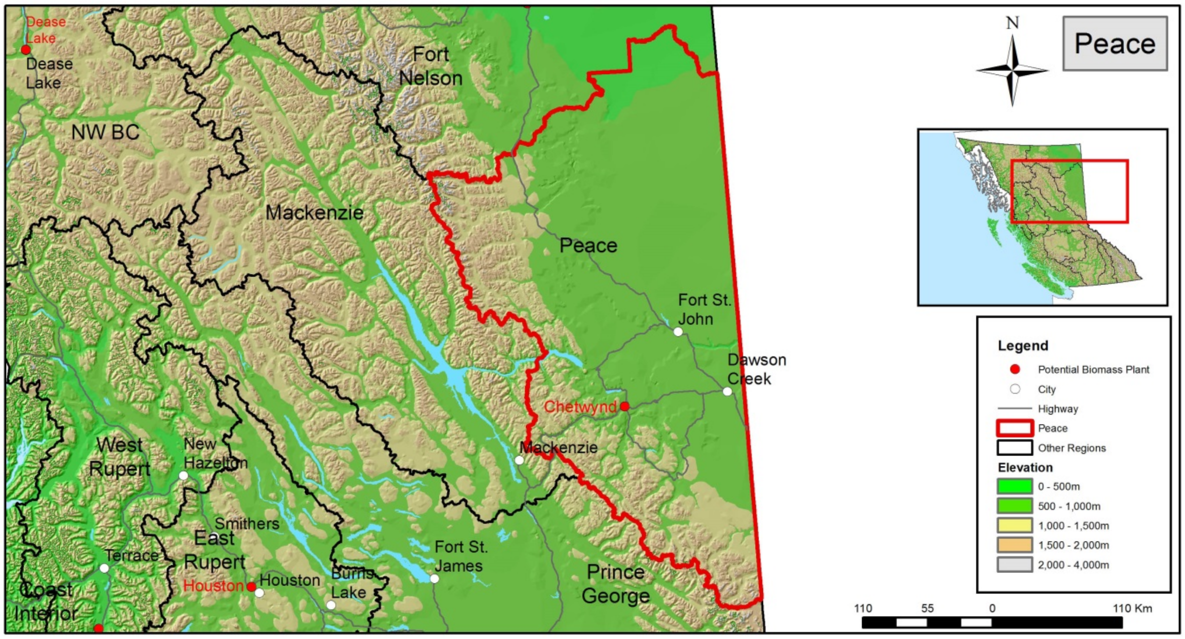
Map 10 shows the location of the Peace Region relative to the Province. The region is unique from the rest of the Interior in that deciduous species play an important role for the forest industry. It is also unique in its difficulty in maintaining a skilled labour force as a result of competing demands from the oil and gas industry. Forests in the region are predominately 35% spruce, 30% pine and 30% deciduous. The MPB-epidemic expanded into the Peace in about 2006 and the epidemic peaked in 2011. Currently, with an inventory volume of about 97 million cubic metres of lodgepole pine, roughly 28 million are dead. Over the long-term, 34 million cubic metres of pine are expected to be impacted by the MPB.

The forecast of biomass availability in this analysis targeted the coniferous rather than deciduous species. Aspen trees in the region are utilized extensively in the production of OSB and pulp. Manufacturing residues at these plants are utilized internally for energy.

Coniferous residues from Chetwynd area sawmills are still incinerated in beehive burners or shipped to Mackenzie. Coniferous residues at Fort St John sawmills are used internally for heat or are shipped to Alberta.

The AAC for the region is about 4.9 million cubic metres. The MPB-epidemic is not expected to have a significant impact on the future AAC.

Map 10. Peace Region



13.2 Existing Industry

The existing industry is comprised of three coniferous sawmills, two OSB plants and two BCTMP pulp mills. The Tembec BCTMP mill closed due to market-related issues in 2012. The mill has since been sold to Paper Excellence and a restart is expected in summer 2015. Canfor is the dominate licensee within the region operating two sawmills and one pulp mill. The pulp mill was recently sold to Canfor's subsidiary Canfor Pulp. Louisiana Pacific operates the two OSB plants in the region. West Fraser Timber operates one sawmill and is in the process of adding a 10MW energy plant to this sawmill. Announced in fall 2014, Canfor and Pacific Bioenergy have partnered to construct two new pellet plants adjacent to each of Canfor's sawmills in Chetwynd and Fort St John. These pellet plants should be operational in 2016.

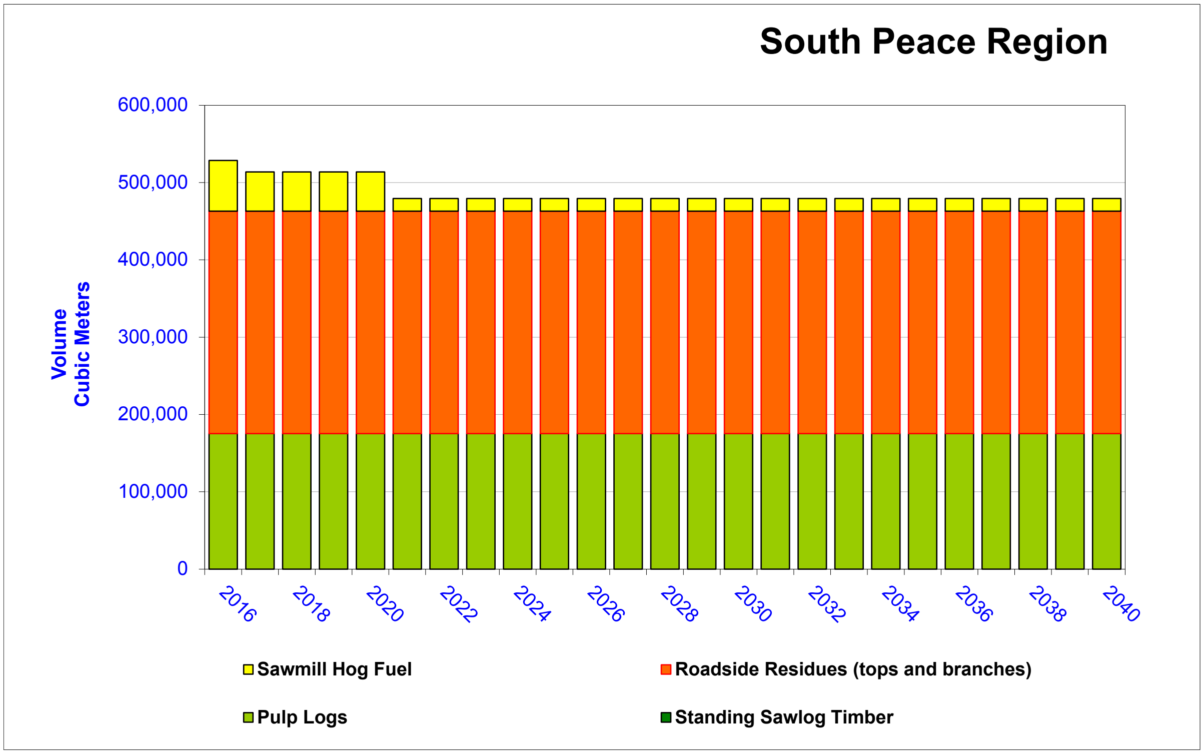
13.3 Demand for Residual Fibre

Completion of the West Fraser power plant and the two new pellet plants will remove surplus sawmill residues that currently exist in with the southern Peace Region. There is no regional demand for roadside logging residues.

13.4 Potential Fibre Sources for Energy

Figure 11 shows the availability of biomass fibre by type over the planning horizon given the assumptions made. A combination of standing timber, pulp logs, and roadside residue are forecast to be available over the future planning horizon.

Figure 11. Net Available Biomass by Type – Peace Region



13.5 Biomass Energy Potential

Table 14 summarizes the biomass potential for this region assuming an electrical generation facility is located in Chetwynd. Given the stability of the available biomass supply within this region, a maximum 31 MW capacity biomass power plant could generate 272 GWh of annual electricity at a forecast cost of $163/MWh over the 25-year planning horizon.

Table 14. Peace Biomass Fuel Supply and Price Forecast

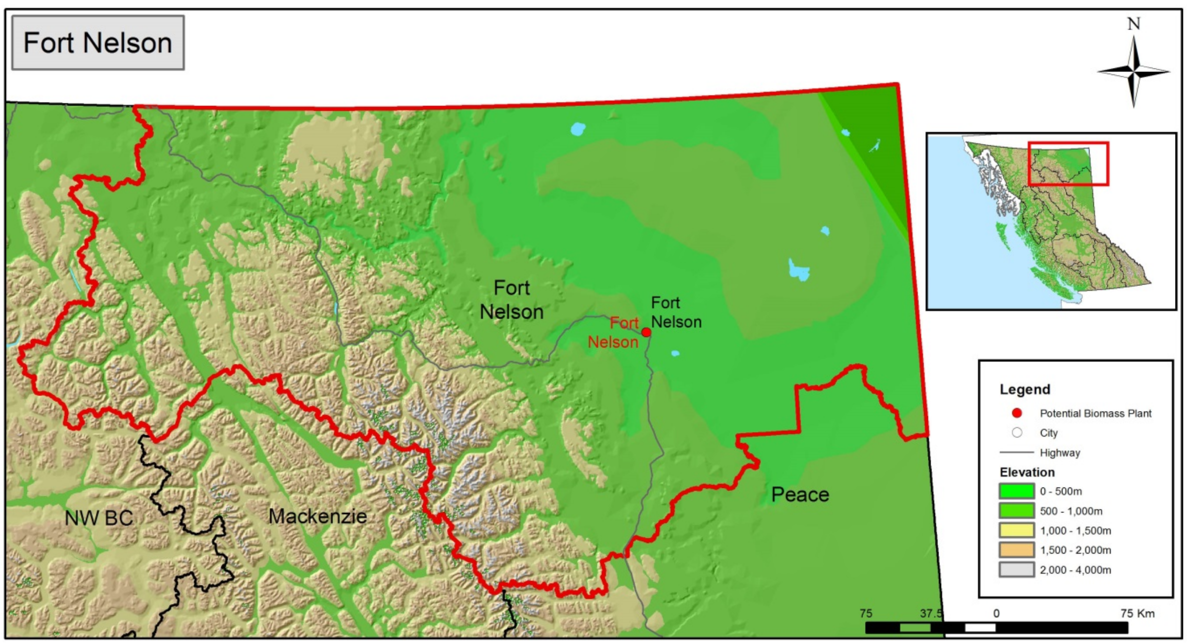
	Biomass Fuel Quantities and Costs	Forecast Years	
		2016 - 2025	2026 - 2040
Surplus Biomass Fuel (GWh per year)	Standing sawlog timber	0	0
	Pulp logs	99	99
	Road-side logging residues	163	163
	Sawmill hog fuel	9	9
	Estimated Sustainable Biomass Supply (GWh/yr)	**272**	**272**
Estimated Biomass Electricity Generation Cost	Biomass Generation Potential (megawatts)	31	31
	Estimated Delivered Cost of Biomass ($/m3)	$36	$41
	Estimated Delivered Cost of Biomass ($/megawatt-hr)	$64	$73
	Assumed Capital and Operating Cost ($/megawatt-hr)	$90	$90
	Total Estimated Energy Cost ($/megawatt-hour)	**$154**	**$163**

14.0 North-East BC (Fort Nelson)

14.1 Background Information

Map 11 shows the location of the north-east region of the Province. This region is coincident with the Fort Nelson Timber Supply Area and though predominately flat, is bisected by steep river valleys. The region is dense with marshes that create access difficulties and result in almost 90 percent of harvesting activities occurring in winter months. Large log inventories are therefore required to carry manufacturing operations through spring, summer and fall. Dominate tree species are spruce and aspen, which typically grow together in mixed-wood stands. This factor requires that any investments into the forest industry in this region have the ability to economically utilize both coniferous and deciduous tree species. Due to the lack of pine and the cold winters experienced in the region, the MPB-epidemic has not had a measurable impact on the Region. The current regional AAC is 1.6 million cubic metres.

Map 11. North East Region



14.2 Existing Industry

There is currently no active forest industry in the north-east Region. Canfor had two whole log manufacturing plants – a coniferous plywood plant and a deciduous OSB plant in Fort Nelson. Both are shut indefinitely in 2008. Canfor has retained its harvesting rights in the region.

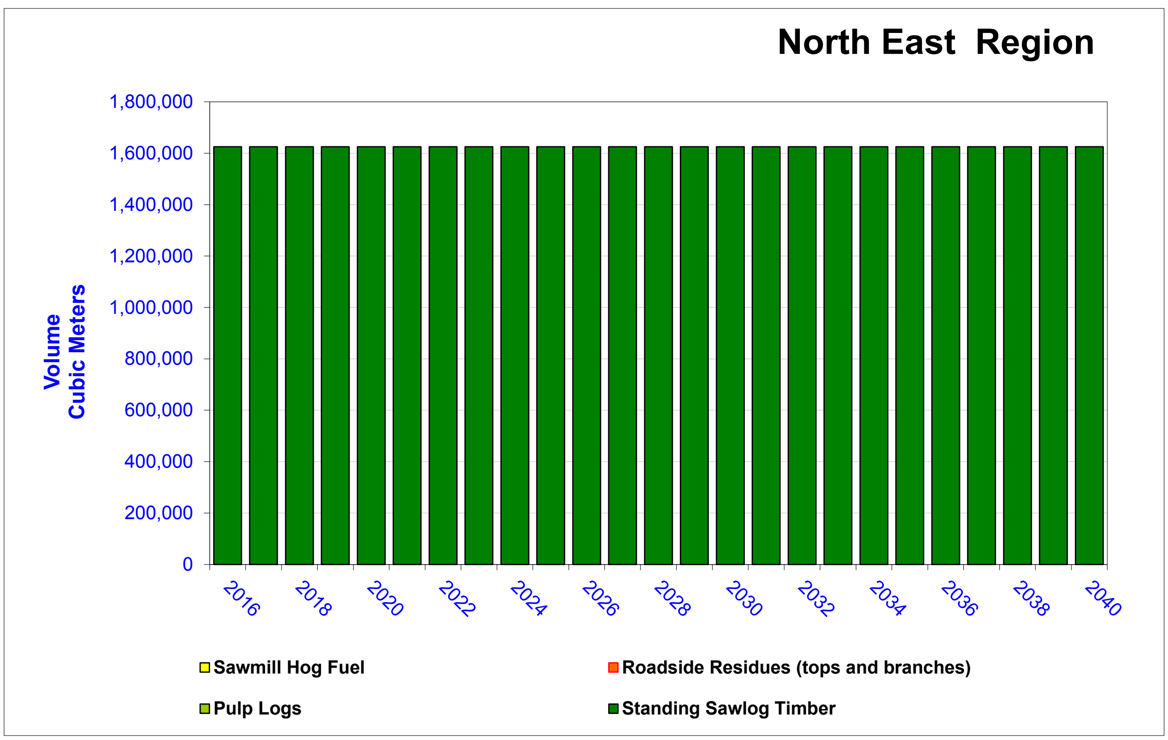
14.3 Demand for Residual Fibre

Since there is currently no industry operating in this region, there is no production or consumption of residual fibre. Although the demand for panels is growing significantly, North American production has been curtailed and will likely come on line prior to the Fort Nelson mills where the high cost of labour and logging makes the future uncertain. The forest industry here is not expected to recover until at least 2022.

14.4 Potential Fibre Sources for Energy

Figure 12 shows the availability of biomass fibre by type over the planning horizon. The lack of any operating forest industry in the region results in significant volumes of standing timber available to support biomass electrical generation over the entire planning period.

Figure 12. Net Available Biomass by Type – North East BC Region



14.5 Biomass Energy Potential

Table 15 summarizes the biomass electrical generation potential for this region assuming the electrical generation facility is located central to the available fibre supply in Fort Nelson. A maximum 105 MW capacity could generate 921 GWh/year of electricity at a forecast cost of $225/MWh over the entire planning horizon. All of this opportunity currently resides in the use of standing timber.

Table 15. North-East BC Biomass Fuel Supply and Price Forecast

	Biomass Fuel Quantities and Costs	Forecast Years	
		2016 - 2025	2026 - 2040
Surplus Biomass Fuel (GWh per year)	Standing sawlog timber	921	921
	Pulp logs	0	0
	Road-side logging residues	0	0
	Sawmill hog fuel	0	0
	Estimated Sustainable Biomass Supply (GWh/yr)	**921**	**921**
Estimated Biomass Electricity Generation Cost	Biomass Generation Potential (megawatts)	105	105
	Estimated Delivered Cost of Biomass ($/m3)	$76	$76
	Estimated Delivered Cost of Biomass ($/megawatt-hr)	$134	$134
	Assumed Capital and Operating Cost ($/megawatt-hr)	$90	$90
	Total Estimated Energy Cost ($/megawatt-hour)	**$225**	**$225**

15.0 East Rupert

15.1 Background information

Map 12 shows the location of the East Rupert Region relative to the Province. The eastern half of the region is relatively flat and heavily treed with pine. In the west, the Coastal foothills transition to mixed forests of pine, spruce and balsam fir. The region has about 141 million cubic metres of pine (comprising 54% of the forests), many of which were killed at the very start of the MPB-epidemic. The epidemic peaked in 2005 and by 2015 approximately 90 million cubic metres of pine have been killed. Another 1 million cubic metres of pine are forecast to die by 2024.

The AAC for the region is approximately 4.7 million cubic metres, down from 5.3 million cubic metres in 2014. This harvest is expected to complete its progressive decline to about 3.1 million cubic metres by 2027, as a result of the loss of merchantable pine trees.

Map 12. East Rupert Region

15.2 Existing Industry

The Region currently has operating three large sawmills, and two pellet plants. The Babine sawmill which was destroyed by fire in 2012 re-commenced operations in 2014. Shortly after the restart of this mill, West Fraser announced the permanent closure of its Houston sawmill. The NewPro particleboard plant in Smithers, which utilized sawmill residues, shut operations indefinitely in January 2014, citing poor market conditions.

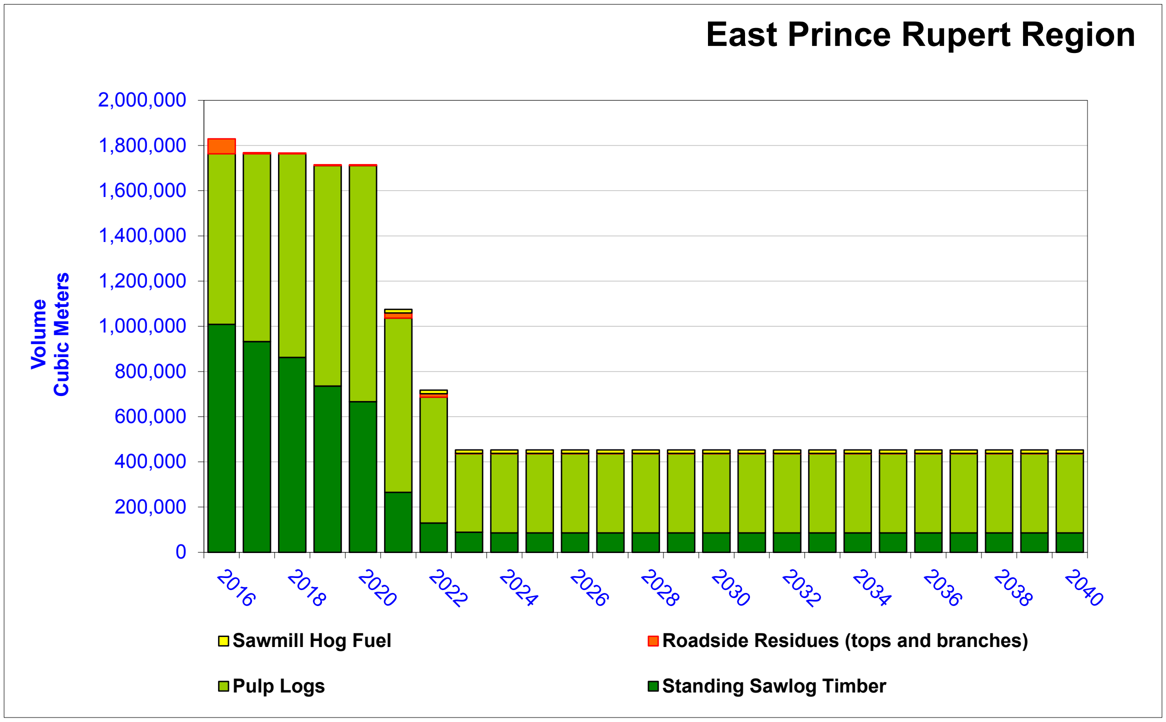
15.3 Demand for Residual Fibre

The closure of the NewPro board plant resulted in that fibre being transferred to the Pellet plant in Houston, as the closure of the West Fraser Houston sawmill resulted in a sudden shortfall in sawmill residues. Additional mill residues in the form of wood chips are transported to Prince George pulp mills. There is currently some demand for roadside residues and biologs as the Pinnacle pellet mill in Burns Lake was forced to develop a fibre basket using almost exclusively forest based fuels while the Babine sawmill was being rebuilt.

15.4 Potential Fibre Sources for Energy

Figure 13 shows the availability of biomass fibre by type over the planning horizon. Significant volumes of standing timber are available during the next 7 years as a result of AAC’s being higher than forecast industry demand. As the AAC is reduced and the industry aligns to the available log supply, this availability declines for the reminder of the planning horizon.

Figure 13. Net Available Biomass by Type – East Prince Rupert Region



15.5 Biomass Energy Potential

Table 16 summarizes the surplus biomass potential for this region assuming an electrical generation facility is located central to the available fibre supply in Houston. A 29 MW capacity biomass power plant could generate 257 GWh per year of electricity at a forecast cost of $195/MWh over a 20-year amortization period.

Table 16. East Rupert Biomass Fuel Supply and Price Forecast

	Biomass Fuel Quantities and Costs	Forecast Years	
		2016 - 2025	2026 - 2040
Surplus Biomass Fuel (GWh per year)	Standing sawlog timber	275	49
	Pulp logs	198	199
	Road-side logging residues	1	1
	Sawmill hog fuel	0	9
	Estimated Sustainable Biomass Supply (GWh/yr)	**474**	**257**
Estimated Biomass Electricity Generation Cost	Biomass Generation Potential (megawatts)	54	29
	Estimated Delivered Cost of Biomass ($/m3)	$55	$59
	Estimated Delivered Cost of Biomass ($/megawatt-hr)	$98	$105
	Assumed Capital and Operating Cost ($/megawatt-hr)	$90	$90
	Total Estimated Energy Cost ($/megawatt-hour)	**$188**	**$195**

16.0 West Prince Rupert

16.1 Background Information

Map 13 shows the location of the West Rupert Region relative to the Province. This Region is characterized by heavy rain falls and mild climate, resulting in some of the most productive growing sites in BC. Hemlock, balsam and cedar are the principle tree species in the region. The old-growth characteristics of existing stands have resulted in trees that are generally large, decay-ridden and are generally less desirable for lumber than interior spruce, pine or fir. Only six percent of the region is covered in pine trees and very little of this has been impacted by the MPB-epidemic. Although the epidemic has encroached on the area, it will not have a measurable impact on the long-term AAC. The current and forecast AAC for the region is about 3.2 million cubic metres.

Map 13. West Rupert Region

16.2 Existing Industry

The current industry is comprised of one operating sawmill. The sawmill in Terrace commenced operations under new ownership in 2012. There is currently no buyer or outlet for the sawmill's residual fibre and it is either stockpiled or land-filled.

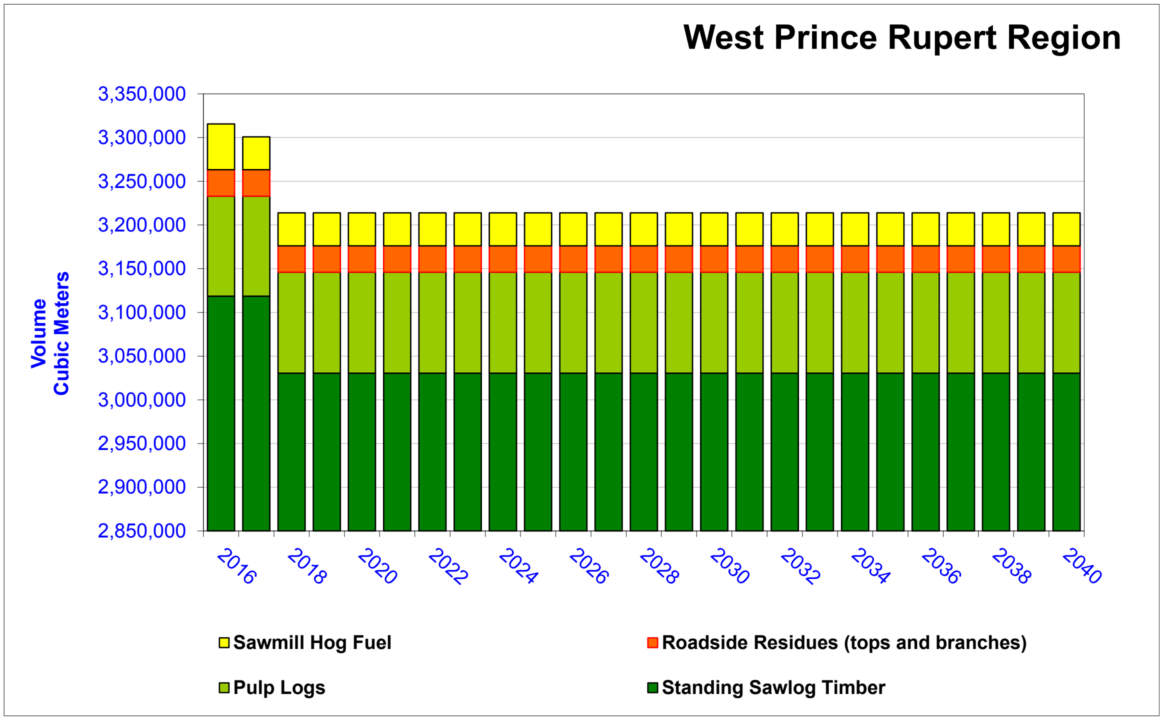
16.3 Demand for Residual Fibre

Following the 2010 closure of the Eurocan pulp mill, there has been no demand for residual fibre in this region.

16.4 Potential Fibre Sources for Energy

Figure 14 shows the availability of biomass fibre by type over the planning horizon, given the assumptions made. As can be seen, lack of a substantial operating forest industry in the region results in significant surplus volumes of standing timber being available to support biomass electrical generation.

Figure 14. Net Available Biomass by Type – West Rupert Region



16.5 Biomass Energy Potential

Table 17 summarizes the biomass potential for the region assuming an electrical generation facility is located in Kitimat. A 208 MW capacity biomass power plant could generate 1822 GWh of electricity annually at a forecast cost of $214/MWh over the entire planning horizon. Most of this opportunity rests in the utilization of standing timber.

Table 17. West Prince Rupert Biomass Fuel Supply and Price Forecast

	Biomass Fuel Quantities and Costs	Forecast Years	
		2016 - 2025	2026 - 2040
Surplus Biomass Fuel (GWh per year)	Standing sawlog timber	1,728	1,718
	Pulp logs	65	65
	Road-side logging residues	17	17
	Sawmill hog fuel	21	21
	Estimated Sustainable Biomass Supply (GWh/yr)	**1,831**	**1,822**
Estimated Biomass Electricity Generation Cost	Biomass Generation Potential (megawatts)	209	208
	Estimated Delivered Cost of Biomass ($/m3)	$69	$70
	Estimated Delivered Cost of Biomass ($/megawatt-hr)	$123	$124
	Assumed Capital and Operating Cost ($/megawatt-hr)	$90	$90
	Total Estimated Energy Cost ($/megawatt-hour)	**$213**	**$214**

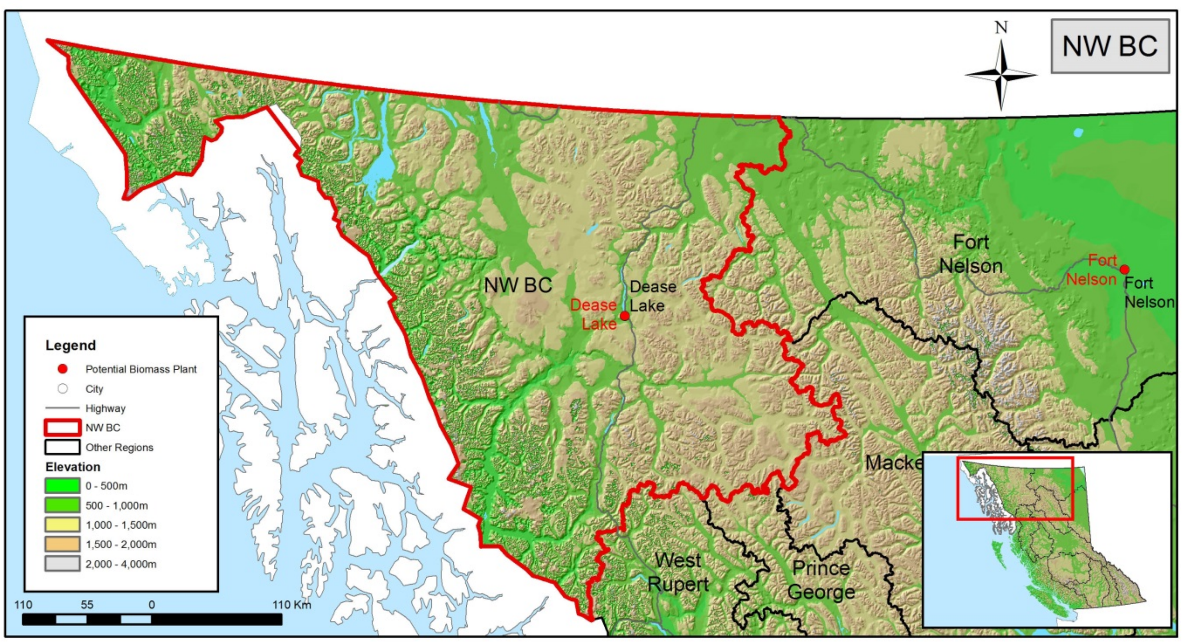
17.0 North-West BC

17.1 Forest and topography

Map 14 shows the location of the North-West Region of BC relative to the rest of the Province. This Region is coincident with the Cassier Timber Supply Area and covers over 15 million hectares. In the west, the region consists of rugged ice-capped mountains, dissected by several major river valleys. To the east, mountains and plateaus are separated by wide valleys and lowlands. Only about 25% of the region is forested – and this is generally located on steep slopes unsuited for forestry operations or is located on very poor growing sites. About 200,000 hectares is considered to support what is largely a very community-based logging industry. The mountain pine beetle has not yet had a measurable impact on the pine forests beyond a few spot infestations in the southern tip of the region.

The AAC for the region was 300,000 cubic metres and dropped to 196,000 cubic metres effective March 2015.

Map 14. North West Region



17.2 Existing Industry

Almost all of the harvested timber from the Region is exported out of the region for processing elsewhere. There are several small portable mills the periodically supply rough lumber to meet intermittent local demand.

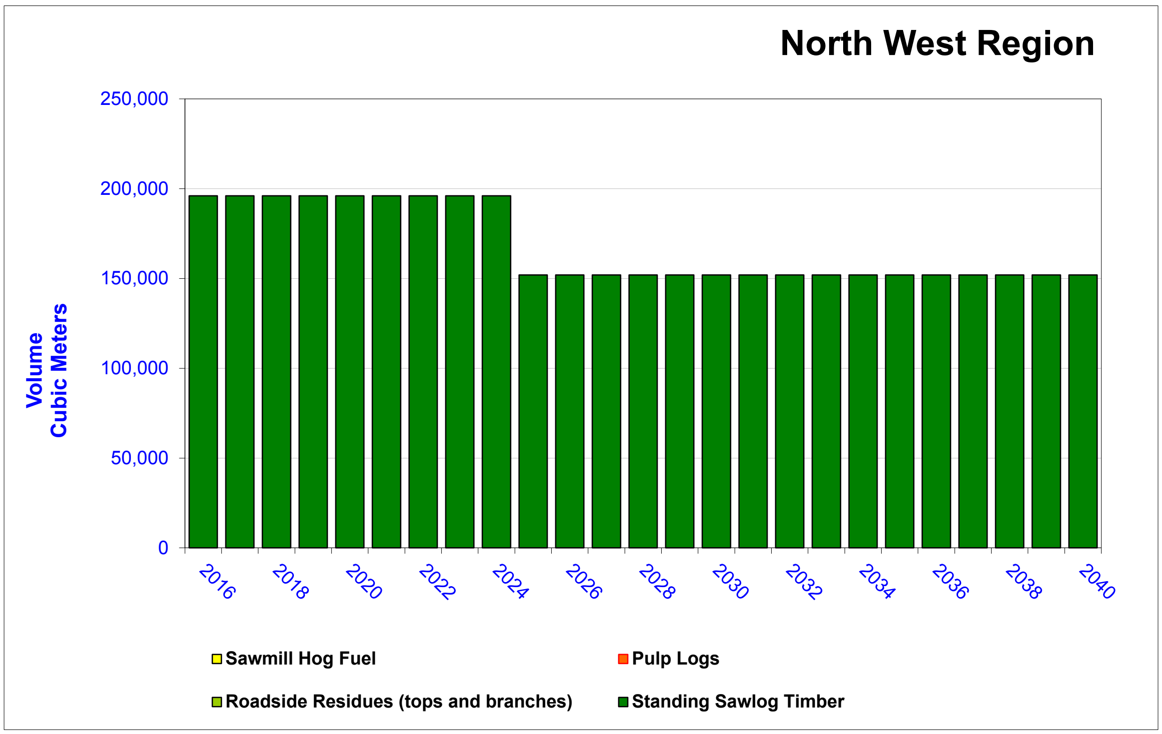
17.3 Demand for Residual Fibre

There is no production or consumption of residual fibre in this region

17.4 Potential Fibre Sources for Energy

Figure 15 shows the availability of surplus biomass fibre by type over the planning horizon, given the assumptions made. Lack of any commercial operating forest industry results in only standing timber being available to support biomass electrical generation.

Figure 15. Net Available Biomass by Type – North West BC Region



17.5 Biomass Energy Potential

Table 18 summarizes the biomass potential for this region assuming tan electrical generation facility is located central to the available fibre supply in Dease Lake. A 10 MW capacity biomass power plant could generate 86 GWh of annual energy at a forecast cost of $225/MWh over the entire planning horizon.

Table 18. North-west BC Biomass Fuel Supply and Price Forecast

	Biomass Fuel Quantities and Costs	Forecast Years	
		2016 - 2025	2026 - 2040
Surplus Biomass Fuel (GWh per year)	Standing sawlog timber	109	86
	Pulp logs	0	0
	Road-side logging residues	0	0
	Sawmill hog fuel	0	0
	Estimated Sustainable Biomass Supply (GWh/yr)	**109**	**86**
Estimated Biomass Electricity Generation Cost	Biomass Generation Potential (megawatts)	12	10
	Estimated Delivered Cost of Biomass ($/m3)	$76	$76
	Estimated Delivered Cost of Biomass ($/megawatt-hr)	$134	$134
	Assumed Capital and Operating Cost ($/megawatt-hr)	$90	$90
	Total Estimated Energy Cost ($/megawatt-hour)	**$225**	**$225**

18.0 Electrical Generation Capacity Sensitivity Assessment

This analysis was completed under an assumption that all biomass within the framework of the AAC and surplus to the needs of the existing forest industry is available for the generation of electrical power through some form of existing bioenergy processing technology. This assumption inherently includes large volumes of high-priced biomass fuel. Two sensitivity analyses were performed for each region to calculate the volume of available biomass fuel and its associated cost if all higher-cost standing timber and non-sawlog fibre (i.e. pulp logs surplus to the pulp and paper sector) were assumed not to be available for use in bio-electrical generation.

Table 19 provides a Regional and Provincial summary of the resultant biomass potential and cost, if: a) Standing sawlog timber was excluded from consideration for electricity generation; and b) All standing timber (sawlogs and pulp logs) were excluded from consideration for bioenergy generation.

Table 19. Sensitivity Analysis

Region	Scenario 2, Exclude Standing Sawtimber as fuel				Scenario 3, Exclude standing sawtimber and pulp logs as fuel			
	2016 - 2025		2026-2040		2016 - 2025		2026-2040	
	Potential Energy (GWh/year)	Cost of Energy ($/MWh)	Potential Energy (GWh/year)	Cost of Energy ($/MWh)	Potential Energy (GWh/year)	Cost of Energy ($/MWh)	Potential Energy (GWh/year)	Cost of Energy ($/MWh)
Coast Mainland	503	146	989,107	144	503	146	561	144
Coast Vancouver Island		145		143		145		143
East Kootenay	97	148	97	148	97	148	97	148
West Kootenay	395	131	407	130	395	131	407	130
Kamloops / Okanagan	0	n/a	0	n/a	0	n/a	0	n/a
Cariboo	17	142	17	142	17	142	17	142
Prince George	102	146	0	n/a	0	n/a	0	n/a
Mackenzie	77	153	29	153	30	153	29	153
South Peace	272	144	272	144	172	143	172	143
North-east	0	90	0	n/a	0	n/a	0	n/a
East Prince Rupert	199	146	208	144	1	146	9	113
West Prince Rupert	103	137	104	137	38	124	38	124
North-west	0	n/a	0	n/a	0	n/a	0	n/a
Total BC	**1,765**	**142**	**1,695**	**141**	**1,253**	**140**	**1,331**	**139**
Total BC Interior	**1,365**	**92**	**1,238**	**85**	**788**	**78**	**809**	**75**

As is apparent in Table 19, the provincial capability to produce electricity from surplus fibre is significantly reduced (62% over the long term) when standing timber is removed from consideration. Provincial capability decreases by 70 percent when both harvesting and salvage of sawlogs and pulp logs (i.e., scenario 3) is removed from consideration for biomass electrical generation.

18.1 Competing Internal Demands

It is impractical to assume that the annual harvest and consumption of all available timber and recovery of all available roadside biomass is feasible. As a result, caution was exercised when considering the utilization of these potential energy sources. Conservatism was applied to the calculation of available biomass fuel, recognizing that biomass fuel volumes will fluctuate over time, and an IPP must consider future short-falls in developing a fuel plan profile.

Not fully factored into this analysis is the uncertainty that sawmills in the BC Interior will consume more of their own residuals internally. They might do this to produce steam energy to dry lumber or veneer. Many log processing plants continue to use natural gas and propane for heat. About one-third of BC Interior mills currently use some portion of their residual steam in Konis-style, low pressure energy systems. Typically these mills use dry shavings from the lumber planing process; however some mills can use green sawdust and hog fuel. While use of residual fibre for this purpose is small, it may limit realization of some of the forecast volumes herein. We have offset some of this uncertainty through the assumption that several BC sawmills will capitalize on BC Hydro's demand side management program through electrical load displacement and the potential to integrate their sawmilling operations with power generation.

18.2 Lumber Re-manufacturing Plants

Lumber remanufacturing in the BC Interior is a relatively insignificant source of fibre given that the vast majority of Interior mills produce 100% dimension lumber for housing markets. In the US dimension-milling process, sawmills produce almost exclusively finished packages of lumber for rail shipment to the buyers in the mid and eastern US. Very little (less than 5%) of BC Interior mills sell lumber to remanufacturing operators who subsequently add value to the wood through additional milling to produce boards or molding. On the BC Coast, remanufacturing is more common because of the properties of cedar and hemlock species. In a typical coastal cedar sawmill up to half of the lumber shipped goes to remanufacturing plants for secondary milling into US siding and molding markets. A smaller, but significant, percentage of the coastal hemlock sawmills sell hemlock lumber to remanufacturers who produce door and molding stock for US and foreign markets. Currently the residual fibre output from the 40+ remanufacturing plants that remain on the BC Coast is used in greenhouses for power or growing medium, agriculture, animal bedding or end up in the pulp/paper mill hog fuel stream.

Appendix 1

Theoretical Biomass IPP Business Case

BC Hydro

Theoretical Biomass Independent Power Producer Business Case for Planning Purpose

JULY, 2015

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BC Hydro

Theoretical Biomass Independent Power Producer Business Case for planning purpose

1 Disclaimer

This business case is presented for discussion purposes only and should be considered speculative in nature. The development of this IPP business case is a means of considering how an Independent Power Producer (IPP) may 'think' when researching potential investments in a biomass-fired power plant producing electricity for the power grid.

The values assumed herein are theoretical in nature, but are based on reasonable operating assumptions and costs as seen within BC or as reported by industry participants.

This report was prepared for BC Hydro to demonstrate the influence of key variables considered in the calculation of unit energy costs for its long term Integrated Resource Planning (IRP) purpose. This report also provides recommendations on costs to assume for the purpose of the IRP.

The authors are not responsible for the use of the data and assumptions presented herein beyond that of the stated intent.

It is recommended to anyone planning to prepare a proposal for any Call for Power that they secure appropriate energy and fibre supply expertise rather than relying on the data and assumptions included herein.

BC Hydro

Theoretical Biomass IPP Business Case

2 Introduction

In order to support the ***Integrated Resource Planning*** process within BC Hydro, the following Theoretical Biomass Independent Power Producer (IPP) business case was prepared to provide perspective on the influence of biomass fuel types to electricity costs to BC Hydro. This report provides recommendations on the costs (unit energy costs) to assume for the purpose of the IRP.

The intent of this document is not to provide a business plan sufficient to support individual biomass electrical generation investment decisions, but rather, to demonstrate key variables that must be considered to evaluate the potential for a biomass electrical generation facility.

2.1 Overview of the Business Model Assumed

The unit energy costs for typical biomass power plants are influenced by conversion factors and key variables that are described in the following table. The values assumed herein are for discussion purposes only.

The authors do not suggest that these variables are specific to any one region or proposed plant, but rather that they are within a range of plausible values and as such are presented by way of example.

3 IPP Business Case Model

This Biomass IPP Business Case Model is a simplified version of those typically used to develop formal business plans in support of investment decisions. It reflects the basic data used in the derivation of unit energy cost and is presented as an information source. Exhibit 1 depicts the Model assumed and the variables that form the basis of the descriptions below.

Exhibit 4. Sample IPP Biomass Business Model

Assumptions for a 35 megawatt Biomass-Fueled Power Plant			
Wood Consumption per megawatt hour	**0.72**	Oven Dry Tonnes per megawatt hour	
Installed Capacity	**35**	megawatts	
Net Saleable Capacity (assume 92% of Gross)	**32.2**	megawatts	
Capacity Factor	**91%**		
Saleable Average Annual Energy (MWh)	256,686	megawatt hours	
Annual Wood consumption	200,884	Oven Dry Tonnes per year	
	492,167	Cubic metres per year	
Investment Cost			
Development Cost ($/megawatt)	**$5,000,000**		
Project Lead and Construction Time	4	Years	
Discount Rate	**7%**	Real Term	
Fixed Operating, Maintenance and Administration Costs	120	$ per kilowatt per year	
Variable Operating, Maintenance and Administration Costs	7	$ per megawatt hour	
Capital Cost Spending Profile			
Year 1	$5,359,563		2.5%
Year 2	$5,008,938		2.5%
Year 3	$84,262,500		45.0%
Year 4	$87,500,000		50.0%
Total Adjusted Development Cost	$182,131,001		
Amortization			
Amortization Period	**20**	years	
Annualized Capital	$17,191,878		
Amortized Cost of Plant (over saleable hours)	**$67**	**per megawatt hour**	
Fuel (wood fibre) Cost	$45	per cubic metre	
Volume to Weight Conversion	2.45	cubic metres per Oven Dry Tonne	
Total Fuel Cost	$110	per Oven Dry Tonne	
Wood Cost per megawatt hour	**$79**	**per megawatt hour**	
Operating Cost			
Annual operating and maintenance cost	$5,996,799		
Operating cost per megawatt hour	**$23**	**per megawatt hour**	
Total Unit Energy Cost	**$170**	**per megawatt hour**	

4 Variable Descriptions and Assumptions

The Biomass IPP business model is discussed with a description of the variables and an overview of considerations required when considering the variable and associated Model outcomes.

4.1 Wood Consumption per Megawatt Hour

It is assumed that in a traditional wood-fired electrical generation facility that 0.72 oven-dry tonnes of wood fibre are required to generate one-megawatt hour of electricity.

It is further assumed that 2.45 cubic metres (solid wood equivalent) of wood fibre are required to make an oven-dry tonne (ODT) of biomass fuel. This conversion factor is based on consideration for the specific gravity of the average tree species harvested within BC, and the assumption that bark (having a relatively lower specific gravity) would provide only a small percent of the feedstock for a new power plant.[6]

In most cases within the current biomass consumption industry in British Columbia (pulp mills, bioenergy plants, pellet plants), wood fibre when delivered to a power plant is measured and paid for using “green” weight. The reason forest industry users do not use “dry” weight as the basis for payment is that the cost of collecting and testing wood samples from each supply source is not considered cost-effective given the current value (price paid) for hog fuel and roadside residual biomass fuel sources. Biomass consumers typically measure supplier-delivered wood-fibre randomly, in order to establish green-weight to dry-weight conversion factors that are then used to negotiate delivered biomass costs.

To demonstrate the relationship between logs and biomass, a dry weight conversion is assumed herein, consistent with conversions used for the transaction of higher-value wood chips.

[6] Sources for the Specific Gravity of wood include:

1) Miles P.D., W.B. Smith Specific Gravity and Other Properties of Wood and Bark for 156 Tree Species found in North American. www.nrs.fs.fed.us/pubs/rn/rn_nrs38.pdf
2) Ung, C.-H., Bernier, P., Guo, X.-J. 2008. Canadian national biomass equations: new parameter estimates that include British Columbia data. Can. J. For. Res. 38: 1123-1132.
3) Standish, J.T., Manning, G.H. and Demaerschalk, J.P. 1985. Development of biomass equations for British Columbia tree species. Information report BC-X-264. Pacific Forest Research Center. 48 p.
4) Nielson, R.W., Dobie, J. and Wright, D.M. 1985. Conversion factors for the forest products industry in Western Canada. Special publication No. SP-24R

Sawmill owners purchase and/or acquire (harvest) wood on a per cubic metre basis. When it is hauled to the mill, it exists in a green or natural form and each cubic metre is made up of wood and water in varying proportions. The amount of water in each cubic metre depends on the species, the time of year and in the case of BC Interior pine, the length of time the tree has been dead.

"Green" wood typically has about 45-50% water. Dead pine can have as little as 13% water. "Oven-dry" wood is bone dry wood that contains no water (0%).

As a result, a cubic metre of green wood in any form (e.g., log, chip, sawdust or hog fuel) will have a different weight when it is transported than a cubic metre of wood that has been dead for some time. However, regardless of the weight (including water) of each cubic metre of wood, it is always a cubic metre on a volumetric basis.

By way of example, consider a pile of logs that have been purchased or harvested and paid for on a per cubic metre basis, and that currently exists as biomass inventory in a sawmill yard. A sawmill owner may wish to sell some of these logs to a biomass generating power plant, but the purchaser wants the wood delivered by truck as hog fuel which is either ground up or chipped.

One cubic metre of pine log, chipped (or ground up), is still have one cubic metre of wood, it is just in a new form called hog fuel and it is now in a container truck.

Once the hog fuel is in a truck, assuming not every cubic metre of log going into the grinder was measured, the volume must somehow be quantified. The simplest way to quantify hog fuel is by weight. However, if some of the logs were green and some had been dead for many years, the amount of water in each cubic metre of log is inconsistent. This is why the derivation of the relationship between wood weight (ODT's) and volume (cubic metres) is so important to a biomass consumer.

What is known is that oven-dry pine (bone-dry pine) weighs 409 kilograms per cubic metre.[7] This is a very consistent relationship within nature. It is defined as the bulk density of pine. Each softwood or hardwood species has its own unique bulk density. Dense woods such as oak, have a higher bulk density (a cubic metre of oak weighs more than pine if both are compared on an oven-dry basis).

One tonne of wood of any species, however, weighs 1000 kilograms.

[7] Nielson, R.W., Dobie, J. and Wright, D.M. 1985. Conversion factors for the forest products industry in Western Canada. Special publication No. SP-24R

Since each species has its own unique bulk density (pounds per cubic metre), it takes a different number of cubic metres of each species to make up an oven-dry tonne of that species. For example, an oven-dry tonne of lodgepole pine requires 2.44 cubic metres (1000kg/409kg = 2.44).

When chipped-up logs are in a truck, the actual weight of the wood will depend on the amount of water that saturated each log that was chipped. Some logs will have lots of water, others will have little. To convert all the green wood (of varying weights as a result of their water content and of uncertain volume) to a number which forms the same basis for transaction or sale purposes, the green weight of the wood must be converted to the oven-dry weight of the wood, based upon a sample. The transaction resulting in the sale of wood then takes place on an "oven-dry" basis, since the relationship between weight and volume for oven-dry wood is constant.

To determine the samples conversion, a truck is weigh-scaled both full of hog fuel and then empty to verify the tonnes of wet hog fuel in the truck. A sample of hog fuel, representative of all the hog in the truck, is then weighed separately. This sample of hog is then put in a hot oven for 24 hours to dry and then re-weighed. At this point, the hog fuel sample is assumed to be oven-dry and contains only wood – no water. The ratio of the "oven dry" weight to the original "green" weight of the sample is considered the oven dry percentage, or in layman's terms, it represents the weight of wood only in the green hog fuel. This ratio is then multiplied by the net weight of green hog fuel in the truck and the oven-dry tonnes of hog fuel results.

Math for a simple example:

- Truck weight (tare) = 45 tonnes
- Truck full of green pine hog fuel = 95 tonnes
- Net weight of green pine hog fuel = 50 tonnes
- Sample of green pine hog fuel = 1 kilogram
- Oven dry sample = 0.5 kg (i.e. 0.5 kgs of water)
- Oven Dry % = 50%
- Oven-dry tonnes of hog fuel = 50 tonnes × 50% = 25 tonnes
- 25 tonnes × 1000 kg per tonne = 25,000 kg of dry hog fuel
- Since the specific gravity of pine is 409 kg per cubic metre, then:
  25,000 ÷ 409 = 61.12 cubic metres of hog fuel
  The green weight (what is hauled and delivered) = 50 tonnes. What is purchased is the calculated dry weight of 25 tonnes.

Regardless if discussing green or dry wood weight, the 61 cubic metres of hog fuel in the truck is constant, *in this example*.

Some transactions of residual fibre (such as planner shavings or sawdust) are sold on a "green" basis, but in these cases the buyer and the seller must agree on the moisture content of the fibre being sold, since it is always sold based upon weight. In places where trees are very uniform in moisture content, the conversion to ODT's is usually agreed upon in advance and only checked sporadically. When live and dead pine logs are mixed together to form the biomass supply stream, the only reliable way to ensure a consistent measurement of the volume of wood sold is to calculate the oven-dry weight of the wood sold via sampling.

The relationship is also applied when utilizing roadside residues. The volume of fibre is typically not measured for its cubic metre input prior to grinding. However, because of the relationship between weight and volume, a biomass sample can be measured to determine the oven-dry percent and back-calculated to derive the cubic metre volume equivalent that was used to make the truck full of roadside residues.

In the foregoing example, a single tree species conversion was assumed for simplicity. In many parts of BC, the fibre supply for a bioenergy plant would likely include a mixture of pine, spruce, balsam, hardwoods, Douglas fir and varying amounts of bark from each species. The actual conversion would be based upon the species being consumed. In this instance, the bulk densities of each species and the proportion of each species expected in the fibre supply would be calculated and substituted for our assumed 2.45 cubic metres per oven-dry tonne average for the province.

4.2 Installed Capacity

This variable reflects the gross electrical capacity assumed to be generated within the proposed plant. The gross capacity is reduced to net, as some power is consumed within the plant itself to power auxiliary equipment such as pumps, motors and pollution control devices.

For purposes of the calculations presented herein, a 35 megawatt plant is capable of producing a maximum of 256,686 megawatt hours of saleable electricity annually (operating with a 91% capacity factor).

The 35 megawatt capacity was selected because it represents a plant large enough to take advantage of most economies of scale and secondly that it represents a plant with a fibre requirement that could be sourced within many regions of the province. As plant sizes increase, plant operating efficiencies may decrease, however the saving may be offset with an increased cost to deliver fuel over a wider range of forest area.

4.3 Saleable Average Energy (Capacity factor)

In order to forecast the amount of electricity that is actually produced (and can be sold) from the power plant, the gross number is reduced for planning and financial purposes to account for operational inefficiencies (i.e., routine maintenance, fuel scheduling, and equipment failures) that prevent the plant from running continuously. Capacity factor is therefore the ratio of delivered annual energy to maximum annual energy if the plant was run flat out at maximum output. Capacity factors may vary from as low as 83 percent to as high as 96 percent. In this hypothetical business case a 91 percent capacity factor was assumed. Saleable energy is therefore the *net* plant size (MW) multiplied by 24 hours per day and 365 days per year and the capacity factor.

4.4 Annual Wood Consumption

The total volume of wood fibre required to support a plant is derived from the assumed plant size and electricity production (in megawatt hours).

For the purposes of the 35 megawatt plant assumed in this example, the plant would require 200,884 oven-dry tonnes of wood fibre (or 492,000 cubic metres (solid wood equivalent)) annually to operate the plant over the course of one year. This is based upon 35MW gross capacity operating at a 91% capacity factor per year and requiring 0.72 ODT per MWh.

4.5 Investment Cost

The cost to purchase equipment and to build a suitably-sized biomass generation facility is included in this cost estimate.

While costs are not directly related to the size of the plant being considered, for the purposes of the report presented herein, it was assumed that the capital cost of a biomass generating plant would be approximately $5,000,000 per megawatt installed. This cost would undoubtedly vary depending on the technology adopted (e.g., stoker boiler, fluidized bed boiler, fixed bed gasifier etc.).

For the 35 megawatt plant assumed herein, an unadjusted capital cost of $175,000,000 was assumed. However, project development typically takes 1 to 2 years of preparatory work (after the award of an EPA), prior to commencement of a two year construction period. Factoring two years of planning and two years of construction into the project (using a discount rate of 7%) results in an adjusted development cost of $5,204,000 per megawatt or $182,131,000 for the project.[8]

4.6 Amortization Period

Amortization of the capital cost of the plant (and in doing so allowing the investor to recuperate the investment as the plant operates) is done by assuming the planning horizon over which the initial investment is paid off. Typically, this also suggests that the plant and equipment will operate over that time frame.

For purposes of this report, an amortization period of 20 years was assumed because this is consistent with the maximum term that the BC Ministry of Forests, Lands and Natural Resource Operations is willing to award a forest licence to produce bioenergy under Sections 13.1 and 14 of the British Columbia Forest Act. Furthermore, longer term amortization periods, while reducing the cost of energy, result in increased risk and uncertainty around fuel supply.

It should be noted that the amortization period for bioenergy projects in particular would be influenced by fibre availability. Any new projects trying to take advantage of near term fibre availability perceived to exist as a result of the BC mountain pine beetle epidemic may be subject to a progressive decline in fuel availability over the next 10 years. Hence a shorter amortization period may be more appropriate, but this will result in a higher unit energy cost. For instance, for a 10 year amortization period, a project cost (before accounting for delivered fibre cost) would increase from $90/MWh to $124/MWh if all other assumptions stay the same.

4.7 Fuel (Wood Fibre) Cost

The fuel wood supply assumed to support a proposed biomass electrical generation facility is quite possibly one of the most important, but difficult to forecast variables in the business plan.

The following fibre types could potentially be accessed to support a proposed plant:

- **Sawmill Residues** including wood chips, sawdust, shavings, and hog fuel.
- **Roadside waste** includes tree tops, branches and other non-sawlog material derived during logging operations.

[8] Assuming a capital spending profile of 2.5% in year 1, 2.5% (year 2), 45% (year 3) and 50% (year 4).

- **Pulp logs** include the portion of standing timber that when harvested that does not meet the quality grade required to produce lumber. Pulp logs, in the context of this report, are a byproduct created from the harvest of sawlogs. Surplus pulp logs shown in the analysis are logs, or portions of logs, that would normally be delivered to a pulp mill, if the demand existed.

- **Standing Timber** includes forests that are not harvested for either pulpwood or sawlogs and for which there is no current economic demand.

When considering the fibre supply for a proposed plant, a number of factors will impact availability and cost, as follows:

Sawmill Residues

Access to sawmill residual fibre including wood chips, sawdust, shavings, and hog fuel, is invariably done through business-to-business relationships between an IPP and a sawmill owner.

Today, a significant proportion of sawmill residues in each region of the Province is already committed to existing pulp, paper, board and pellet plant operations or used internally by the producing mill for their own energy production.

There are a variety of purchase and sale contract types covering sawmill residues. Some sawmill residual fibre is tied up in virtual perpetuity, some is tied in long-term renewable contracts and some is sold in the “spot market”.

Each of these fibre types are transacted based upon average regional prices that are impacted by a number of factors such as supply and demand, end use pricing (residual chips are often priced based upon the price of Northern Bleached softwood Kraft pulp). Once a purchase price is set, organizing transportation logistics and cost to deliver the fibre from the supplier mill to the consuming mill is typically the responsibility of the buyer. These logistic costs are basically limited to transportation distance, road speeds, hauling cycle times and the price for diesel fuel. On the rare occasion that trucks can be utilized to back-haul a different fibre type, costs are reduced.

The observation was made to BC Hydro by its bioenergy stakeholder group that any new bioenergy plant located in areas having an existing demand for sawmill residues would significantly increase the current cost of sawmill residues. In consideration for this observation, the regional cost of sawmill residues assumed in this report were doubled from that currently experienced by the existing bioenergy industry, to reflect increased competition.

Roadside Residues

Roadside residues include tree tops (crowns), branches, and other non-sawlog material that has been harvested, but not transported to a consuming mill. Roadside logging residues typically accumulate along forest roads where sawlogs and pulp logs are loaded onto logging trucks.

Access to this fibre is typically accomplished through a cooperative agreement with tenure holders who initially harvested these sites.

The process of accessing this fibre includes:

- Mobilization of appropriate equipment including grapple excavator and grinder to the site
- Mobilization of trucks capable of being loaded and more importantly, unloaded at the receiving mill
- Picking up and grinding the residual roadside fibre into a size and form suitable for use within the plant
- Hauling the biomass material to the receiving plant

Today, roadside residues are accessed to supplement fibre supplies for mills that traditionally used sawmill residues as their primary fibre source. This has occurred at a time when reduced sawmill activity has created sawmill fibre supply shortfalls.

The cost of roadside residues is very sensitive to haul distance. Once again, further to discussion with a BC Hydro bioenergy stakeholder group, we increased the average travel radius from 100km to 150km to account for the increased distance a new IPP would be subjected to in areas where competition for roadside residues may already exist.

Pulp logs and Standing Timber

Since the majority of BC forests exist on Crown land, standing timber and/or pulp logs acquired during a sawlog harvest can be accessed in one of two ways:

1. Purchase of logs from an existing tenure holder who holds a right to harvest, or
2. Acquisition of tenure from the Crown that allows an IPP to harvest a given volume of timber on their own.

In either case, standing timber is likely the highest cost fibre type available to the IPP because the cost of the timber includes the additional costs of:

- Finding suitable forest.
- Developing the appropriate cutting permits and licences to harvest.
- Paying the Crown a stumpage fee – the cost of which varies based upon the quality of the wood.
- Surveying, marking and measuring the trees.
- Locating and developing roads and bridges to the site.
- Harvesting the trees – the cost of which varies based upon the size and density of the trees.
- Processing and loading the logs onto logging trucks.
- Delivering the logs – the cost of which varies based on travel distance and road speeds.
- Rehabilitating the harvested area by planting new trees – the cost of which may vary based upon the quality of the growing site and the amount of brush competition that can inhibit the re-establishment of a commercial tree species.
- Surveying the harvested area to ensure that a suitably stocked plantation establishes itself over the ensuing 10-20 year period.

In past versions of this report, we assigned a cost for surplus pulp logs to be consistent with roadside residues. This assumption however was not the practice that has evolved in the BC interior. Major forest licensees would rather burn pulp logs at road side, than provide them to a biomass consumer at anything less than a fair market value. Fair market value today is approximately 75 percent of the average regional delivered sawlog cost (excluding stumpage).

The volume of each type of biomass fuel that goes towards developing a fuel profile will vary for each business plan and may vary on an annual basis. Exhibit 2 illustrates a possible distribution of fuel types assumed to be consumed in the example presented herein. The resultant fuel profile has an average fibre cost of approximately $45 per oven-dry tonne.

The depicted fibre costs are typical of BC Interior operations and the assumed fuel distribution results in an average delivered fuel cost of $79 per megawatt hour.

Exhibit 5. Fibre Cost Estimator

		Dry Shavings	Sawdust	Roadside Residue	Hog Fuel	Standing Timber	Total / Average
Fibre Supply by Source	% Supply	5%	5%	35%	5%	50%	100%
Regional Fibre Cost	($/ODT)	$35	$20	$5	$5	$113	$61.25
Average Delivery Cost	($/ODT)	$10	$10	$50	$10	$60	$49.00
Total Delivered Fibre Cost	**($/ODT)**	$45	$30	$55	$15	$173	**$110.25**
Total Delivered Fibre Cost	($/m3)	$18	$12	$22	$6	$71	**$45.00**

4.8 Operating, Maintenance and Administration Costs (fixed and variable)

These cost items are intended to include all expenses related to:

- Manpower,
- Operating costs including fuels (other than wood fibre delivered and conversion costs),
- Maintenance costs (other than capital replacement),
- Related “day-to-day” costs.

BC Hydro’s consultation with industry stakeholders revealed that while some of these annual costs can be directly related to plant capacity size, other portions of the operating costs are fixed – regardless of plant size. Further consultation with AMEC Foster Wheeler Engineering Consultants identified generically that the fixed and variable portions of these costs can be attributed to a rate of $120/kW-annum of installed capacity, plus $7/MWhr of saleable energy.

For simplification, annual operating cost for a 35MW plant equates to about 3.3% of the project development cost.

4.9 Unit Energy Cost

Unit Energy Cost (at gate) is divided into two components – the cost of project and the cost of delivered fuel. In this hypothetical business case the resultant cost of project is $90 per megawatt hour. This value was utilized in support of the report describing the Biomass Energy Potential in BC in 2015 “Wood Biomass Energy Potential of British Columbia”. The cost can vary considerably with modification to the assumptions described herein.

Fuel cost varies throughout the Province based on available profile, regional fibre demand, transportation distances and delivery methods.

The Unit Energy Cost is the summation of the cost of project and delivered fuel cost. In this business case, Unit Energy Cost is estimated at $170 per megawatt hour assuming 7% real and the hypothetical fuel profile depicted in Exhibit 2.