Current inventory and modelling of sawmill residues in Eastern Canada

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ABSTRACT

Integration within the forest industry in Canada historically developed to optimize use of the available timber resource. Sawmill residues, which were at one time considered waste, changed into a sought-after resource for panel and pulp manufactures. With the downturn in the Canadian forest industry and the 46.5% decrease in nationwide sawn lumber production between 2004 and 2009, the potential for utilizing sawmill residues to develop novel markets presents itself with added encouragement from national and global pressures towards creating a sustainable bio-based economy. Scarcity of information related to quantity and quality of local sawmill residue feedstocks leads to a lack of reliable data that can be used by entrepreneurs to develop sustainable supply chains for this resource. The development of an easily updateable sawmill database for all provinces, Manitoba eastwards, is explained in detail along with the comprehensive presentation of a sawmill residue output calculation model for sawdust, bark, chips/slabs, and shavings. These tools will help to predict current and future sawmill residue availability and aid in the most efficient uses of this resource in the bioeconomy.

Key words: sawmills, residues, model, database, predict, bioenergy, biomass, forestry, market, economy, Eastern Canada, sustainable supply chain

RÉSUMÉ

Historiquement l'intégration de l'industrie de forestière au Canada, s'est faite dans le but d'optimiser l'utilisation des ressources disponibles de bois de sciage. Les résidus de sciage qui ont longtemps été considérés comme des déchets, sont devenus une ressource recherchée pour la production de panneaux et de pâte. Suite au ralentissement de l'industrie forestière canadienne et la réduction de 46,5 % de la production nationale de bois de sciage entre 2004 et 2009, le potentiel d'utilisation des résidus de sciage pour développer de nouveaux marchés est devenu bien réel, encouragé par les pressions nationales et internationales pour créer une bioéconomie durable. Le peu d'information disponible sur la quantité et la qualité des stocks locaux de résidus de sciage a entraîné un manque de données fiables pour les entrepreneurs désirant développer des chaînes d'approvisionnement durable pour cette ressource. Le développement d'une base de données pouvant être facilement mise à jour pour toutes les provinces à partir du Manitoba vers l'est, est expliqué en détail et est accompagné d'une présentation globale d'un modèle de calcul de production de résidus de sciage incluant les sciures, l'écorce, les copeaux et les dosses, ainsi que les rabotures. Ces outils aideront à prédire la disponibilité actuelle et future de résidus de sciage et permettront les utilisations les plus efficaces de cette ressource dans le cadre de la bioéconomie.

Mots clés : scieries, résidus, modèle, base de données, prédiction, bioénergie, biomasse, foresterie, marché, économie, Est du Canada, chaîne d'approvisionnement durable

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Introduction

One of the possible reasons for what has been called a crisis in the forest industry (RNNR 2008) is that there has been a lack of meaningful innovation within it and a heavy reliance on the traditional products and processes that have sustained it (Hansen *et al.* 2007). Innovations leading to an expanded range of products, especially in the softwood sawmills of North America have been slow to come (Crespell *et al.* 2006). Conversely, there have been a number of significant improvements in technologies and processes that allow for more effective and efficient harvesting and sawing of logs, decreasing the amount of wasted resources (Stoddard and Stoddard 1987, Williston 1988). However, these improvements have all targeted increasing the yields of traditional forestry products, which may not always have a strong market waiting for them.

Items traditionally regarded as disposable wastes (Williston 1988) of the sawmilling process have been proposed by many as having a greater role to play in the forest industry (Tillman 1978, Cheremisinoff 1980, Dobie 1981, Stoddard and Stoddard 1987, FAO 1990). The potential still remains for these residues to increase revenue streams under present and possibly future unfavourable traditional wood market conditions (RNNR 2008). Residues of the sawmilling process such as bark, chips, sawdust, shavings, and slabs, are often sold individually or combined together for sale as mulch, firewood, hog fuel, animal bedding, for use in particle or strand boards, and for pulp recovery (Harkin 1969, Williston 1988).

The Canadian forest industry has been experiencing a downturn over the past decade. Especially hard-hit has been lumber sales, dropping from \$16.9 billion CDN in 2004 to \$5.9 billion CDN in 2009, a loss of 65% (Germain 2012). Lumber sales contribute 2.9% of total manufacturing sales in Canada (2009) (Germain 2012) and the logging and sawmilling industries contribute to the well-being of over 200, mainly rural communities, nationwide. In 2010, about 148 500 people were directly employed by the forest industry (CFS 2011) making any sawmill closures, large or small, significant. The industry is also a large contributor to Canada's international trade (CFS 2011). Much of the downturn that was witnessed in the Canadian industry can be attributed to the decline of the American housing market (RNNR 2008). Between 2005 and 2009, new residential housing starts decreased by 73.2%, from 2.0681 million to 553.9 thousand (USCB 2012). Approximately 81.1% of timber harvested and processed in Canadian sawmills was exported to the USA in 2004, with that number decreasing to 58.7% by 2010 (Germain 2012). Although the slowdown in the American housing market also corresponded to a similar lag in Canadian building rates between 2005 and 2009, its impact was not as large, resulting in a decrease of 76 400 units or 33.9% (StatCan 2012b).

Corresponding to the significant downturn in the Canadian forest industry, from 84 589 thousand m³ in 2004 to 45 258 thousand m³ of sawn lumber production in 2009 (StatCan 2012a), sawmill residue production has also seen considerable decline in spite of rising demand created by proposed large-scaled biomass projects across Canada (Bradley 2010, Kennedy *et al.* 2011). While there have been a number of studies that have estimated the potential biomass available in various regions of Canada (Wood and Layzell 2003, NRCan/FPAC 2006, Townsend 2008, Levin *et al.* 2011), these

studies tend to provide large-scale, historical snapshots—often of little use for validating long-term sustainable supply for business ventures. The lack of up-to-date, detailed, spatial information concerning the availability of biomass precludes determination of biomass delivered costs, which is paramount in understanding the feasibility of any new bio-processing enterprises.

With the growing interest in sustainable energy sources, forest biomass has increased in the public's awareness. There are generally considered to be two main sources of forest biomass; 1) forest harvest residues and 2) sawmill residues. Harvest residues are “tops, branches, and leaves from harvest and thinning operations that are left in the forest or at roadside after delimbing” (Bradley 2010). The potential of forest harvest residues in Canada is largely unexploited to-date but with increased interest and further understanding of collection systems, economic feasibility, impacts on forest ecosystems, energy returned on energy invested (EROEI) and green house gas benefits, their prospect is highly encouraging. Alternatively, sawmill residues are produced during sawmilling operations and include chips, sawdust, shavings, and bark. These residues are generally clean, and consistent in form and size (Perlack *et al.* 2005). They are easily accessible and have a predictable availability. They are well utilized in Canada, commonly for energy generation, pulp, board and pellet production, compost, playground cover, and livestock bedding (Fonseca 2005, Bradley 2010, Levin *et al.* 2011).

A thorough search of literature and government agencies revealed that the most current and comprehensive source of information on sawmill-generated residues in Canada is from a 2005 report, *Estimated Production, Consumption and Surplus Mill Wood Residues in Canada – 2004*, published jointly by Natural Resources Canada and the Forest Products Association of Canada (NRCan/FPAC 2006). However, in addition to this information being dated, our research has shown that the methodology and type of information collected by each province is far from consistent. Significant discrepancies in the quantities of sawmill residues reported can be observed in the differences between information reported by the provinces and those reported in the report (Table 1). Many provinces collect sawmill residue data; however, this information is often considered private and generally is not available to the public (NBDNR 2010). Instead, aggregate data, as seen in Table 1, are made available (NSDNR 2011). This provides no insight into where the residues are generated on a spatial level.

For more efficient use of mill residues and to gain their full potential in the bio-economy, it is critical to understand quantities and quality available on a timely and geographic basis. Thus, the main goals of this study are; 1) to determine the amount of wood-processing residues available on a spatial basis, and 2) to understand the scope of the wood fibre supply that could potentially be made available for both conventional and new opportunities. In order to meet these objectives a database of mills in eastern Canada (Manitoba and east provinces) was established and a model for predicting mill residues from specific mill types was created. Ultimately, this information will be made available to the public via a user-friendly interface on the world-wide web to assist potential business planners in determining the quantity and geographic location of specific residue supplies. The model,

Table 1. Information on sawmill residues across Eastern Canada

Jurisdiction	Year	Sawmill residues (ODT)	Source of information	Updated annually	Sawmill residues (NRCan/FPAC 2006) (ODT)
Canada	2004	21 229 000	NRCan/FPAC 2006	No	21 229 000
Quebec	2010	7 307 671	Gauthier ^d	Yes	2 433 217
Ontario		Not available	Koivisto ^e	No	1 321 904
Newfoundland and Labrador	2009	41 211 ^a	Jayasinghe 2011	Yes	92 496
New Brunswick	2009	2 862 601 ^b 806 589 ^c	NBDNR 2010	Yes	233 497
Nova Scotia	2010	1 337 179	NSDNR 2011	Yes	340 427
Prince Edward Island	2011	Minor quantities	Watts ^f	No	0

^ain green tonnes^bmill residues in m³^cbark residue in tonnes^dR. Gauthier, Industry Development Officer, Ministère des Ressources naturelles et de la Faune. Personal communication, 2011.^eJ. Koivisto, Forestry Innovation and market Development, Ontario Ministry of Natural Resources. Personal communication, 2011.^fS. Watts, Products market Development Officer, P.E.I. Department of Environment, Energy and Forestry. Personal communication, 2011.

when associated with a mapping application and a user-friendly online interface, will allow business planners to determine not only the potential quantities of residues from individual sawmills, but the geographic location of the residues and the cost to transport these residues to their own bio-processing plants.

Methods

Sawmill database

For the purpose of the database, a sawmill is considered a facility that takes in tree logs, and processes them to create lumber products, whether finished or unfinished. The information collected for the establishment of the sawmill database was designed to provide the input data for the sawmill residue prediction model. The idea is that the model's inputs would come from the database and the model would generate mill-specific predictions on residue quantities. Such a database would only be relevant if it increases the knowledge and understanding of the existing residue resource potential, and is accessible to be updated at regular intervals.

The database was created on a Microsoft Excel 2007 platform. It consists of a number of data field columns, where information relating to an individual sawmill occupies its own row. A description of the data fields is provided in Table 2. Sawmills included in the database are those that have a physical location represented by a building(s), or are of a portable nature for which information was found. Buildings that have been demolished were excluded where possible.

To compile the information for the database various sources of information were consulted. Directories and publications provided by provincial Ministries or Departments legislated to regulate forest resources were of primary importance. Often they had the most up-to-date data and provided a basis to localize and identify sawmills and also included information on timber harvesting. These sources tended to only include sawmills that harvested timber from Crown land and failed to provide information on sawmill operations that relied on timber from private woodlots. Another very helpful

resource was the trade publication, Madison's Canadian Lumber Directory (Logging & Sawmilling Journal 2010). This is a Canada-wide directory that encourages Canadian mills to advertise their operations by not charging a fee. It provides a significant amount of additional data that is not found in the provincial directories, such as the tree species processed and often their proportions, the type of mill products produced, the mill numbers and grading agencies associated with the mills, and their actual operating capacity.

Additional sources of information used to populate the database included online business directories, such as the Yellow Pages (<http://www.yellowpages.ca>) and ProFile Canada (<http://www.profilecanada.com>), which were mainly used to identify sawmills and provide contact information. Sawmill company Web sites were also visited to obtain information on their equipment, products, and tree species processed. In order to determine if a particular mill was in operation, an online search was conducted using the Google search engine (<http://news.google.ca>) for news articles from 2010 to the present that mentioned a mill's status.

Sawmill residue model

Wood residues that can be produced through mill operations include chips, sawdust, wood shavings, and bark. Wood residue production, which is inversely related to output lumber yield, is significantly affected by log characteristics and mill configurations. Log characteristics are non-controllable factors, such as log length, diameter, taper, and defects (Steele 1984, Fonseca 2005). On the other hand, mill configurations are controllable factors that can influence wood residue and/or lumber yield. These factors include saw kerf size, sawing variation, sawing methods, and product mix (Steele 1984, Fonseca 2005). As new high-value markets are developed for wood residues, sawmills may be motivated to change their relative proportion of lumber to residue, in order to maximize revenues.

The second objective of this research project was to create a model that is capable of predicting residue output from

Table 2. A description of the data fields in the sawmill database, including the field names and a description of the field information

Field name	Field description
Operational	Indicates whether the sawmill is currently in operation, is idled or permanently shut down.
Mill #, Grading Agency	Mill number that has been assigned to the sawmill by National Lumber Grades Authority member grading agency.
Mill Name, Address, Postal Code, Municipality, Province, Phone, E-Mail	Full contact information for the mill
Type of Mill	Indicates the type of forest product enterprise. At present, the database only has sawmill entries.
Model Input Mill	Indicates the type of mill as classified by its output products. Where available, a percentage breakdown of the output products is also given. (e.g., 1 (50%) = board, 2 (25%) = stud, 3 (25%) = dimension, and 4 (0%) = hardwood)
Feedstock (Species)	Indicates tree species that are processed by the sawmill. Where available, a percentage breakdown of the tree species processed are also given. (e.g., white pine (25%), red pine (25%), white spruce (50%))
Diameter Range	Indicates the diameter ranges in inches of the logs processed by the sawmill. Measurements could be provided at breast height, top end, or butt end.
Quality	Indicates the quality of lumber produced by the sawmill.
Equipment Details	Indicates the equipment found within the sawmill. This can include the types of saws used in the manufacturing of lumber, as well as if kiln drying takes place.
Actual Operating Mill Production (AOMP)	Indicates the amount of lumber product, in board feet (fbm) that the sawmill produces within a specified time period, such as a regular shift or per year. (e.g., 25 MMfbm/year; 5 Mfbm/year; 100 fbm/8 hour shift, where MM = million and M = thousand)
Estimated Annual Mill Production ^a (m ³) (EAMP)	<p>Converts AOMP into cubic metres (m³) by the following method: if AOMP is listed as an annual rate, then</p> <p>[1] EAMP = AOMP x f, where f = 2.36 m³/1000 fbm, which is an fbm-to-m³ conversion factor (Briggs 1994).</p> <p>If AOMP is a daily or shift rate, then</p> <p>[2] EAMP = AOMP x f x d x t, where d = average amount of days in a week that the sawmill is operating, and t = average amount of weeks in a year that the sawmill is operating.</p>
Tree Volumes Harvested	Indicates the annual volume (m ³) of trees harvested for processing within the specific sawmills, most commonly in the form of a range or a maximum allowable cut.
Mill Products	Indicates the type of final lumber or other wood products that the sawmill may produce.
Forms of Residues	Indicates the types of residues that the sawmill produces.
Integrated Operations	Indicates whether the sawmill uses any of its own or other residues for the generation of energy or electricity to be used by its or others' facilities.
Heat Value	Indicates the amount of heat energy released by combusting a specific quantity of residues that are produced by the sawmill.

^aIn order to calculate estimated annual production, [1] and [2], the terms d and t were left constant, at 5, and 52 respectively. This represents the very liberal estimate that a given sawmill operates 5 days a week, for 52 weeks a year, but allows us to standardize estimated operation numbers for a full year for each sawmill, regardless of its actual operational duration.

individual mills, without relying on individual mill configurations. Scholarly research was undertaken to determine the types of models, formulas, or methods that exist within the industry. It was found that past studies can be categorized into four types; 1) regression equations based on observed mill outputs (Plank 1985, Maness and Lin 1995), 2) machine specific or general residue conversion factors (Wade *et al.* 1992, Liu *et al.* 2009, Lin *et al.* 2011), 3) patented sawing simulation software such as Optitek (Goulet 2006) and PROYIELD (Govett *et al.* 2005), and 4) geometric and mathematical theory (Hallock 1962, Steele and Hallock 1979). Most models fell into category 1 or 2, which calculated lumber recovery or lumber recovery factor (LRF) based on actual mill studies, and focused on very specific configurations such as saw kerf thickness or saw types. For example, many researchers concluded that there is a negative relationship between saw kerf size and output lumber yield, which implies a positive relationship between wood residue and saw kerf size (Hallock 1962, Wade *et al.* 1992, Maness and Lin 1995).

Lumber recovery factor (LRF) is “an expression of the number of board feet of lumber obtained by a sawmill per cubic foot, log scale, of log input” (Briggs 1994). Because this approach describes “the conversion efficiency of sawmills” (Wade *et al.* 1992), it is a common method to determine the potential finished lumber output of sawmills. However, this approach does not favour a deeper understanding of the wood fibre supply that could potentially be made available for both conventional and new opportunities. Due to the varied physical and chemical properties of residues, knowledge of the quantities of each specific type helps to establish feasibility or benefit in end use. LRF is an indirect means to determine the amount of residue output from a sawmill, but not the specific types of residues.

However, there are only a few studies combining a variety of factors to calculate mill residue production. The model developed in this project builds upon a number of previous works, primarily done by Winters (2005) and Jayasinghe (2011) and Fonseca (2005). Winters (2005) and Jayasinghe (2011) identified the relationship between saw types and residue recovery in a number of Newfoundland and Labrador sawmills, while Fonseca (2005) classified sawmills into four types based on output products, and modeled the average residue recoveries for each sawmill type on log size. These two models were combined into a new model developed to calculate the estimated wood residue production in four types of sawmills.

Results

Sawmill database

The sawmill database generated in this study may be the most recent compilation of public information available at this time, replacing the Natural Resources Canada Sawmill map 2003 (The Atlas of Canada 2003). Even though most of the provinces surveyed in our research indicated that sawmill facilities are provincially licensed, the directories of these facilities are not available to the public (OMNDM 2011, MRNF 2011, NSDNR 2011). Therefore, it was not possible to fully populate the database due to lack of information available through the reported sources. Missing data in the spreadsheet are denoted with a red background. It was found that for the larger companies there was likely to be more publically available information than for the smaller companies. To fully

Fig. 1. Number of sawmills by province represented in the database.

populate the database it would be necessary to conduct a survey of individual mills.

The sawmill database currently has 783 separate mill entries representing each of the provinces from Manitoba heading eastward. The provincial sawmill percentage breakdown in the database is as follows: Manitoba has 2%, Ontario 21%, Quebec 46%, Newfoundland and Labrador 6%, New Brunswick 7%, Nova Scotia 17%, and Prince Edward Island <1% (Fig. 1). These numbers are a reflection of the information that was compiled in each province, with provinces that had more complete information obviously being more highly represented in the database. The most complete information provided regarding sawmill localization was from the provinces of Quebec and Nova Scotia (MRNF 2011, NSDNR 2011). According to Statistics Canada surveys (StatCan 2011) approximately 12.5% of Canada's sawmill establishments closed between 2004 and 2006.

In order to authenticate the comprehensiveness of the database we compared the percentage of sawmills to provincial sawlog and bolt harvest data, which can serve as a proxy for the overall production capacity of sawmills in each target province (National Forestry Database 2012). It could be expected that provinces with more harvest activity would have more mills. The most recent data for 2010 indicate the following provincial tree harvest statistics (in thousands of m³): Quebec – 24 384, Ontario – 5898, New Brunswick – 4422, Nova Scotia – 1925, Newfoundland – 358, Manitoba – 284, and Prince Edward Island – 49 (National Forestry Database 2012). After determining what percentage of each provincial harvest contributes to the total for the target provinces, a comparison can be made with the percentage contribution of the number of mills for each province to the entire total in the sawmill database (Fig. 2). It would appear that the sawmill entries in the database correspond somewhat with provincial harvests, with the exception of New Brunswick and Nova Scotia. Sawlog and bolt harvests in Nova Scotia were lower than in New Brunswick, but the database has more sawmill entries for Nova Scotia than New Brunswick.

It is also important to note that the sawmill database does not include portable sawmills. Portable sawmills are often used for harvesting timber from private woodlots and only process wood from about 50 hectares (Dansereau and

Fig. 2. A comparison of the percentage of sawmills in the database by province of origin to the percentage of 2010 sawlog and bolt harvests attributed to each province.

deMarsh 2003). The proportion of private woodlots varies by province representing relatively small proportions in Manitoba (3%) and Ontario (8%) and relatively high proportions in New Brunswick (50%) and Nova Scotia (68%). Often, the timber harvested from these lands is not recorded in any provincial directory.

Sawmill residue model

The model was built for four classes of sawmills, based on their output product(s), Table 3 (Fonseca 2005). Regression models were calculated based on the in-coming, small end log diameter (independent variable) for each sawmill type. Another independent variable used in the model is the species of logs. Because weight is often used in the wood residue market rather than volume, which is traditionally used in the lumber market, the output of the model should be in green tonnes. In order to convert the volume inputs to the weight outcomes, the model uses species-specific “specific

Table 3. Sawmill classification by product outputs

Sawmill classification	Product description		
	Thickness (inch)	Length (foot)	Width (inch)
Board	1 or smaller	2 multiples	4–12
Stud	2	6–10	3–6
Dimension	2 or greater	10–20	4–12
Hardwood	N/A	N/A	N/A

Table 4. Data sources for tree species information

Data	Sources
Tree species name	FBMC N/D, NSDNR 2007, Muma 2012, NLDNR 2012, TreeCanada 2012
Specific gravity	Fonseca 2005, Bergman <i>et al.</i> 2010
Shrinkage	Simpson 2001, Fonseca 2005, Bergman <i>et al.</i> 2010
Bark volume	Fonseca 2005, Bergman <i>et al.</i> 2010
Bark specific gravity	IPST n.d., Miles and Smith 2009

gravity” to calculate the weight and shrinkage of the residue generated. All native and commercial tree species in Canada are available in the model, Table 4. The complete list of input data required for the model is listed in Table 5.

The sawmill residue model, modified from the work of Winters 2005 and Jayasinghe 2011 (Table 6) is:

$$\text{Total Residues in Green Tonnes} = \sum_{R=1}^5 W_R + W_b$$

$$[1] \text{ where, } W_R = \sum_{j=1}^4 V \times PO_j \times PQ_{R,j} \times PS_j \times \frac{SG_j}{(1 - M_R)}$$

$$[2] \text{ and, } W_b = V \times PS_b \times PB_b$$

As mentioned above, this model is for mill-level residue calculation so that multiple output-products, species, and log diameters can be combined into the model. The output product types are the most important factor in determining the production quantities of green chips/slabs, dry chips, sawdust, shrinkage, and planer shavings, eq. 1. They have a greater effect on residue generation than does the specific saw types. On the other hand, the type of species has the most significant effect on predicting bark production because tree bark ratio can vary from 5% to 25% of log volume depending on species. Thus, the calculation of bark production is independent from other residues, eq. 2, depending on whether the sawmill has a debarker. If the sawmill does not own the debarker, eq. 2 will be 0. Three scenarios and model/mill database output are illustrated in Table 7.

Conclusions

An essential element in developing new and innovative forest bio-enterprises is an understanding of the quantity and quality of raw material available as well as its cost of procurement. The most easily accessible and consistent supply of woody biomass in Canada comes in the form of sawmill residues; however, information concerning its current availability, quality and location is not readily available to business planners and the public. To fill this gap in information, an easily updateable sawmill database has been established that contains detailed information on 783 individual sawmill enterprises. The information contained in the sawmill database feeds into a sawmill residue output model, that was developed in conjunction with the database, to predict current or scenario based residue outputs from each mill.

To facilitate the use of this information by business planners, the model and database should be incorporated into an online interface such as the Biomass Information Mapping and Analysis Tool (BIMAT) by Agriculture and Agri-Food Canada (AAFC 2012), or a similar spatially based platform. Integration of the sawmill residue information with information already provided on BIMAT, will provide a complete picture of biomass available from forestry and agricultural operations. Combining this model and database with forest inventory or annual allowable cut data across the country would allow the forest industry to better plan its business activities.

Within the scope of this project, actual on-site verification of the model was not possible. In future work, a sawmill residue analysis will be conducted at each of the four types of mills specified in the model. The model may be further refined by understanding how variables within each sawmill

Table 5. Required input in the sawmill residue model

Required input	Input description	Unit
Log volume	Volume of log input into the mill	Cubic metre
Presence of debarker	Does the mill have a debarker on site	Yes / No
Small-end diameter (SED)	Diameter of the small-end of log	Inch
Proportion of SED	Proportion of each SED class	Percent
Target moisture content	Moisture content of output products	Percent
Species	Tree species of logs	Percent
Proportion of species	Proportion of each species	Percent
Output product types	Output product types of lumber. See Table 3 for detailed information.	Board / Stud / Dimension / Hardwood

Table 6. Variable definitions in the sawmill residue model

Variables	Description	Unit
R	Types of residue produced	
R ₁	Green chips/slabs	
R ₂	Dry chips	
R ₃	Sawdust	
R ₄	Planer shavings	
R ₅	Shrinkage	
W _R	Quantity of residue, R, produced	Green tonnes
W _b	Quantity of bark, b, produced	Green tonnes
V	Volume of log input	m ³
J	Type of output product produced	
j ₁	Board mill	
j ₂	Stud mill	
j ₃	Dimension mill	
j ₄	Hardwood mill	
PO _j	Proportion of log input volume, V, that is directed towards making a specific output products, j	%
PQ _{R,j}	Proportion of log input volume, V, that is expected to turn into residue, R, while making specific output product, j	%
PS _j	Proportion of output product, j, that originates from a specific tree species	%
SG _j	Green specific gravity of the tree species that has becomes a specific end product, j	
M _R	Moisture content of residue produced, R = 100 – (100 – %radial shrinkage) * [1 – (% tangential shrinkage / 100)] (Fonseca 2005)	
PS _b	Proportion of bark, that originates from a specific tree species	%
PB _b	Proportion of log input volume, V, that is expected to turn into bark	%

category affects the residue outputs. However, with further refinement there is the risk that the model will become overly specific and may lose its intended value, which is to provide useful information on a wide geographic scale.

Although this model and the accompanying sawmill database are not intended to replace more thorough methods of business planning, they can provide interested entrepreneurs with some current data and also allow them to evaluate future supply scenarios based on mill closures or increases in mill production. In addition to understanding quantity and quality of residue available, it is essential for new business ventures to link directly with prospective sawmills and transport companies to formulate the beginnings of a logical and comprehensive supply chain system (Awudu and Zhang 2012). The

information provided by the model will contribute to a base foundation of supply information that can be used in conjunction with the principles of economics to build more solid business opportunities. Therefore, the results of this work allow industries to understand residue characteristics, variability, and availability, to predict what residues could be available to drive secondary forest industries, to plan better strategies for developing value-added opportunities for their own residues, and to use a predictive tool that is not currently available.

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Table 7. Sawmill residue model predicted output on percentage of original log volume compared to literature values

	Inputs				Outputs (volume % after debarked) ^a					
	Debarker	Output products	Species	SED	Bark	Green chips /slabs	Dry chips	Sawdust	Shrinkage	Shavings
Model scenario 1 (volume)	Yes	100% stud	60% Balsam fir 40% Black spruce	50% 10 in 50% 12 in	17.8	20.7	4.4	7.7	3.4	9.8
Canada average (UNECE/FAO 2010)	No	–	Softwood	–	–	N/A	38.0 (green and dry chips combined)	8	4	5
U.S. study (Fonseca 2005)	No		Softwood	–	–	N/A	31–33 (green and dry chips combined)	7–12	3	8–13
Model scenario 1 (weight)	Yes	100% stud	60% Balsam fir 40% Black spruce	50% 10 in 50% 12 in	17.1	16.4	3.5	6.1	2.7	7.8
Canada (NRCan/FPAC 2006)	Yes	–	All	All	14.6	N/A	N/A	6.8	N/A	5.4
Model scenario 2 (volume)	No	100% hardwood	70% American beech 30% Red oak	50% 15 in 50% 18 in	N/A	10.1	4.2	16.9	3.4	9.8
Canada average (UNECE/FAO 2010)	No	100% hardwood	Hardwood	–	N/A	25 (green and dry chips combined)	–	14	–	7
Model/Database scenario 3 (volume) Manitoba sawmill 188 800 m ³	estimate No	estimates 30% board 40% stud 25% dimension 5% hardwood	70% White spruce 25% Jack pine 5% Trembling aspen	estimates 5% 12 in 95% 14 in	N/A	18.9 (35 736 m ³)	4.2 (7 888 m ³)	9.4 (17 716 m ³)	3.4 (6 431 m ³)	10.7 (20 134 m ³)
Model/Database scenario 3 (volume) Nova Scotia sawmill 283 200 m ³	estimate No	estimates 50% studs 25% dimension 25% boards	75% White spruce 20% White pine 5% Eastern hemlock	estimates 25% 11 in 75% 13 in	N/A	19.7 (55 855 m ³)	4.1 (11 569 m ³)	8.5 (24.122 m ³)	3.1 (8 845 m ³)	10.1 (28 683 m ³)

^aIn percent of original volume except where specified

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References

- [AAFC] **Agriculture and Agri-Food Canada. 2012.** Biomass Inventory Mapping and Analysis Tool (BIMAT) [online]. Available at <http://www4.agr.gc.ca/AAFC-AAC/display-afficher.do?id=1226509218872&lang=eng> [Accessed April 3, 2012].
- Awudu, I. and J. Zhang. 2012.** Uncertainties and sustainability concepts in biofuel supply chain management: A review. *Renewable and Sustainable Energy Reviews* 16(2): 1359–1368.
- Bergman, R. et al. 2010.** Wood handbook – Wood as an engineering material. General Technical Report FPL-GTR-190. U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, Madison, WI. 508 p. Available at http://www.fpl.fs.fed.us/documents/fplgtr/fpl_gtr190.pdf.
- Bradley, D. 2010.** Canada Report on Bioenergy 2010. Canadian Bioenergy Association [online]. Available at <http://www.canbio.ca/>

upload/documents/canada-report-on-bioenergy-2010-sept-15-2010.pdf [Accessed March 1, 2012].

Briggs, D.G. 1994. Forest products measurements and conversion factors: with special emphasis on the U.S. Pacific Northwest. College of Forest Resources, University of Washington: Seattle, WA. 161 p.

[CFS] Canadian Forest Service. 2011. The State of Canada's Forests: Annual Report 2011. Natural Resources Canada [online]. Available at <http://cfs.nrcan.gc.ca/publications?id=32683>. [Accessed November 25, 2011].

Cheremisinoff, N.P. 1980. Wood For Energy Production. Ann Arbor Science Publisher Inc., Ann Arbor, MI. 152 p.

Crespell, P., C. Knowles and E. Hansen. 2006. Innovativeness in the North American Softwood Sawmilling Industry. *Forest Science* 52(5): 568–578.

Dansereau, J. and P. deMarsh. 2003. A portrait of Canadian woodlot owners in 2003. *The Forestry Chronicle* 79(4): 774–778.

Dobie, J. 1981. Residues. In E. Mullins and T. McKnight (eds.). *Canadian Woods: Their Properties and Uses: 3rd Edition*. University of Toronto Press, Toronto, ON. 389 p.

[FAO] Food and Agriculture Organization of the United Nations. 1990. Energy Conservation in the Mechanical Forest Industries. FAO Forestry Paper 93. Food and Agriculture Organization of the United Nations, Rome. Available at <http://www.fao.org/docrep/T0269E/T0269E00.htm> [Accessed March 15, 2012].

[FBMC] The Forestry Branch of Manitoba Conservation. n.d. Field Guide – Native Trees of Manitoba. Available at <http://www.gov.mb.ca/conservation/forestry/pdf/health/fieldguidefinal.pdf> [Accessed January 31, 2012].

Fonseca, M.A. 2005. The measurement of roundwood – methodologies and conversion ratios. CABI Publishing, Cambridge, MA. 288 p.

Germain, B. 2012. An Overview of the Lumber Industry in Canada, 2004 to 2010. Statistics Canada [online]. Available at <http://www.statcan.gc.ca/pub/11-621-m/11-621-m2011089-eng.htm> [Accessed March 13, 2012].

Goulet, P. 2006. Optitek: User's Manual. Document E-4130. Forintek Canada Corp. Quebec, QC. 136 p.

Govett, R., R. Damm, S. Bowe and T. Mace. 2005. PROYIELD – Sawmill Yield Analysis User's Manual. College of Natural Resources, University of Wisconsin, Stevens Point, WI. 27 p.

Hallock, H. 1962. A mathematical analysis of the effect of kerf width on lumber yield from small logs. USDA, Forest Service, Forest Products Laboratory, Madison, WI. Rep. No. 2254. 82 p.

Hansen, E., H. Juslin and C.D. Knowles. 2007. Innovativeness in the global forest products industry: exploring new insights. *Canadian Journal of Forest Research* 37(8): 1324–1335.

Harkin, J.M. 1969. Uses for Sawdust, Shavings, and Waste Chips. USDA, Forest Service, Forest Products Laboratory, Madison, WI. Research Note#: FPL-0208. Available at <http://www.fpl.fs.fed.us/documents/fplrn/fplrn208.pdf>.

[IPST] Georgia Institute of Technology, Institute of Paper Science and Technology. n.d. Technical Reviews [online]. Available at http://www.ipst.gatech.edu/faculty/ragauskas_art/ragauskas_tech_reviews.html#Biofuels [Accessed February 7, 2012].

Jayasinghe, P. 2011. Provincial Inventory of Forest Biomass Residues. Final report prepared for Centre for Forest Science and Innovation, Forestry Services Branch, Newfoundland and Labrador Department of Natural Resources. 63 p.

Kennedy, M., R. Wong, A. Vandenbroek, D. Lovekin and M. Raynolds. 2011. An assessment of Ontario-sourced forest-based biomass for electricity generation [online]. Available at: <http://www.opg.com/power/thermal/Pembina%20Biomass%20Sustainability%20Analysis%20Final%20Rev%2015%20April%202011.pdf>. [Accessed April 10, 2012].

Levin, R., S. Krigstin and S. Wetzel. 2011. Biomass availability in eastern Ontario for bioenergy and wood pellet initiatives. *The Forestry Chronicle* 87(1): 33–41.

Lin, W., J. Wang, J. Wu and D. DeVallance. 2011. Log sawing practices and lumber recovery of small hardwood sawmills in West Virginia. *Forest Products Journal* 61(3): 216–224.

Liu, C., J.C. Ruel, A. Groot and S.Y. Zhang. 2009. Model development for lumber volume recovery of natural balsam fir trees in Quebec, Canada. *The Forestry Chronicle* 85(6): 870–877.

Logging & Sawmilling Journal. 2010. Madison's 2010 Canadian Lumber Directory: 50th Edition. Logging & Sawmilling Journal, North Vancouver, BC.

Maness, T.C. and Y. Lin. 1995. The influence of sawkerf and target size reductions on sawmill revenue and volume recovery. *Forest Products Journal* 45(11/12): 43–50.

Miles, P.D., and W.B. Smith. 2009. Specific gravity and other properties of wood and bark for 156 tree species found in North America. Research Note NRS-38. U.S. Department of Agriculture, Forest Service, Northern Research Station, Newtown Square, PA. 35 p. Available at http://www.nrs.fs.fed.us/pubs/rn/rn_nrs38.pdf.

[MRNF] Ministère des Ressources naturelles et de la Faune de Québec. 2011. Répertoire des usines de transformation primaire du bois. Édition juillet 2011 [online]. Available at <http://www.mrn.gouv.qc.ca/forets/entreprises/entreprises-transformation-publications-industrie-table.jsp> [Accessed January 5, 2012].

Muma, W. 2012. Trees and Shrubs – Native Species [online]. Available at http://ontariotrees.com/main/alien_native.php?type=N [Accessed January 31, 2012].

National Forestry Database. 2012. Net Merchantable Volume of Roundwood Harvested by Category, Ownership, and Province/Territory [online]. Canadian Council of Forest Ministers. Available at http://nfdp.ccfm.org/data/compendium/html/comp_51e.html [Accessed March 13, 2012].

[NRCan/FPAC] Natural Resources Canada and Forest Products Association of Canada. 2006. Estimated production, consumption and surplus mill wood residues in Canada, 2004. Natural Resources Canada, Canadian Forest Service, Headquarters, Ottawa, and the Forest Products Association of Canada. 60 p. Available at <http://publications.gc.ca/collections/Collection/Fo4-7-2004E.pdf> [Accessed November 21, 2011].

[NBDNR] New Brunswick Department of Natural Resources. 2010. Timber Utilization Report for the Year 2009. Forest Management Branch. File #: 813-09-0004.

[NLDNR] Newfoundland and Labrador Department of Natural Resources. 2012. Tree Species [online]. Available at <http://www.nr.gov.nl.ca/nr/forestry/forest/treespecies/index.html> [Accessed January 31, 2012].

[NSDNR] Nova Scotia Department of Natural Resources. 2007. Tree Identification Guide for Common Native Trees of Nova Scotia [online]. Available at www.gov.ns.ca/natr/forestry/treeid/TreeID2007.pdf [Accessed January 31, 2012].

_____. 2011. Registry of Buyers of Primary Forest Products 2010 Calendar Year. Registry of Wood Buyers [online]. Available at http://gov.ns.ca/natr/forestry/registry/ann_report.asp [Accessed November 28, 2011].

[OMNDM] Ontario Ministry of Northern Development and Mines. 2011. Mill List 2011. [online]. Available at http://www.mndmf.gov.on.ca/forestry/documents/mill_list_2011.xls [Accessed November 28, 2011].

Perlack, R.D., L.L. Wright, A.F. Turhollow, R.L. Graham, B.J. Stokes and D.C. Erbach. 2005. Biomass as feedstock for a bioenergy and bioproducts industry: the technical feasibility of a billion-ton annual supply. U.S. Department of Energy and U.S. Department of Agriculture. Available at <http://www1.eere.energy.gov/library/default.aspx?page=1> [Accessed March 21, 2012].

Plank, M.E. 1985. Lumber recovery from ponderosa pine in the Black Hills, South Dakota. Res. Pap. PNW-328. U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, OR. 14 p. Available at http://www.fs.fed.us/pnw/pubs/pnw_rp328.pdf.

- [RNNR] **Canadian House of Commons Standing Committee on Natural Resources. 2008.** Canada's Forest Industry: Recognizing the Challenges and Opportunities [online]. Parliament of Canada. Available at <http://www.parl.gc.ca/HousePublications/Publication.aspx?DocId=3534643&Language=E&Mode=1&Parl=39&Ses=2> [Accessed December 20, 2011].
- Simpson, W.T. 2001.** Chapter 1 Properties of Wood Related to Drying. In W.T. Simpson (ed.). Dry Kiln Operator's Manual. USDA Agricultural Handbook AH-188. U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, Madison, WI.
- [StatCan] **Statistics Canada. 2011.** Principal statistics for manufacturing industries, by North American Industry Classification System (NAICS). CANSIM Database [online]. Available at <http://www5.statcan.gc.ca/cansim/a26?lang=eng&retrLang=eng&id=3010006&tabMode=dataTable&srchLan=-1&p1=-1&p2=9> [Accessed November 28, 2011].
- _____. **2012a.** Sawn lumber production and shipments, annual (cubic metres dry). CANSIM Database [online]. Available at <http://www5.statcan.gc.ca/cansim/a26?lang=eng&retrLang=eng&id=3030009&tabMode=dataTable&srchLan=-1&p1=-1&p2=9> [Accessed February 20, 2012].
- _____. **2012b.** Canada Mortgage and Housing Corporation, housing starts, under construction and completions, all areas, annual (units). CANSIM Database [online]. Available at <http://www5.statcan.gc.ca/cansim/a26?lang=eng&retrLang=eng&id=0270008&paSer=&pattern=&stByVal=1&p1=1&p2=-1&tabMode=dataTable&csid> [Accessed February 20, 2012].
- Steele, P.H. 1984.** Factors determining lumber recovery in sawmilling. General Technical Report FPL-39. U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, Madison, WI. 8 p.
- Steele, P.H. and H. Hallock. 1979.** A mathematical model to calculate volumes of lumber and residue produced in sawmilling. Research Paper FPL-336. U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, Madison, WI.
- Stoddard, C.H. and G.M. Stoddard. 1987.** Essentials of Forestry Practice: 4th Edition. John Wiley & Sons, New York. 407 p.
- The Atlas of Canada. 2003.** Sawmills. Natural Resources Canada – Earth Sciences Sector [online]. Available at <http://atlas.nrcan.gc.ca/auth/english/maps/environment/forest/useforest/sawmills/> [Accessed November 23, 2011].
- TreeCanada. 2012.** Trees in Canada [online]. Available at http://www.treecanada.ca/trees/species.php?sort=la_species&lang=en [Accessed January 31, 2012].
- Tillman, D.A. 1978.** Wood as an Energy Resource. Academic Press, New York. 252 p.
- Townsend, P. 2008.** Forest Biomass of Living, Merchantable Trees In Nova Scotia [online]. Renewable Resources Branch, Nova Scotia Department of Natural Resources. Report #: FOR 2008-9. Available at http://www.gov.ns.ca/natr/forestry/reports/Biomass_Inventory.pdf.
- [UNECE/FAO] **United Nations Economic Commission for Europe/Food and Agriculture Organization of the United Nations. 2010.** Forest product conversion factors for the UNECE region. Geneva Timber Forest Discussion Paper 49. ECE/TIM/DP49. Timber Section, Geneva. 50 p.
- [USCB] **United States Census Bureau. 2012.** New residential construction. Business and Industry Database Search [online]. U.S. Department of Commerce. Available at <http://www.census.gov/econ/currentdata/resconst/?programCode=RESCONST&yearStart=1959&yearEnd=2012&categoryCode=STARTS&dataTypeCode=TOTAL&geoLevelCode=US&adjusted=0¬adjusted=0¬adjusted=1&errorData=0> [Accessed February 20, 2012].
- Wade, M.W., S.H. Bullard, P.H. Steele and P.A. Araman. 1992.** Estimating hardwood sawmill conversion efficiency based on sawing machine and log characteristics. Forest Products Journal 42(11/12): 21–26.
- Williston, E.M. 1988.** Lumber Manufacturing: The Design and Operation of Sawmills and Planer Mills. Miller Freeman Publications, San Francisco, CA. 486 p.
- Winters, R. 2005.** Sawmill Residue Production and Current Disposal Methods in Newfoundland and Labrador. Newfoundland and Labrador Lumber Producers' Association.
- Wood, S.M and D.B. Layzell. 2003.** A Canadian Biomass Inventory: Feedstocks for a Bio-based Economy. BIOCAP Canada Foundation, Queen's University, Kingston, ON. Available at http://www.biocap.ca/images/pdfs/BIOCAP_Biomass_Inventory.pdf.