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STATUS OF ENERGY USE IN CANADIAN WOOD PRODUCTS SECTOR

IN COLLABORATION WITH FPINNOVATIONS – FORINTEK DIVISION, WESTERN REGION

CIPEC

Canada

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Disclaimer

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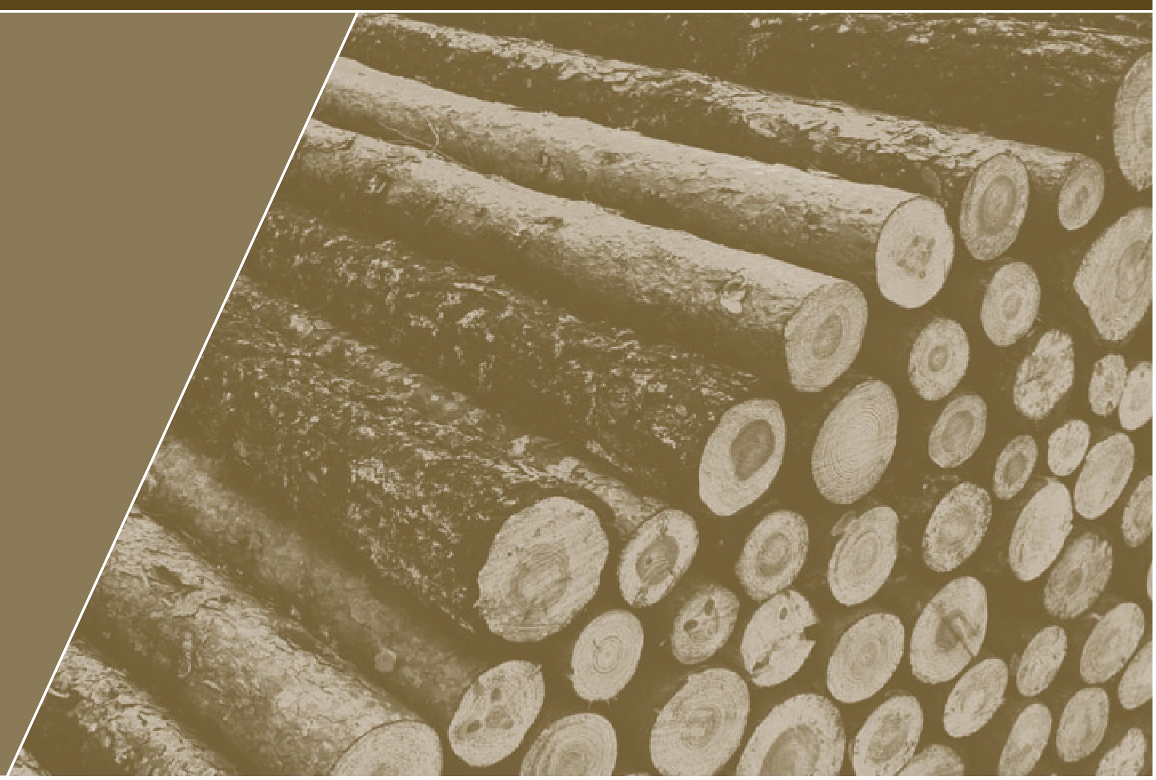

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1 INTRODUCTION

Canada's wood products industry has long played an important role in the Canadian economy. It is a diverse industry, producing both commodity and value-added products in every region of the country.

This energy use status report focuses on five commodities produced within the broadly defined wood products sector: softwood lumber, softwood plywood, oriented strand board (OSB), particleboard (PB) and medium density fibreboard (MDF).

The study, conducted by FPInnovations – Forintek Division, takes a different approach than other Canadian Industry Program for Energy Conservation (CIPEC) reports. It does not focus solely on gross facility manufacturing energy use, but also puts this energy use in context by relating it to upstream energy required to procure raw material and energy inputs. In addition, the study tracks direct and indirect greenhouse gas (GHG) emissions by fuel type and accounts for the carbon sequestered in wood products and thus, presents a carbon balance for each finished product at the plant gate.

Using a life-cycle analysis approach, this report documents the cradle-to-gate energy use in the production of the five commodities, so each industry segment can better appreciate how it draws upon and uses materials and energy resources and how it may reduce its energy use in the future.

1.1 Industry overview

The entire Canadian forest sector is going through an exceptionally difficult period. Since 2003, the industry has endured about 300 plant closures and curtailments involving pulp and paper mills, sawmills and panel board plants. Yet despite shifting market conditions and these consequential mill closures, Canada's wood products industry remains one of the leading industrial sectors in the country.

The Canadian wood products sector is as a diverse industry, producing both traded commodities (e.g. softwood lumber and assorted panel products) and value-added products (e.g. kitchen cabinetry and hardwood flooring). Wood manufacturing uses relatively little energy. Typically, energy costs in the solid wood products sector represent less than 5 percent of the cost of goods sold. Consequently, energy use has not attracted the same level of focus as controlling and monitoring labour and wood raw material costs. However, the industry's expenditures on energy inputs doubled over the past decade (Statistics Canada, 1998 – 2008 Annual Survey of Manufacturers).

Since 1990, absolute energy use by the wood products industry increased 30 percent, but its gross product output also grew 45 percent, and its contribution to gross domestic product grew 44 percent (CIEEDAC, 2009). It is estimated that energy intensity per unit of output for the industry declined by 10 percent between 1997 and 2007. Figure 1-1 provides a 10-year summary of energy use in the wood products industry by fuel type.

Between 1997 and 2007, energy use in the wood products industry grew from about 125 petajoules (PJ[1]) to 140 PJ. It is particularly noteworthy that more than 50 percent of the industry's current

[1] 1 petajoule (PJ) equals 10^{15} joules; 1 terajoule (TJ) equals 10^{12} joules; 1 megajoule (MJ) equals 10^{6} joules

energy use is derived from renewable biomass fuel (derived from co-products of production). Electricity and natural gas each account for about 20 percent of the industry's fuel mix, and other fossil fuels (middle distillates – diesel fuel oil, gasoline, liquefied petroleum gas [LPG] and residual fuel oil) account for the remaining 10 percent of the fuel mix.

Fuel use trends shown in Figure 1-2 indicate that electricity use increased slightly since 1997. However, the biggest change was in the substitution of natural gas for renewable biomass or hog fuel. Natural gas use declined 10 percent, causing a 10 percent increase in biomass fuel use.

Statistics Canada no longer provides regular reports on each of the subsectors of the wood products industry, thus making it difficult to determine energy use within these industry subsectors. However, statistics indicate that the softwood lumber industry alone is responsible for more than 40 percent of energy use in the wood products sector, making it the single largest energy user in the sector. Also, it is estimated that panel products (e.g. plywood, OSB, PB and MDF) account for another 15 percent of the energy used by the sector.

Figure 1-1 Wood products manufacturing energy use by fuel type

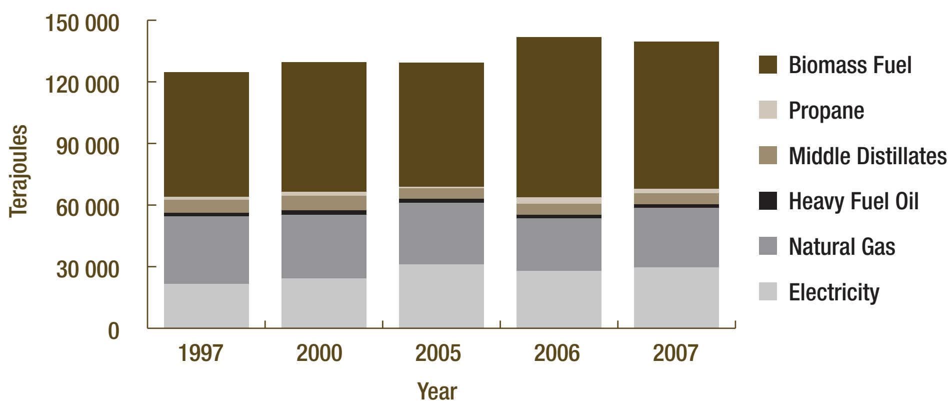
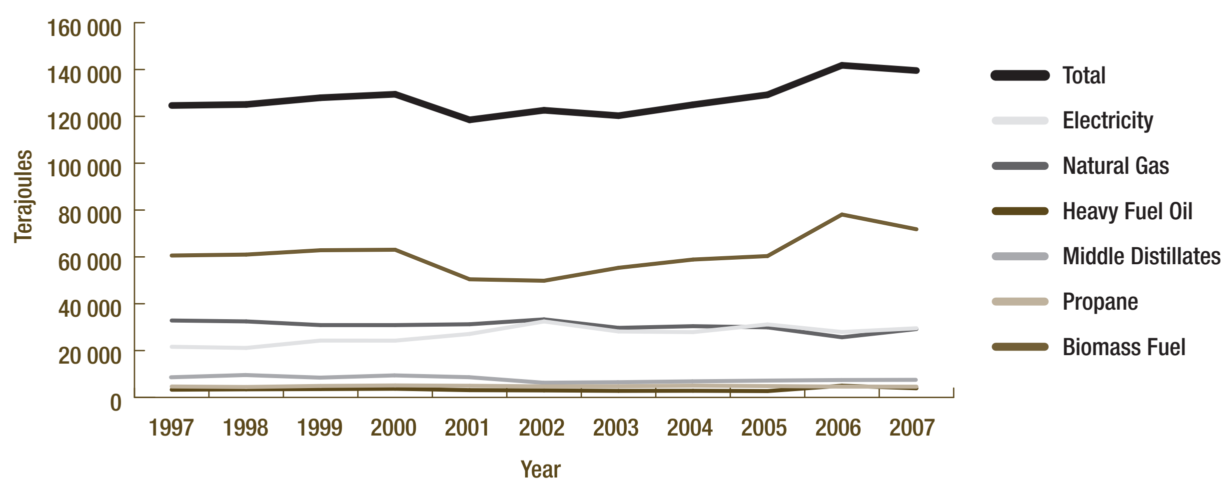


Figure 1- 2 Trend analysis of wood products manufacturing energy use by fuel type



1.2 Industry participants

The benchmark metrics and data developed for the five commodities discussed in this report were derived from surveys of selected mill facilities in each product category. The number of surveys for each product category was determined by the size of the industry and represents a mix of production and energy use data for the years 2006 to 2008.

The goal of the survey was to capture a reasonable snapshot of manufacturing resource and energy use in each product category, based on either the number of establishments or the production output of the sector. Efforts were also made to make the mill sample regionally representative of the product subsector.

Fifteen mills were sampled to construct the benchmark energy use profile for the softwood lumber industry. While there are more than 1000 mills producing lumber in Canada, the industry's production is concentrated in about 200 larger mills in four provinces: British Columbia, Alberta, Ontario and Quebec.

Except for one mill located in New Brunswick, the mills providing resource and energy use data for this study operated in these four primary producing provinces as follows: British Columbia (4 mills), Alberta (2 mills), Ontario (3 mills) and Quebec (5 mills). Combined, the 15 plants surveyed produced more than 5.7 million cubic metres (m^3) annually and accounted for about 8 percent of all softwood lumber produced in the country in 2007. Overall, the average production for the sample mills was about 200 million board feet (470 000 m^3) per year.

Canada's structural softwood plywood production was approximately 2.2 billion m^3 in 2006, 80 percent of which is consumed in Canada. More than 80 percent of softwood sheathing plywood production is located in British Columbia. In 2006 there were 12 softwood plywood sheathing plants operating in Canada. The three British Columbia mills participating in this study represent 25 percent of the plants producing softwood plywood in Canada. Mill data were for the 2006 calendar year. The size of participating production facilities ranged from about 182 to 257 million square feet (MMSF) 3/8-inch basis[2] annually.

Four OSB mills participated in the study, from British Columbia, Alberta, Ontario and Quebec. The four mills represent more than 10 percent of OSB manufacturing establishments, and their combined production is approximately 15 percent of OSB produced in Canada in 2006. Mill data were from the 2006 calendar year. The size of participating production facilities ranged from about 167 to 625 MMSF 3/8-inch basis annually.

Seven composite panel mills were surveyed: three PB and four MDF mills. The PB mills were located in eastern Canada (Quebec and New Brunswick), where the majority of PB is produced in the country, while the MDF mills were dispersed across the country (British Columbia, Alberta, Ontario and New Brunswick). Mill data were from the 2006 calendar year.

The size of production facilities ranged from about 107 to more than 357 MMSF 3/4-inch basis[3] annually. The size of MDF production facilities ranged from about 74 to 168 MMSF 3/4-inch basis

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[2]Thousand square feet (MSF) on a 3/8-inch basis of plywood and OSB is the typical product reporting convention used by the industry. 1 MMSF = 1000 MSF; 1 MSF 3/8-inch basis equals 0.844 m^3.

[3]Thousand square feet (MSF) on a 3/4-inch basis of PB and MDF is the typical product reporting convention used by the industry. 1 MSF 3/4-inch basis equals 1.76979 m^3.

annually. In 2006, 10 PB plants operated in Canada. However, since then, several have either shut down or curtailed production due to resource availability constraints and market conditions. Similarly, seven MDF plants operated in Canada in 2006, but two of these had closed their doors by the time of this study and report.

1.3 Renewable biomass combustion – greenhouse gas reporting versus carbon balance accounting

This report uses a life-cycle approach to track energy use from the cradle (the forest) to the manufactured product at the plant gate. Similarly, it tracks sequestered carbon from the forest and reports a net carbon balance (less GHG emissions) for the manufactured products at the plant gate.

Typical reporting policy for the energy sector (IPCC, 2006) is to consider carbon dioxide (CO_2) emissions from biomass combustion (CO_2 biogenic) as carbon "neutral," because these emissions are part of the natural carbon cycle of the forest. However, under the inventory reporting framework developed by the Intergovernmental Panel on Climate Change (IPCC), it is **not** assumed that biomass combustion is carbon neutral. The assumption is that net carbon emissions from biomass combustion are accounted for under the Land-Use Change and Forestry (LUCF) sector.

In other words, it is assumed that if the combustion of biomass leads to a net change in the stocks of biomass carbon, that change will be captured under the LUCF accounting, and therefore can be ignored for energy emissions reporting purposes. This approach was taken because of the problem with double counting if emissions were estimated under the energy sector and then also accounted for under the LUCF sector. So although CO_2 emissions from biomass burned for energy are typically considered as being neutral for GHG energy sector reporting, these emissions are accounted for when calculating a net carbon balance.

Because a carbon balance includes the carbon sequestered in growing biomass (i.e. CO_2 removed from air), all the associated carbon emissions (including those from biomass combustion) must be taken into consideration when determining the net carbon balance. This study reports the global warming potential[4] (GWP) associated with both fossil fuel and biomass combustion. Remember that when you calculate energy-related GHG emissions from the statistics in this study, the biomass-related GWP values can be ignored (i.e. treated as neutral). However, when you calculate the net carbon balance for a particular product, the biomass-related GWP emissions must be included.

[4]An equivalence method for aggregating all GHGs relative to the effect of adding a similar unit of CO_2 to the atmosphere.

1.4 Report layout

The remainder of this report is organized into the following chapters:

- Chapter 2 discusses the energy use and intensity in the procurement of the wood raw material resource that the industry depends upon.
- Chapter 3 presents the gross energy profile results for the softwood lumber industry.
- Chapter 4 presents the energy profile results for the softwood plywood industry.
- Chapter 5 presents energy benchmark findings for the OSB industry.
- Chapter 6 presents the energy use results for the non-structural composite panel industry – PB and MDF.
- Chapter 7 presents a summary of the five commodities.
- Chapter 8 provides an overview of how the various Canadian wood product subsectors compare with similar international studies of energy use and intensity.
- Chapter 9 reviews potential energy reduction technologies and management practices relevant to the industry.

2 RESOURCE EXTRACTION, FOREST MANAGEMENT AND RESOURCE TRANSPORTATION

2 RESOURCE EXTRACTION, FOREST MANAGEMENT AND RESOURCE TRANSPORTATION

As part of the survey of softwood lumber mills, the study questionnaire gathered energy use information associated with resource extraction (wood harvesting), forest management and transportation of fibre to the mills, to determine the energy use involved in these key upstream activities.

In the past, the majority of Canada's softwood lumber industry was integrated back to the forest and the industry directly operated and controlled its own woodlands operations. Today the industry is more likely to contract or outsource this activity to subcontractors. Hence, companies that own and operate mills have less control and less first-hand information available concerning woodlands operations and are more reliant on their third-party contractors to provide the information on the harvesting, management and hauling of wood to their mills. This study relies on a mix of information from companies that either operate their own forestry divisions or use third-party contractors to supply their mills.

Twelve of the 15 mills in the study completed questionnaires about resource harvesting, forest management and transportation. Eight of the mills are in Ontario and Quebec (eastern Canada) and four are in British Columbia and Alberta (western Canada). Table 2-1 presents western and eastern Canada averages for salient operating parameters from the forest to the mill gate.

Wood harvesting is dominated by mechanical systems in both eastern and western Canada. While spruce is the primary wood specie harvested in eastern Canada, pine dominates the species mix in western Canada. Overall, the SPF (spruce, pine, fir) species group represents 90 percent of the species mix harvested and used by the softwood lumber industry. A small amount of poplar and birch is also harvested from mixed stands.

Based on the species mix harvested, an average density of 392 kilograms per cubic metre (kg/m^3) was calculated. As trees grow, they sequester carbon. The carbon content of wood is approximately 50 percent (varies between 48 percent and 53 percent, depending on the species). Given an average SPF density of 392 kg/m^3 and a stored carbon content of 50 percent, it is estimated that, on average, 1 m^3 of raw wood arriving at the mill gate contains 196 kg of carbon (C) or 719 kg on a CO_2 equivalent (CO_2e) basis[5] (392*0.5*44/12).

On average, wood fibre is transported 100 kilometres (km) from the forest to the mill. Hauling distances are 20 percent farther for eastern plants compared to western plants. For every cubic metre of merchantable wood harvested, about 52 m^2 (or 0.0052 hectares [ha][6]) of forest are harvested (66 m^2 in the east and 36 m^2 in the west).

The difference between eastern and western area requirements per cubic metre is primarily a function of tree size at time of harvest. The average tree size is larger and the average rotation age is longer in the west than in the east (102 versus 87 years). The survey data also indicated that, for every cubic metre harvested, about 3.5 seedlings are planted and 92 milligrams (mg) of seeds are broadcast.

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[5]Molecular weight of CO_2 (44) relative to C (12).

[6]1 ha equals 10 000 m^2.

Diesel fuel is the primary energy input utilized by the industry in both wood harvesting and hauling operations; minor amounts of liquid propane and purchased electricity is also used. Generally, energy use was similar for both harvesting and transportation activities, but lower in the west than in the east for both harvesting (stump-to-roadside) and hauling (roadside-to-mill). The lower energy use in the west reflects a generally larger resource size (fewer pieces handled per m^3 harvested) and shorter hauling distances relative to eastern Canada.

Table 2-1 Operating parameters and fuel use by activity from forest to mill

Item	Unit	Canada	Eastern	Western
		Averages		
Sample size*	number	12	8	4
Harvesting method	percentage			
Mechanical felling	%	97	99	94
Manual felling	%	3	1	6
Tree species	percentage			
Spruce	%	40	54	21
Pine	%	42	21	68
Fir	%	10	14	6
Other	%	8	11	5
Average density (volume green, mass oven dry)	kg/m^3	392	383	402
Carbon content	CO_2e kg/m^3	719	702	737
Average hauling distance	km	103	111	88
Silviculture and land use	per m^3 harvested			
Seedlings planted	number	3.5000	3.9000	3.1000
Aerial seeding	mg	92.0000	82.0000	37.8000
Area harvested	ha	0.0052	0.0066	0.0036
Rotation age at harvest	years	94.0000	87.0000	102.0000
Energy use by fuel type	per m^3 harvested and delivered			
Diesel fuel (harvesting)	L	2.8400	3.2900	2.2600
Liquid propane gas (LPG)	L	0.0006	0.0000	0.0013
Electricity	kWh	0.0296	0.0296	0.0296
Diesel fuel (hauling)	L	3.1100	3.3000	2.7000

*The sample size indicates the number of completed surveys received and used to construct the regional and national averages reported in Table 2-1.

Table 2-2 summarizes wood harvesting and transportation energy use on the basis of common heat content (MJ) per cubic metre harvested and delivered to the plant. It also provides a measure of the GHG emissions (GWP) on a CO_2e basis associated with harvesting and wood transportation,[7] as well as a net carbon balance for wood delivered to the plant gate. Across Canada, it takes about 265 MJ to harvest and transport 1 m^3 of round wood to a mill. In the process, about 19 kg of GHGs are emitted. Upon arrival at the plant, the net carbon balance of wood is approximately 700 kg/m^3 on a CO_2e basis.

Table 2-2 Harvesting and transportation energy use, GHG emissions and net carbon balance

Item	Unit	Canada	Eastern	Western
Energy use by fuel type	per m^3 harvested and delivered	Averages		
Diesel fuel (harvesting)	MJ	126.780	146.870	100.890
Liquid propane gas (LPG)	MJ	0.018	0.000	0.039
Electricity (Primary Energy)	MJ	0.150	0.150	0.150
Diesel fuel (Hauling)	MJ	139.010	147.120	120.590
Total energy use	MJ	**266**	**294**	**222**
Global warming potential	CO_2e kg	19	21	16
Carbon balance at mill gate	CO_2e kg	700	681	721

[7]See Appendix A for heating values and GWP factors by fuel type used throughout this report.

3 SOFTWOOD LUMBER MANUFACTURE

3 SOFTWOOD LUMBER MANUFACTURE

The softwood lumber industry is the largest sector within the Canadian wood products industry. In 2007, the industry produced about 72 million m^3 of lumber, down from its peak production of 85 million m^3 in 2004.

Canada has more than 1000 softwood sawmills, with capacities of up to 1 billion board feet (1.6 million m^3). Although softwood lumber is produced across the country, production is concentrated in British Columbia, Alberta, Ontario and Quebec. Since its peak production in 2004, the industry has shrunk dramatically due to increasing trade and economic pressures.

The two typical mill set-ups for producing softwood lumber are dimension type and stud type.

Dimension-type mills typically produce a wide array of widths and lengths of

- boards nominally 1 inch (in.) (19 millimetres [mm]) thick
- construction-grade lumber in boards nominally 2 in. (38 mm) thick
- material greater than 2 in. (38 mm) nominal thickness, commonly referred to as a shop or specialty grade lumber

Stud-type mills are highly specialized facilities dedicated to producing 2-in. nominal (38 mm) construction grade lumber in lengths typically used in wall construction – 8 to 10 feet (2.4 to 3 m).

Of the 15 mills in the study, 63 percent were dimension mills and 26 percent were stud mills. Another 11 percent of the sample mills ran both dimension and stud lines in the same mill facility.

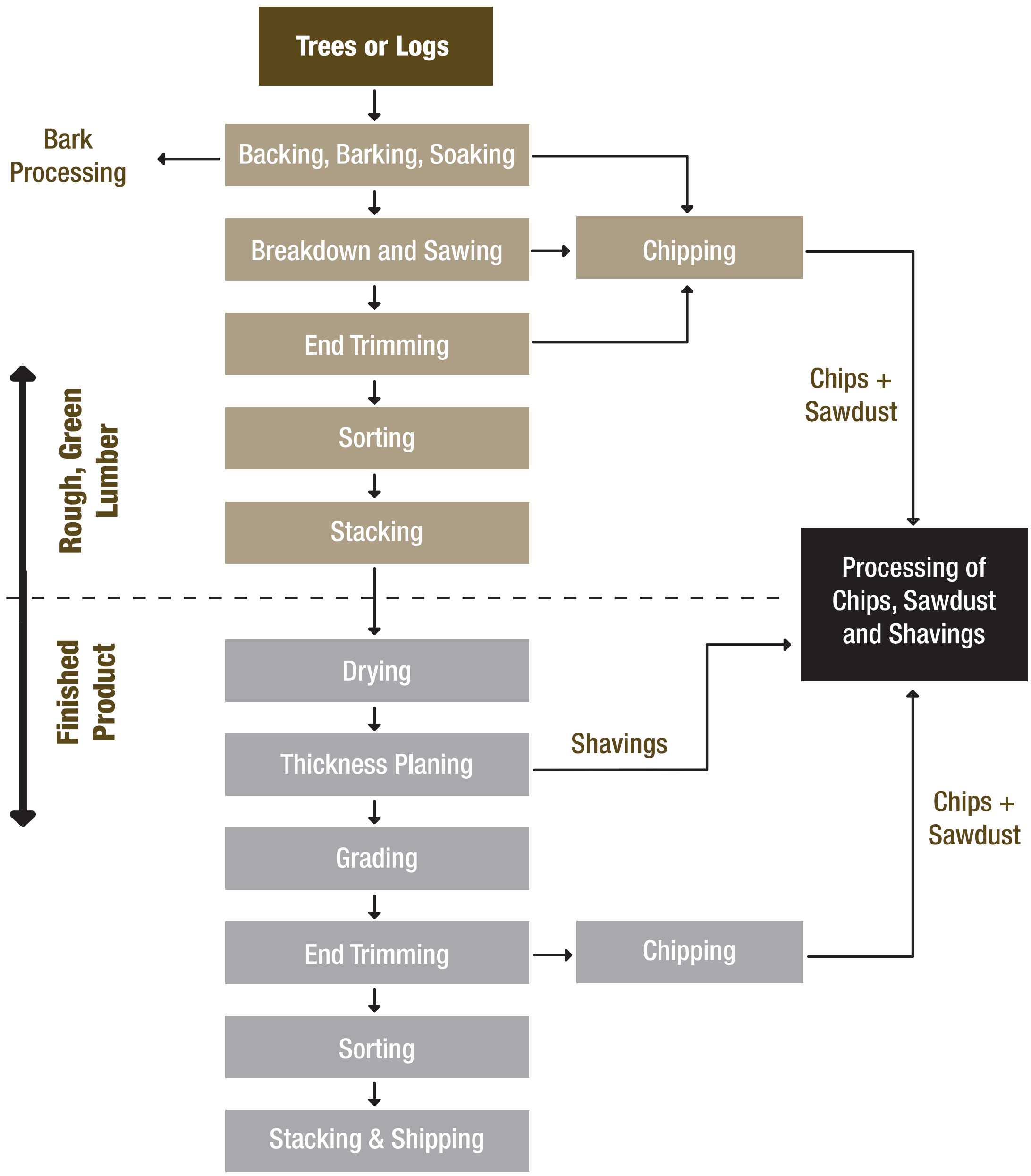
The lumber size profile produced by the sample mills was dominated by the production of 2-in. construction-grade lumber (95 percent) with 2x4s (38 mm x 89 mm) and 2x6s (38 mm x 140 mm) accounting for more than 75 percent of the total production. Combined, the 15-mill sample produces 5.7 million m^3 annually, which is about 8 percent of the softwood lumber produced in the country. The average production for the sample mills was about 200 million board feet (470 000 m^3 per year[8]).

The production of softwood lumber entails three discrete and linear unit processes – sawing, kiln drying, and surface planing and packaging. Figure 3-1 provides an overview of the milling process.

The sawing process includes all handling, sorting and debarking of logs. It also includes the breakdown of logs into rough green lumber of various thicknesses, widths and lengths. During the sawing process, co-products of production are produced (sawdust, pulp chips, trimmings, bark and wood fines). A large portion of the co-products is sold to other wood processors while other portions remain on site to be used to fuel boiler systems to heat site buildings and to dry lumber. The sawing unit process is highly automated, employing computer controlled scanning, optimizer and conveyance systems.

[8]Canadian government production statistics use a conversion factor of 2.36 m^3 per thousand board feet (Mfbm) of lumber. However, this conversion factor is based on the nominal volume of lumber produced instead of the actual volume of lumber produced; i.e. the 2.36 factor would apply if the lumber were actually 2 in. x 4 in. But in fact, a nominal 2x4 is only 1.5 in. x 3.5 in. Later in the report, a conversion factor of 1.594 m^3/nominal Mfbm of lumber is used to represent the actual wood volume produced in cubic metres.

Figure 3-1 Schematic overview of softwood lumber production



In the drying unit process, packets or charges of rough green lumber are loaded into kilns to be dried to a moisture content of less than 19 percent. Often, the lumber packets are presorted by dimension, species, and/or initial moisture content to better control the drying process. The lumber is usually heated by steam or by hot oil coils, and fans circulate and displace the humid air produced during the drying process. The kiln drying unit process uses the largest amount of process heat energy in the production of lumber, and the process is closely monitored to achieve the target final moisture content and to minimize degradation of the lumber.

The third unit process is surface planing and packaging. After the drying, the rough-dry lumber goes to the planing mill. Pieces are fed into a planer and machined to their final thickness and width. After exiting the planer, the pieces are trimmed to their final length and then graded. Similar size and grade material are stacked, strapped and wrapped in preparation for final shipment. During the planing process, several co-products are produced, such as sawdust, planer shavings, pulp chips and trim ends. Some of these co-products will be sold or transferred to other wood processors, and some may be retained to fire on-site wood boilers.

So that mills can compare their own energy performance against the average presented for the 15 mills in this survey, the results of this study have been limited to gross energy use in the manufacture of softwood lumber from the forest to the completed product ready for shipment at the plant gate.

That means that the study does not allocate or attribute a portion of the energy used to the production of co-products sold or transferred to other wood processors (which is the conventional practice for a detailed life-cycle assessment study of a multiproduct system). It is believed that most of the mills have their basic plant energy use data accessible and can compare their energy use intensity to the manufacturing energy values reported herein.

Table 3-1 presents a wood mass balance for the production of softwood lumber for the 15-mill study sample. Of the solid wood (excluding bark) entering an SPF sawmill, 47 percent is processed into lumber. Pulp chips are the second largest product component, averaging 35 percent of the output, while sawdust and planer shavings represent 12 percent of the output. Bark and wood waste represent around 10 percent of the output.

Table 3-2 summarizes the gross cradle-to-gate energy use for the production of Canadian softwood lumber on both a nominal Mfbm (thousand board feet) and an actual m^3 (cubic metre) basis. It also provides a breakdown of energy use in physical fuel use and common energy units for resource harvesting and softwood lumber manufacturing activity stages. On average, manufacturing 1 Mfbm of lumber requires 3.9 m^3 of logs[9] and 3454 MJ of energy. Harvesting and resource transportation use mostly diesel fuel and use 30 percent of the gross energy required to produce softwood lumber.

[9]Across the 15-mill sample, an average density of 393.7 kg/m^3 was calculated on the basis of species mix entering the mills.

Table 3-1 Wood mass balance for softwood lumber production

Inputs and outputs	Unit	Per m^3	Per Mfbm	Percentage (%)
Inputs				
Roundwood (including bark)	kg	968	1543	100
Total inputs	kg	**968**	**1543**	**100**
Outputs				
Softwood lumber	kg	417	665	43
Bark	kg	86	137	9
Planer shavings	kg	61	97	6
Sawdust	kg	54	87	6
Pulp chips	kg	334	533	35
Trim ends	kg	6	9	1
Chipper fines	kg	2	3	0
Wood waste	kg	7	12	1
Total outputs	kg	**967**	**1543**	**100**

Within lumber manufacturing, renewable biomass accounts for 51 percent of the total gross energy used. Purchased electricity is the next most used energy form (24 percent), followed by natural gas (17 percent) and diesel fuel (7 percent) (used to power mobile yard equipment).[10] Fuel use for other mobile equipment (gasoline and LPG) accounts for less than 1 percent of gross energy use.

Survey respondents also provided a breakdown of gross energy use across the three unit manufacturing processes – sawing, kiln drying, and surface planing and packaging of lumber (see Table 3-3). Results show that kiln drying is the most energy-intensive unit process, accounting for 66 percent of the energy used in the production of softwood lumber. The sawing and surface planing and packaging unit processes account for 24 percent and 10 percent of manufacturing energy use, respectively. The sawing unit process uses most of the purchased electricity (70 percent), while kiln drying uses 73 percent of the natural gas and 97 percent of the biomass thermal fuels consumed in the manufacture of softwood lumber.

Table 3-4 presents a cradle-to-gate compilation of the GHGs (GWP on a CO_2e mass basis) emitted in the production of softwood lumber due to fossil fuel use and biomass combustion. It also presents the net cradle-to-gate carbon balance for softwood lumber. The process of producing 1 m^3 of softwood lumber emits 188 kg of GHGs on a CO_2e mass basis, 52 percent of which emanates from the combustion of renewable biomass (hog fuel). However, the same amount of softwood lumber has a carbon content of 765 kg CO_2e basis and thus achieves a net carbon sequestration of 577 kg CO_2e basis. This calculation shows that there is about **four times more carbon sequestered** in a cubic metre of softwood lumber than is released to the atmosphere during its manufacture.

[10] Note: One plant operated a co-generation facility and sold electricity back to the grid. The value reported in Table 3-2 reflects the net electricity use in lumber manufacturing after sales back to the grid. In addition, several mills purchased steam from nearby pulp facilities.

Table 3-2 Gross cradle-to-gate energy use – softwood lumber manufacture

Fuel type in physical units	Unit	Resource harvest and transport	
		Per m^3	Per Mfbm
Diesel fuel (harvesting)	L	6.980	11.13
Liquid propane gas (LPG)	L	0.001	0.00
Electricity	kWh	0.073	0.12
Diesel fuel (hauling)	L	7.640	12.19
(based on Canadian average resource harvesting values with resource transportation adjusted to a 103-km hauling distance)			
Fuel type in physical units	**Unit**	**Lumber manufacture**	
		Per m^3	**Per Mfbm**
Electricity	kWh	70.83	112.90
LPG	L	0.19	0.30
Diesel	L	2.57	4.10
Natural gas	m^3	6.09	9.70
Gasoline	L	0.06	0.10
Hog fuel (internal)	kg	40.96	65.30
Steam (hog fuel) from pulp	MJ	127.29	202.90
Primary energy use in MJ	**Unit**	**Resource harvest and transport**	
		Per m^3	**Per Mfbm**
Diesel fuel (harvesting)	MJ	311.64	496.78
LPG	MJ	0.04	0.07
Electricity	MJ	0.37	0.59
Diesel fuel (hauling)	MJ	341.27	544.01
Subtotal	MJ	**653.33**	**1041.45**
Primary energy use in MJ	**Unit**	**Lumber manufacture**	
		Per m^3	**Per Mfbm**
Electricity	MJ	358.73	571.84
LPG	MJ	5.71	9.11
Diesel	MJ	114.82	183.02
Natural gas	MJ	257.24	410.06
Gasoline	MJ	2.51	4.00
Hog fuel	MJ	647.24	1031.74
Steam (hog fuel external)	MJ	127.29	202.90
Subtotal	MJ	**1513.54**	**2412.67**
Grand total	MJ	**2166.87**	**3454.12**

Table 3-3 Gross manufacturing stage energy use – softwood lumber

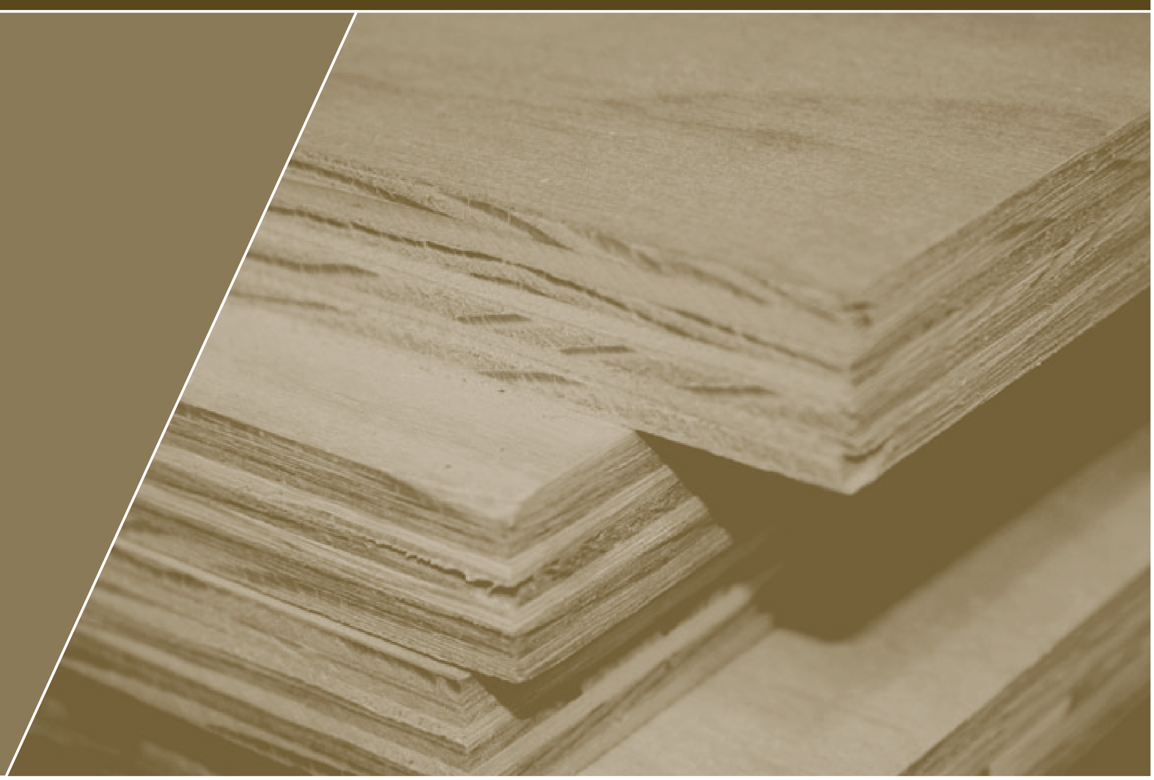
Primary energy use	Unit (per m³)	Total	Sawing	Kiln drying	Surface planing and packaging
Electricity	MJ	359	251	32	75
LPG	MJ	6	2	1	3
Diesel	MJ	115	58	30	27
Natural gas	MJ	257	41	188	28
Gasoline	MJ	3	2	0	1
Hog fuel	MJ	647	–	647	–
Steam (hog fuel external)	MJ	127	13	102	13
Total manufacturing	MJ	**1514**	**367**	**1000**	**146**
Percentage	%	**100**	**24**	**66**	**10**

Table 3-4 Global warming potential and net carbon balance – softwood lumber

GWP due to	Unit	Per m³	Per Mfbm
Fossil fuel use*	CO_2e kg	90.45	144.18
Biomass combustion	CO_2e kg	97.19	154.93
Total	CO_2e kg	**187.64**	**299.11**
Carbon sequestered in softwood lumber	CO_2e kg	764.55	1218.73
Net carbon balance			
excluding biomass GHGs	CO_2e kg	674.10	1074.55
including biomass GHGs	CO_2e kg	576.91	919.62

*Includes combustion and precombustion effects associated with the use of thermal fossil fuel (process heat and mobile equipment) and the Canadian average electricity grid in harvesting, transporting and manufacturing softwood lumber.

4 SOFTWOOD PLYWOOD MANUFACTURE



4 SOFTWOOD PLYWOOD MANUFACTURE

This chapter presents the results of a cradle-to-gate life-cycle assessment (LCA) study of Canadian softwood plywood production completed in the first quarter of 2008.[11] The study used both secondary and primary data sources to arrive at a life-cycle environmental profile for plywood production.

The primary material and energy use data were collected from three British Columbia plywood facilities during the 2006 calendar year. The three plants and their combined production comprise more than 25 percent of Canadian softwood plywood manufacturing establishments and softwood plywood sheathing produced in the country. The production size of the facilities ranged from about 154 000 to 217 000 m^3 (182 to 257 MMSF 3/8-inch basis) annually.

Some data in the LCA study were adjusted to include recent data developed for this report. For example, the resource extraction data reflect those presented in Chapter 2 of this report for western Canada. In addition, the LCA study accounted for a number of ancillary inputs (e.g. adhesives and packaging materials) and used attributional partitioning to isolate the net effect of resource, energy and environmental flows to plywood and its co-products of production leaving the plywood system boundary. For this energy use status report, the values reported are for gross energy use without any allocation to co-products or accounting for ancillary material use.

The manufacture of plywood involves a series of processing steps. After the log is delivered to the mill, it is debarked and then conditioned in a log pond to improve the peel quality. The log is sent from the log pond to a lathe. As the lathe spins, a sharp cutter blade peels the log (now called a block) into a continuous sheet of veneer, 3 mm thick. The veneer is cut into lengths and sorted by moisture content, in preparation for drying.

Veneers are dried in "continuous dryers" to a moisture content of 3 to 8 percent. Veneers are then coated with phenol-formaldehyde resin and laid into panels (alternating the orientation of each layer) for hot pressing. Heat and pressure cure the resin, thereby bonding the veneer layers to make plywood. After being pressed, the plywood panels are trimmed, patched where necessary, and sorted by grade. Plywood mills typically use process wood waste (hog fuel) and/or natural gas to fire boilers to meet their process heat needs. Figure 4-1 provides a graphic overview of the plywood manufacture process.

Manufacturing plywood is a multiproduct system. During the process, several co-products are produced (e.g. pulp chips, peeler cores, veneers and clippings, and hog fuel [bark and sawdust]). Table 4-1 provides a mass balance summary of the inputs and outputs for the three plywood mills surveyed for this study, on both a cubic metre (m^3) and a thousand square feet (MSF) 3/8-inch basis.

The mass balance indicates that 50 percent of the raw wood and purchased veneer input becomes softwood plywood.[12] Another 11 percent of the incoming biomass is used internally as a thermal fuel (referred to as hog fuel) to dry veneer and in pressing operations. Sold or transferred co-products of production (e.g. veneers, pulp chips, peeler cores and hog fuel) represent 36 percent of the wood input, while the remaining 3 percent of the hog fuel produced is stockpiled on site. None of the mills reported any incoming resource as waste destined for landfill.

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[11] Athena Institute (2008). A cradle-to-gate life-cycle assessment of Canadian softwood plywood sheathing. Prepared for FP Innovations, Forintek Division, Vancouver, B.C.

[12] Gross roundwood input was determined to be 1.7 m^3/m^3 of plywood output (1.96 m^3/MSF of plywood 3/8-inch basis).

Figure 4-1 Schematic overview of softwood plywood production

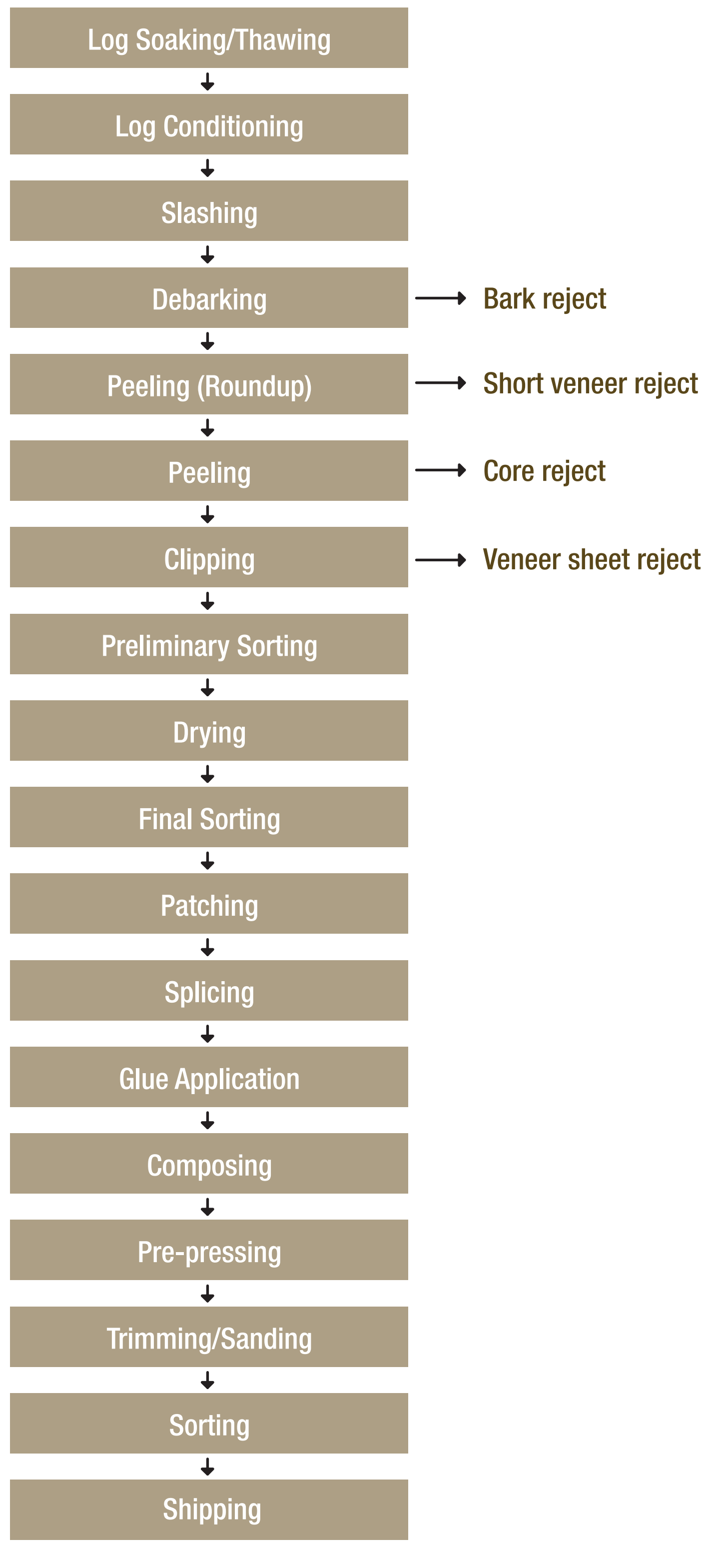


Table 4-1 Wood mass balance for softwood plywood production

Inputs and outputs	Unit	Per m^3	Per MSF (3/8-inch basis)	Percentage (%)
Inputs				
Roundwood (including bark)	kg	629.6	746	97.9
Purchased veneer dry	kg	6.8	8.1	1.1
Purchased veneer, green	kg	6.7	7.9	1.0
Total inputs	kg	**643.1**	**762.0**	**100.0**
Outputs				
Softwood plywood (wood only)	kg	320.2	379.33	49.8
Wood hog fuel (produced and used internally)	kg	72.4	85.76	11.3
Veneer, sold (green and dry)	kg	2.2	2.65	0.3
Peeler cores, sold	kg	57.9	68.55	9.0
Pulp chips, sold	kg	124.7	147.8	19.4
Hog fuel sold	kg	49.0	58.0	7.6
Wood hog fuel stockpiled (inventory)	kg	16.8	19.9	2.6
Total outputs	kg	**643.1**	**762.0**	**100.0**

Table 4-2 summarizes the gross energy use in the manufacture of plywood, including that associated with the harvesting and transport of wood fibre to the plant for the production of 1 m^3 and MSF 3/8-inch basis softwood plywood.

Eighty-two percent of the energy used in the production of plywood is consumed during the manufacturing stage. Fifty-nine percent of the direct energy inputs into manufacturing is derived from renewable biomass fuel. Natural gas is the next most used fuel in the manufacturing of plywood and accounts for 34 percent of the gross energy input.

Both natural gas and biomass fuels are primarily used in the drying of the veneer prior to lay-up, and the drying process typically accounts for 80 percent of all energy used in the plant.[13] Three percent of the energy used in the plant is electricity, and is primarily consumed in material conveyance, peeling and pressing operations. The majority of other fuels (diesel, gasoline and LPG) are used to operate yard and plant mobile equipment. Given these gross energy values, it is apparent that any energy use reduction program should first focus on thermal fuel used in veneer drying.

Table 4-3 summarizes the GWP (CO_2e kg) associated with the production of softwood plywood. It also presents a carbon balance for softwood plywood from the forest to the finished product at the plant gate. The production of 1 m^3 of plywood creates 209 kg of CO_2e GHG emissions.

Biomass combustion contributes 64 percent of these GHGs. However, CO_2 emissions from renewable biomass are typically considered to be carbon neutral and are otherwise not considered a

[13]Forintek files – Plywood Improvement Program, various years.

direct contributor to global warming and climate change. However, as discussed in Section 1.3, the Intergovernmental Panel on Climate Change[14] adopted a protocol for reporting a carbon balance, which calls for crediting sequestered carbon ("carbon from air") but also debiting any anthropogenic releases of carbon ("carbon to air"), including those due to biomass combustion. Hence the net carbon balance for plywood is reduced when biomass combustion emissions are included but remain significantly positive – that is, the **carbon sequestered in plywood is 2.8 times more** than that emitted during its production.

Table 4-2 Gross cradle-to-gate energy use – softwood plywood manufacture

Fuel type in physical units	Unit	Resource harvest and transport	
		Per m³	Per MSF
Diesel fuel (harvesting)	L	3.690	4.370
LPG	L	0.002	0.003
Electricity	kWh	0.049	0.058
Diesel fuel (hauling)	L	5.590	6.620
(based on western Canada resource harvesting values with resource transportation adjusted to a 110-km hauling distance)			
Fuel type in physical units	**Unit**	**Plywood manufacture**	
		Per m³	**Per MSF**
Electricity	kWh	103.21	122.29
LPG	L	0.27	0.32
Diesel	L	1.23	1.46
Natural gas	m³	15.77	18.68
Gasoline	L	0.03	0.03
Hog fuel	kg	72.42	85.8
Primary energy use in MJ	**Unit**	**Resource harvest and transport**	
		Per m³	**Per MSF**
Diesel fuel (harvesting)	MJ	164.670	195.110
LPG	MJ	0.065	0.077
Electricity (B.C. grid)	MJ	0.029	0.034
Diesel fuel (hauling)	MJ	249.360	295.450
Subtotal	MJ	**414.124**	**490.671**
Primary energy use in MJ	**Unit**	**Plywood manufacture**	
		Per m³	**Per MSF**
Electricity (B.C. grid)	MJ	60.48	71.66
LPG	MJ	8.20	9.72
Diesel	MJ	55.01	65.17
Natural gas	MJ	666.49	789.68
Gasoline	MJ	1.01	1.20
Hog fuel	MJ	1144.16	1355.64
Subtotal	MJ	**1935.35**	**2293.07**
Grand total	MJ	**2349.47**	**2783.74**

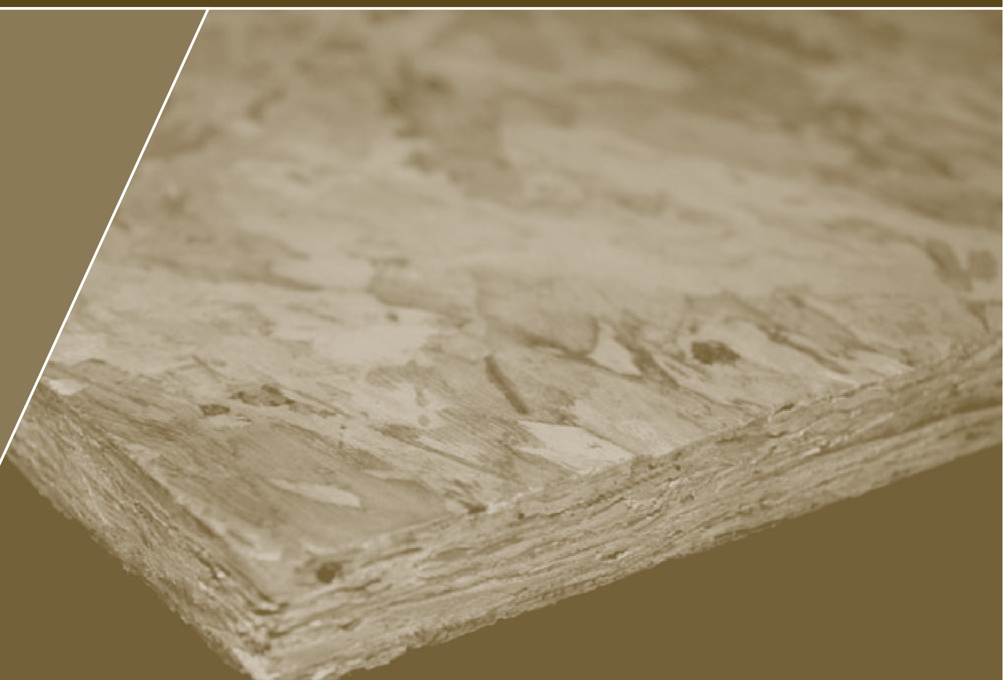
[14]Intergovernmental Panel on Climate Change – Land Use, Land-use Change and Forestry 2006.

Table 4-3 Global warming potential and net carbon balance – softwood plywood

GWP due to	Unit	Per m^3	Per MSF
Fossil fuel use*	CO_2e kg	76.08	90.14
Biomass combustion	CO_2e kg	133.24	157.87
Total	CO_2e kg	**209.32**	**248.01**
Carbon sequestered in plywood	CO_2e kg	586.95	695.44
Net carbon balance			
excluding biomass GHGs	CO_2e kg	510.87	605.30
including biomass GHGs	CO_2e kg	377.63	447.43

*Includes combustion and precombustion effects associated with the use of thermal fossil fuel and the B.C. electricity grid in harvesting, transporting and manufacturing plywood.

5 ORIENTED STRAND BOARD MANUFACTURE



This chapter uses results from a cradle-to-gate LCA study of Canadian OSB production completed in the first quarter of 2008. The study used both secondary and primary data sources to arrive at a final life cycle environmental profile for OSB. The primary material and energy use data were collected from four OSB facilities during the 2006 calendar year.

Canada's OSB production capacity in 2006 was approximately 10 billion m^3 (14 billion square feet [sq. ft.] 3/8-inch basis); 75 percent of production is typically exported to the United States. Production peaked in 2005 and has since reduced due to a decrease in housing starts in the United States. In 2006, 36 OSB plants operated in Canada.

The four OSB mills in this study represent slightly more than 10 percent of all plants producing OSB in Canada and 13 percent of all OSB produced in the country in 2006. The four mills are located in different provinces (British Columbia, Alberta, Ontario and Quebec), providing a good representation of geographical distribution of Canadian OSB production.

The annual production size of participating facilities ranged from about 167 to 625 MMSF 3/8-inch basis. Some data in the LCA study were adjusted to reflect more recent data developed for this study. For example, the resource extraction data reflect those presented in Chapter 2 of this report for Canada.

Also, the OSB LCA study accounted for several ancillary inputs (e.g. adhesives, wax and packaging material inputs) and apportioned some of the manufacturing resource and energy use and emissions to air, water and land to the co-products as they leave the OSB system boundary. For this energy benchmarking report, the values reported are for gross energy use without any allocation to co-products. Ancillary material use was also excluded.

The manufacture of OSB involves a series of processing steps. Figure 5-1 illustrates the steps involved in manufacturing OSB.

At the mill, the logs are soaked in a heated pond to remove ice and debris and to condition the wood for strand manufacturing. The logs are then debarked; the bark is used as fuel in the mill's energy supply. Strands are cut from the debarked logs in dimensions of up to 150 mm (6 in.) long. The strands are put in bins and dried until the appropriate moisture content is reached. After they are dry, the strands are blended with resin binders and wax, which improves the efficiency of the resin binder and enhances the panel's resistance to moisture absorption.

Strands go through a forming line where cross-directional layers are formed. The layers are pressed together under intense heat and pressure to form a rigid, dense structural panel. The OSB panels are cooled, cut to size, graded and edge-coated.

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[15]Athena Institute (2008). A cradle-to-gate life cycle assessment of Canadian Oriented Strand Board. Prepared for FP Innovations, Forintek Div. Vancouver, B.C.

Figure 5-1 Schematic overview of OSB production

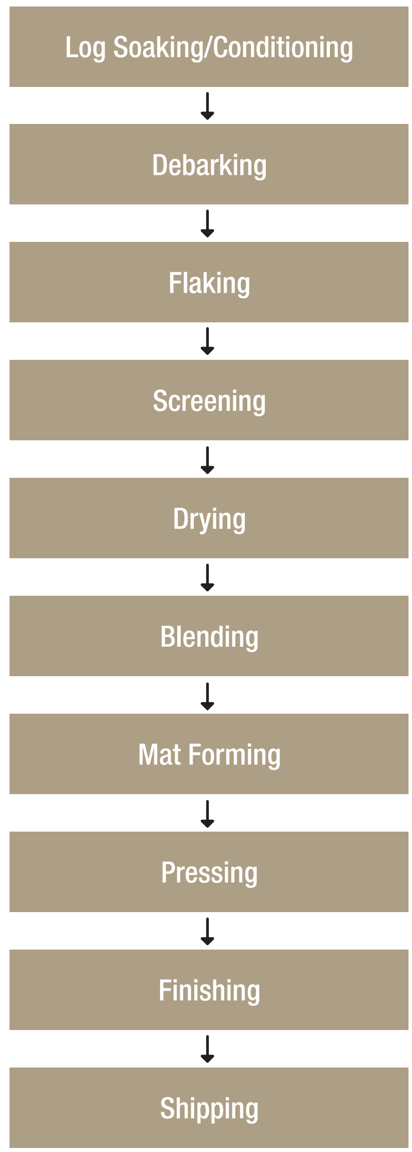


Table 5-1 provides a mass balance summary of the wood inputs and outputs for the four OSB mills surveyed for this study on both a m^3 and MSF basis.

Table 5-1 Wood mass balance for OSB production

Inputs and outputs	Unit	Per m^3	per MSF (3/8-inch basis)	Percentage (%)
Inputs				
Roundwood (including bark)	kg	529.4	627.35	100.0
Total inputs	kg	**529.4**	**627.35**	**100.0**
Outputs				
OSB (wood only)	kg	420.0	497.66	79.3
Wood used as fuel	kg	86.2	102.12	16.3
Wood by-products transferred	kg	15.5	18.42	2.9
Wood stockpiled	kg	6.1	7.22	1.2
Wood waste	kg	1.6	1.93	0.3
Total outputs	kg	**529.4**	**627.35**	**100.0**

The mass balance indicates that approximately 79 percent of the raw wood input becomes the primary product (OSB), and another 16 percent of the incoming biomass is used as a thermal fuel in the drying of wood strands. Of the remaining raw wood resource input, 2.9 percent becomes by-products that are transferred to other wood processors. Another 1.2 percent of the by-products are stockpiled, and wood waste comprises 0.3 percent of the log input and is deposited in a landfill.

Table 5-2 summarizes the gross energy use in the manufacture of OSB as well as that associated with the harvesting and transport of wood fibre to the plant for the production of 1 m^3 and 1000 sq. ft. 3/8” basis OSB. Raw wood procurement (harvesting and transport) uses 14 percent of the energy used in OSB production. Seventy percent of the direct energy inputs into OSB manufacturing is derived from renewable biomass fuel.

Electricity is the next most-used energy input in the manufacturing of OSB and accounts for 24 percent of the gross manufacturing energy use. Process heat derived from biomass is primarily used in the drying of the strands prior to lay-up and to provide the heat required during board pressing. The majority of other fuels (diesel, gasoline and LPG) are used to operate yard and plant mobile equipment.

Table 5-2 Gross cradle-to-gate energy use – OSB manufacture

Fuel type in physical units	Unit	Resource harvest and transport	
		Per m³	Per MSF
Diesel fuel (harvesting)	L	3.520	4.170
LPG	L	0.001	0.001
Electricity	kWh	0.037	0.044
Diesel fuel (hauling)	L	4.760	5.640
(based on Canadian average resource harvesting values with resource transportation adjusted to a 127-km hauling distance)			
Fuel type in physical units	**Unit**	**OSB manufacture**	
		Per m³	**Per MSF**
Electricity	kWh	104.4100	123.7100
LPG	L	0.1400	0.1700
Diesel	L	1.1900	1.4100
Natural gas	m^3	2.0800	2.4700
Gasoline	L	0.0000	0.0035
Hog fuel	kg	96.6400	114.5000
Fuel oil	L	0.1266	0.1500
Primary energy use in MJ	**Unit**	**Resource harvest and transport**	
		Per m³	**Per MSF**
Diesel fuel (harvesting)	MJ	157.290	186.360
LPG	MJ	0.023	0.027
Electricity	MJ	0.186	0.220
Diesel fuel (hauling)	MJ	212.650	251.960
Subtotal	MJ	**370.149**	**438.567**
Primary energy use in MJ	**Unit**	**OSB manufacture**	
		Per m³	**Per MSF**
Electricity	MJ	528.84	626.59
LPG	MJ	4.36	5.16
Diesel	MJ	53.12	62.94
Natural gas	MJ	88.13	104.42
Gasoline	MJ	0.12	0.14
Hog fuel	MJ	1526.88	1809.10
Fuel oil	MJ	5.65	6.70
Subtotal	MJ	**2207.10**	**2615.05**
Grand total	MJ	**2577.25**	**3053.62**

The production of 1 m[3] of OSB creates 244 kg of GHGs on a CO_2e basis (see Table 5-3). Biomass combustion produces 73 percent of these GHGs. Based on final product density, the carbon sequestered in OSB is approximately 770 kg on a CO_2e basis. The net carbon balance for OSB, including the GHG emissions related to biomass combustion, is 527 kg CO_2e or **three times** the amount of GHGs emitted from its production.

Table 5-3 Global warming potential and net carbon balance – OSB

GWP due to	Unit	Per m^3	Per MSF
Fossil fuel use*	CO_2e kg	65.66	77.80
Biomass combustion	CO_2e kg	177.81	210.68
Total	CO_2e kg	**243.48**	**288.48**
Carbon sequestered in OSB	CO_2e kg	770.07	912.4
Net carbon balance			
excluding biomass GHGs	CO_2e kg	704.40	834.60
including biomass GHGs	CO_2e kg	526.59	623.92

*Includes combustion and precombustion effects associated with the use of thermal fossil fuel and the Canadian average electricity grid for harvesting, transporting and manufacturing OSB.

6 COMPOSITE PANEL BOARD MANUFACTURE

6 COMPOSITE PANEL BOARD MANUFACTURE

The composite panel board industry is a large manufacturing segment that produces various products (e.g. PB, medium and high density fibreboard) with varying densities, moisture contents and finishes (e.g. veneered and plastic laminates may be added). This study's scope is limited to the production of raw PB and MDF, and therefore, excludes any downstream production of primed or laminated products. Both PB and MDF are regarded as non-structural panel products used as underlayment for various floor materials, cabinetry, countertops, furniture and millwork.

The Canadian PB and MDF industry is almost exclusively dependant on other primary wood product processors (sawmills, plywood and OSB facilities) for their raw wood furnish to manufacture composite boards.

One might categorize PB and MDF manufactures as the original recyclers of wood co-products and residues from other wood processors. This wood resource is often composed of mixed by-products (e.g. sawdust, wood chips, planer shavings, clippings and hog fuel) procured from other facilities and sometimes from considerable distances.

All of these inputs originated in the forest; to maintain continuity with earlier primary product profiles, this study relates these wood input flows back to the forest to provide a measure of the energy used to procure these wood inputs. In a typical life-cycle inventory study, a portion of the energy used to produce these wood residues in the originating plants would also be allocated to these residues as they are sold or transferred to PB and MDF plants; that is, as they leave the system boundary for the product under consideration. However, earlier sections of this report present unallocated, or gross, energy profiles for the manufacture of various commodities.

Therefore, to maintain this reporting practice, this study does not include any allocated share of upstream energy use in these plants to the residues used in the production of PB and MDF, except that associated with the harvesting and transport of the wood from which these wood residues were initially derived.

This chapter is based on the surveys designed to capture material and energy use inputs as well as other flows to and from the environment in the production of PB and MDF. These manufacturing data were collected from three PB and four MDF plants in 2008, for annual production periods between 2006 and 2008. Sections 6.1 and 6.2 summarize the survey findings for PB and MDF, respectively.

6.1 Particleboard panel manufacture

This section discusses PB panel manufacture as opposed to moulded PB processes.

PB panels typically have a finished density of 590 to 800 kg/m^3 (37 to 50 pounds/cu. ft.) with a moisture content of 6 to 8 percent. Panels are typically composed of three to five layers (core and face layers) of wood particles (derived from sawdust, planer shavings and wood chip residue) blended with urea formaldehyde resin (a binder) and wax. Small amounts of catalysts (to accelerate curing) and scavenger chemicals (to reduce formaldehyde emissions) are also used and become part of the product.

The general steps in the production of PB panels include material procurement, particle refining, sizing and screening, drying and blending with resin and wax, layering and forming into a mat, prepressing and final pressing, and finishing (panel trimming and sanding).

Table 6-1 presents the raw wood material mass balance for the production of 1 m^3 and 1000 sq. ft. 3/4-inch basis PB, as derived from a survey of three manufacturers. The mass balance indicates that 87 percent of the wood furnish processed by the mill goes into PB, another 11 percent is used as fuel, 2 percent is used in close-loop in the process and less than 1 percent of the processed wood furnish becomes waste destined for landfill. Note that PB plants purchase another 54 kg of hog fuel for each cubic metre of PB to meet their energy input demands (see Table 6-2).

In addition to wood, the manufacture of 1 m^3 of PB requires the input of urea formaldehyde resin (65 kg), catalyst (2.6 kg), wax (1 kg) and scavenger (1 kg). PB is comprised of 86.8 percent wood, 8.7 percent urea formaldehyde resin and less than 4.5 percent catalyst, wax and scavenger.

Table 6-2 summarizes the gross energy use in the production of PB (m^3 and MSF 3/4-inch basis), including harvesting, wood residue transport, and manufacturing energy use in both physical fuel and common energy units (MJ). The cradle-to-gate energy used to manufacture PB is approximately 3303 MJ/m^3 of PB. The procurement of wood inputs for the production of PB and as fuel uses about 11 percent of the total energy use.

Of the 2941 MJ of energy used in the PB manufacturing stage, renewable biomass fuel use is 64 percent of the total manufacturing energy use. Electricity is the next most used energy form at 26 percent. Fossil fuels account for the remaining 10 percent of fuel use.

The survey of PB manufacturers asked respondents to apportion their energy use by fuel type across three unit processes – wood preparation, board lay-up and pressing, and board finishing. Results indicate that the wood preparation process used the most energy (72 percent) (see Table 6-3). Wood preparation includes the handling, refining and/or hammering and screening of the wood inputs, the drying of particles and their blending with various ancillary inputs (resin, wax, etc.) prior to being formed into a layered mat and entering the pre-press. Almost all of the energy derived from biomass and natural gas and half of the electricity use is consumed in the wood preparation processing stage.

Table 6-4 presents the cradle-to-gate carbon balance for PB on the basis of both a m^3 and MSF 3/4-inch basis. Three hundred and ten kilograms of GHGs (CO_2e basis) are emitted in the production of 1 m^3 of PB. The carbon sequestered in PB is equivalent to 1000 kg of CO_2e. That means there is **about three times as much CO_2 sequestered as emitted**. The net carbon balance is a positive 690 kg/m^3 at the plant gate and remains in the product throughout its service life.

Figure 6-1 Schematic overview of PB production

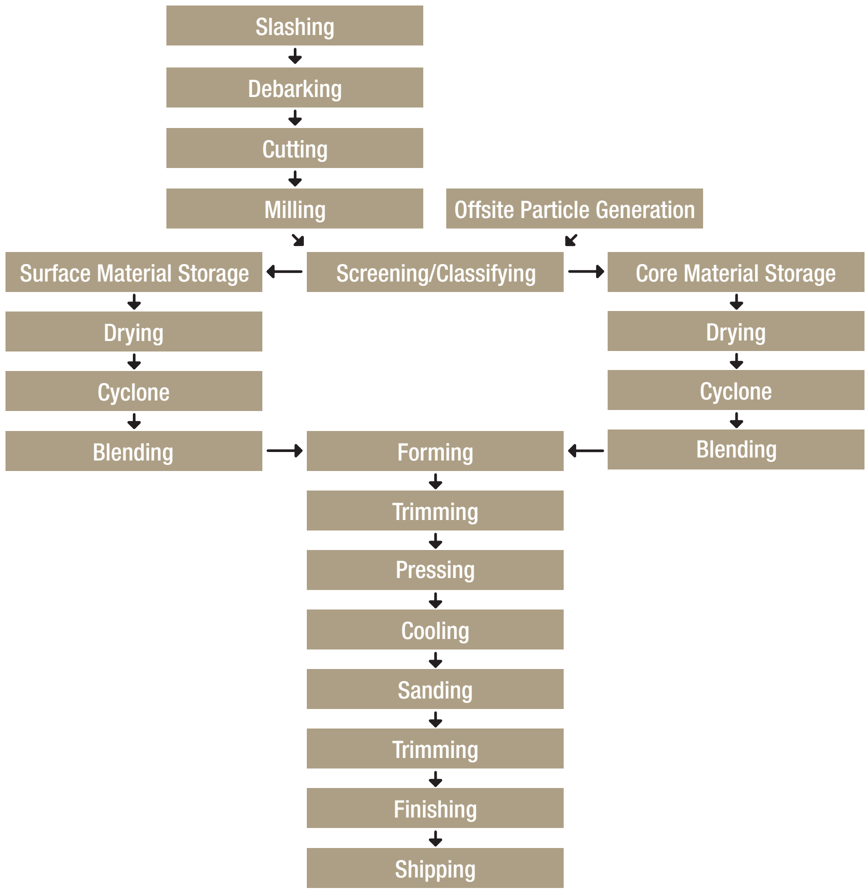


Table 6-1 Wood mass balance for PB production

Inputs and outputs	Unit	Per m^3	Per MSF (3/4-inch basis)	Percentage (%)
Inputs				
Logs	kg	54.40	96.2	8.700
Purchased wood residues	kg	558.10	987.7	89.400
Wood fibre generated in house	kg	11.70	20.7	1.900
Total inputs	kg	**624.20**	**1104.7**	**100.000**
Outputs				
Particleboard (wood only)	kg	545.40	965.2	87.400
Sander dust	kg	67.00	118.6	10.700
Sawtrim	kg	11.70	20.7	1.900
Wood waste	kg	0.05	0.1	0.008
Total outputs	kg	**624.20**	**1104.7**	**100.000**

Table 6-2 Gross cradle-to-gate energy use – PB manufacture

Fuel type in physical units	Unit	Resource harvest and transport	
		Per m³	Per MSF
Diesel fuel (harvesting)	L	0.390	0.690
LPG	L	0.000	0.000
Electricity	kWh	0.004	0.007
Diesel fuel (hauling)	L	7.730	13.680
(based on Canadian average resource harvesting values with resource transportation adjusted to a 160-km hauling distance)			
Fuel type in physical units	**Unit**	**Particle board manufacture**	
		Per m³	**Per MSF**
Electricity	kWh	149.5100	264.6000
LPG	L	0.5800	1.0300
Diesel	L	4.3500	7.7000
Natural gas	m³	1.9200	3.4000
Gasoline	L	0.0022	0.0039
Hog fuel (internal)	kg	67.0100	118.6000
Hog fuel (purchased)	kg	53.7400	95.1000
Primary energy use in MJ	**Unit**	**Resource harvest and transport**	
		Per m³	**Per MSF**
Diesel fuel (harvesting)	MJ	17.4500	30.8900
LPG	MJ	0.0025	0.0044
Electricity	MJ	0.0200	0.0400
Diesel fuel (hauling)	MJ	344.9900	610.5500
Subtotal	MJ	**362.4625**	**641.4844**
Primary energy use in MJ	**Unit**	**Particle board manufacture**	
		Per m³	**Per MSF**
Electricity	MJ	757.26	1340.20
LPG	MJ	17.67	31.27
Diesel	MJ	194.22	343.73
Natural gas	MJ	81.21	143.73
Gasoline	MJ	0.09	0.16
Hog fuel (internal)	MJ	1058.81	1873.88
Hog fuel (purchased)	MJ	831.28	1471.20
Subtotal	MJ	**2940.55**	**5204.16**
Grand total	MJ	**3303.02**	**5845.65**

Table 6-3 Gross energy use in PB manufacture by unit process

Primary energy use	Unit (per m³)	Total	Wood prep and drying	Lay-up and pressing	Board finishing
Electricity	MJ	757.000	273	295	189.000
LPG	MJ	18.000	0	0	18.000
Diesel	MJ	194.000	157	16	23.000
Natural gas	MJ	81.000	13	68	0.000
Gasoline	MJ	0.088	0	0	0.088
Hog fuel	MJ	1868.000	1672	196	0.000
Total manufacturing	MJ	**2918.088**	**2115**	**575**	**230.088**
Percentage	%	**100**	**72**	**20**	**8**

Table 6-4 Global warming potential and net carbon balance – PB

GWP due to	Unit	Per m³	Per MSF
Fossil fuel use*	CO_2e kg	88.09	155.90
Biomass combustion	CO_2e kg	222.18	393.21
Total	CO_2e kg	**310.27**	**549.11**
Carbon sequestered in PB	CO_2e kg	999.85	1769.53
Net carbon balance			
excluding biomass GHGs	CO_2e kg	911.75	1613.60
including biomass GHGs	CO_2e kg	689.59	1220.43

*Includes combustion and precombustion effects associated with the use of thermal fossil fuel and the Canadian average electricity grid for harvesting, transporting and manufacturing particleboard.

6.2 Medium density fibreboard panel manufacture

Similar to the PB industry, the MDF industry in Canada is completely dependent on procuring wood residues from other primary wood processing plants (sawmills, plywood and OSB mills) for its production. MDF is a more homogeneous product than PB and is produced in densities varying between 500 to 800 kg/m³. North American industry production is typically measured on an MSF 3/4-inch basis, which converts to about 1.77 m³.

The manufacture of MDF begins with the procurement of wood residues from various primary wood product plants. The wood furnish, consisting of sawdust, planer shavings, pulp chips, clippings and trim ends, first passes through a digester (a pressurized vessel that cooks and softens wood fibres). A mechanical refiner reduces the digested furnish into individual fibres. The fibres are then blended with urea formaldehyde resins, catalyst, wax and scavenger in a blowline prior to entering a flash tube dryer. In the dryer the average moisture content of the wood furnish is reduced to about 8 percent.

The dried furnish moves to a forming line, where it is distributed into either a 3- or 5-layered flat mat (core and face layers).[16] The formed mat enters a pre-press to reduce the mat thickness and then moves into a multiple stack, multiple opening hot press that applies pressure and heat to consolidate the mat into the final panel. Hot panels leaving the press are cooled, sanded to the correct thickness and trimmed to the final size. See Figure 6-2 for a diagram of MDF manufacturing steps.

Table 6-5 lists the wood mass balance for the production of MDF on both a m^3 and MSF 3/4-inch basis. Of the 782 kg of wood furnish entering the plant to produce 1 m^3 of MDF, 86 percent is reconstituted in the product, while 13 percent is wood fibre (of which 84 percent becomes biomass fuel used internally and 16 percent is used in the process line) and the remaining 1 percent is landfilled.

The cradle-to-gate gross energy use in the production of 1 m^3 of MDF is 6966 MJ (see Table 6-6). Resource transportation energy use is 11 percent of the gross energy input and uses primarily diesel fuel. On a primary energy use basis, MDF manufacturing is almost equally dependent on three fuels – electricity (35 percent), renewable biomass (34 percent) and natural gas (29 percent).

Less than 1 percent of on-site manufacturing energy use is consumed as diesel, gasoline and LPG – fuels typically used in mobile material handling equipment. It is noted that in addition to the internally produced biomass fuel (sander dust and panel trim), another 52.5 kg of hog fuel is purchased for each cubic metre of MDF produced, for use solely as an energy source. This additional purchased hog fuel is accounted for in the gross energy use profile reported in Table 6-6.

Table 6-7 provides a breakdown of energy use within the plant on a unit process basis. The largest on-site energy use is in the wood preparation and drying phase of the MDF production process (84 percent). The other two primary process activities, board lay-up/pressing and finishing, account for 11 percent and 6 percent of energy use, respectively. Wood preparation (handling, digesting, refining, blending and drying) consumes 76 percent of electricity, 90 percent of natural gas and 87 percent of renewable biomass-derived heat used to manufacture MDF. Therefore, wood preparation and drying is the most obvious area to target for energy conservation efforts.

Like all wood products, half the mass of the wood in MDF is carbon (C). Each cubic metre of MDF sequesters about 1234 kg of CO_2e (see Table 6-8), which offsets 536 kg CO_2e basis of GHGs emitted in the production of MDF. The result is a positive cradle-to-gate carbon balance of 698 kg CO_2e basis per cubic metre of product.

[16]Only two mills in Canada are configured for 3-layer processing, however, neither is currently using this capacity.

Figure 6-2 Schematic overview of MDF production

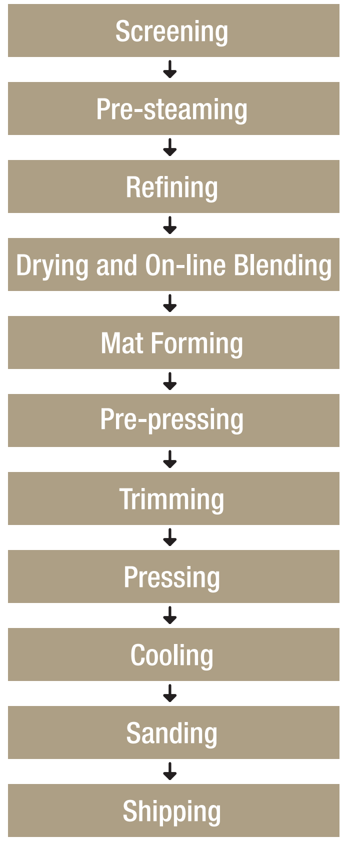


Table 6-5 Wood mass balance for MDF production

Inputs and outputs	Unit	Per m³	Per MSF (3/4-inch basis)	Percentage (%)
Inputs				
Purchased wood residues	kg	766	1355	98
Sanderdust generated in house and used in process line	kg	17	29	2
Total inputs	kg	**782**	**1384**	**100**
Outputs				
MDF (wood only)	kg	673	1191	86
Sanderdust and sawtrim (84% used internally as fuel, 16% in process line)	kg	101	179	13
Wood waste	kg	8	15	1
Total outputs	kg	**782**	**1384**	**100**

Table 6-6 Gross cradle-to-gate energy use – MDF manufacture

Fuel type in physical units	Unit	Resource harvest and transport	
		Per m³	Per MSF
Diesel fuel (harvesting)	L	0.00	0.00
LPG	L	0.00	0.00
Electricity	kWh	0.00	0.00
Diesel fuel (hauling)	L	16.49	29.18
(based on Canadian average resource harvesting values with resource transportation adjusted to a 260-km hauling distance)			
Fuel type in physical units	**Unit**	**MDF manufacture**	
		Per m³	**Per MSF**
Electricity	kWh	432.76	765.90
LPG	L	0.31	0.55
Diesel	L	1.36	2.40
Natural gas	m³	42.65	75.49
Gasoline	L	0.02	0.03
Hog fuel (internal)	kg	84.48	149.51
Hog fuel (purchased)	kg	52.49	92.90
Primary energy use in MJ	**Unit**	**Resource harvest and transport**	
		Per m³	**Per MSF**
Diesel fuel (harvesting)	MJ	0.00	0.00
LPG	MJ	0.00	0.00
Electricity	MJ	0.00	0.00
Diesel fuel (hauling)	MJ	736.09	1302.72
Subtotal	MJ	**736.09**	**1302.72**
Primary energy use in MJ	**Unit**	**MDF manufacture**	
		Per m³	**Per MSF**
Electricity	MJ	2191.95	3 879.28
LPG	MJ	9.44	16.70
Diesel	MJ	60.54	107.14
Natural gas	MJ	1803.19	3 191.26
Gasoline	MJ	0.68	1.20
Hog fuel (internal)	MJ	1334.77	2 362.26
Hog fuel (purchased)	MJ	829.38	1 467.82
Subtotal	MJ	**6229.92**	**11 025.66**
Grand total	MJ	**6966.01**	**12 328.38**

Table 6-7 Gross energy use in MDF manufacture by unit process

Primary energy use	Unit (per m^3)	Total	Wood prep and drying	Lay-up and pressing	Board finishing
Electricity	MJ	2192	1666	307	241
LPG	MJ	9	2	0	8
Diesel	MJ	61	36	1	24
Natural gas	MJ	1803	1623	90	90
Gasoline	MJ	1	0	0	0
Hog fuel	MJ	2164	1883	281	0
Total manufacturing	MJ	**6230**	**5209**	**679**	**364**
Percentage	%	**100**	**84**	**11**	**6**

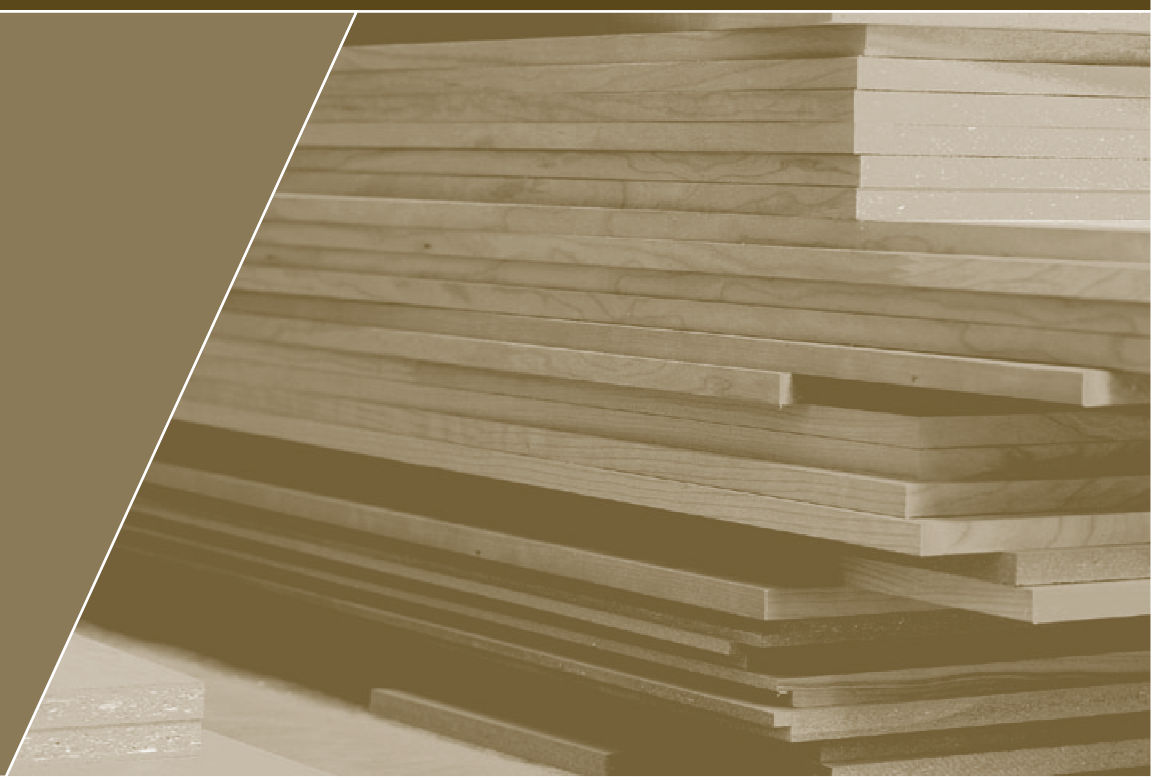
Table 6-8 Global warming potential and net carbon balance – MDF

GWP due to	Unit	Per m^3	Per MSF
Fossil fuel use*	CO_2e kg	283.92	502.47
Biomass combustion	CO_2e kg	252.03	446.03
Total	CO_2e kg	**535.94**	**948.51**
Carbon sequestered in MDF	CO_2e kg	1233.76	2183.50
Net carbon balance			
excluding biomass GHGs	CO_2e kg	949.85	1681.03
including biomass GHGs	CO_2e kg	697.82	1234.99

*Includes combustion and precombustion effects associated with the use of thermal fossil fuel and the Canadian average electricity grid for harvesting, transporting and manufacturing MDF.

7

GROSS ENERGY AND CARBON BALANCE SUMMARY



7 GROSS ENERGY AND CARBON BALANCE SUMMARY

This chapter contrasts some of the salient findings of the energy use results with carbon balance outcomes across the five commodities: softwood lumber, softwood plywood, oriented strand board, particleboard and medium density fibreboard. Figure 7-1 illustrates the gross cradle-to-gate primary energy use for the five commodities by fuel type.

Particularly noteworthy in Figure 7-1 is the degree to which manufacturing energy use increases when there is a decrease in the size of the raw fibre processed for each product. Both softwood lumber and plywood retain much of the incoming wood's characteristics (sawing and peeling); OSB processes relatively large wood strands; PB processes hammered residues; and MDF goes a step further by processing (digesting and refining) wood fibre.

Generally, as the wood processing method becomes more complex, the fibre size decreases, the products become denser, and manufacturing energy use increases. What is also notable is the amount of electricity, diesel fuel, natural gas and biomass that the products use during processing.

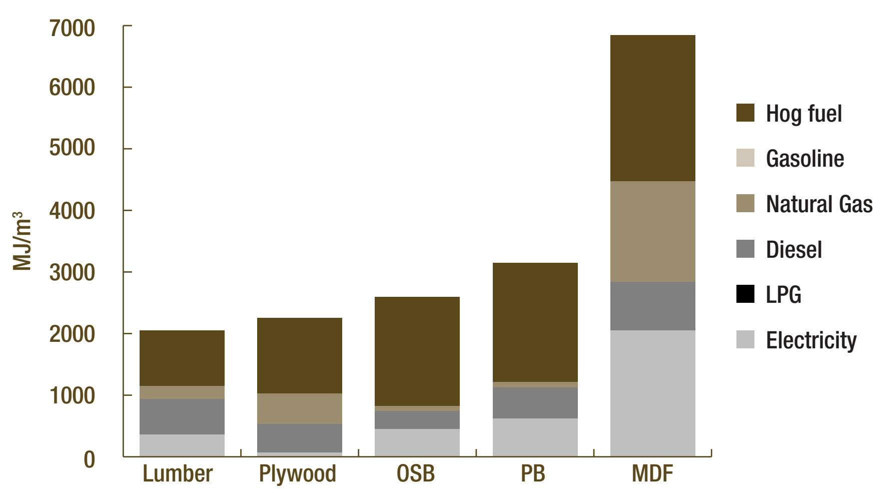
All these fuels warrant attention from an energy conservation perspective. Most diesel fuel is used during harvesting and wood transport and may be beyond the direct control of wood processing facilities that are reliant on third-party raw material contractors or suppliers.

Natural gas and (to some degree) electricity are fossil fuel-based and their use is likely be affected by increasing and fluctuating prices.

Biomass is an interesting fuel because when it is used as a fuel, less is available for use as a raw material for products. Also, if biomass is used inefficiently as a fuel, more biomass is consumed to satisfy the same energy requirement, which presents a major in-house conservation variable.

All five commodities use renewable biomass in their manufacture, but OSB and the reconstituted board products (PB and MDF) use proportionally more biomass fuels than either plywood or softwood lumber.

Figure 7-1 Gross cradle-to-gate primary energy use by fuel type



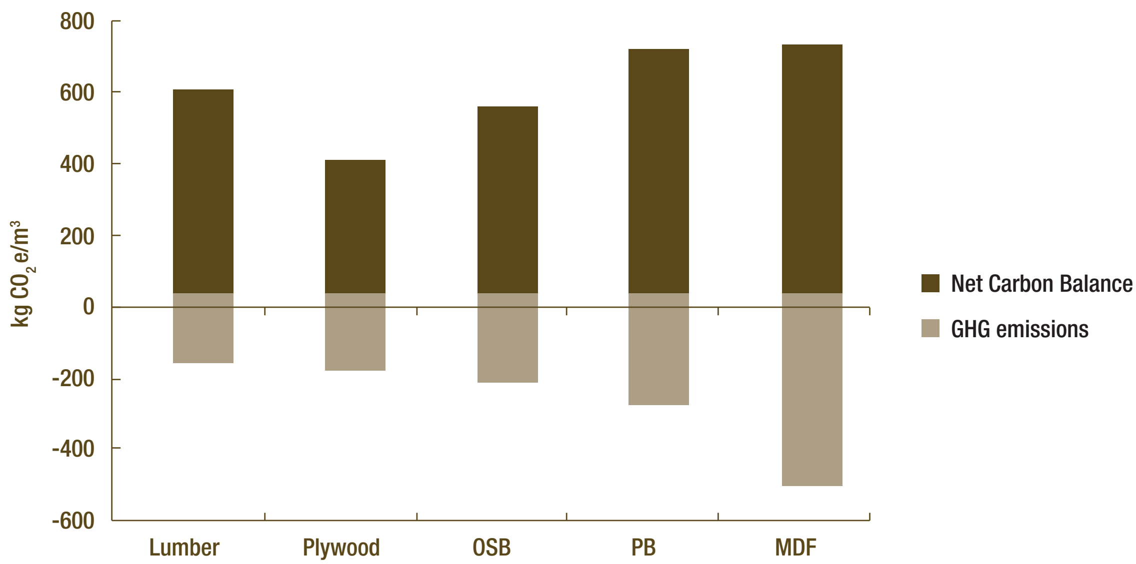
One of the merits of wood products is that carbon is sequestered in them for long periods of time – basically throughout their service life.

Figure 7-2 portrays the GWP of the five commodities relative to the carbon sequestered in the products. Each product's GWP (i.e. GHG emissions) mirrors its energy use depicted in Figure 7-1. The net carbon balance, while a function of energy intensity and associated emissions of GHGs, is also a function of the amount of wood (i.e. carbon) contained in 1 m^3 of product.

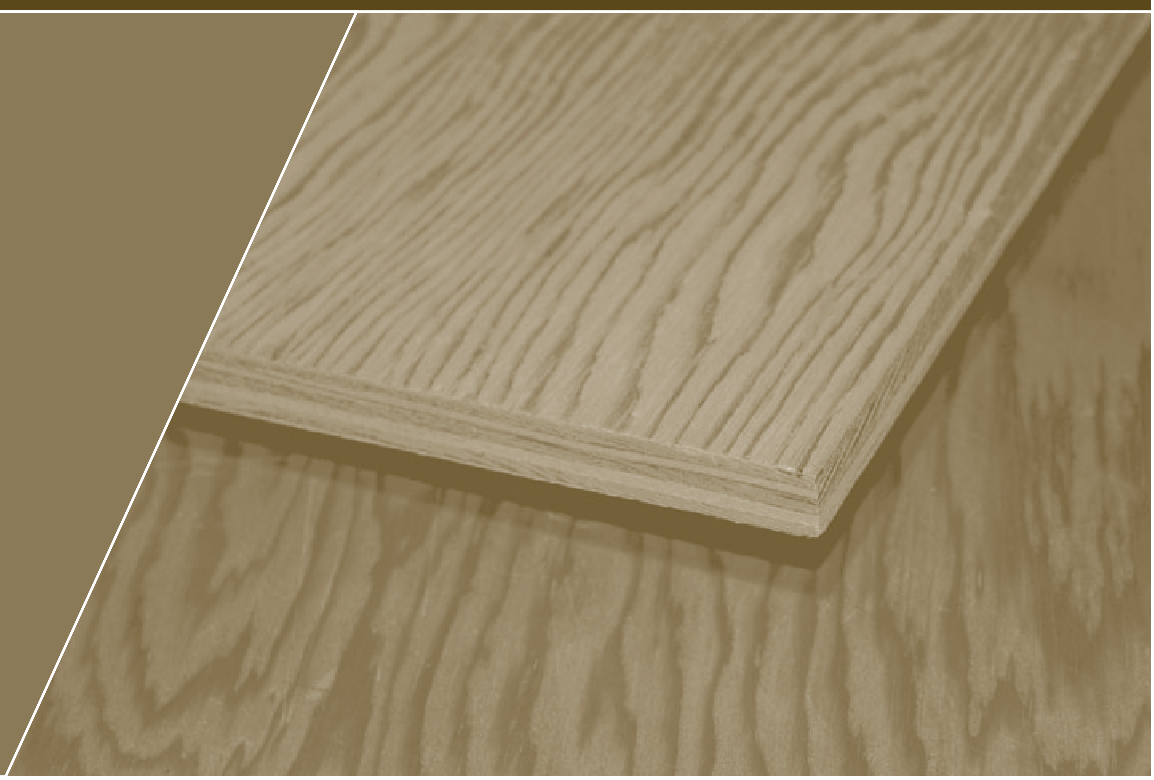
For example, although softwood lumber and plywood have similar energy use profiles, softwood plywood is primarily derived from lower density spruce as opposed to a mix of SPF, in which pine is more dense than spruce. Therefore, plywood attains a lower net carbon balance.

OSB (which has a finished density of more than 600 kg /m^3) and PB and MDF (which have densities between 500 and 800 kg/m^3) contain more wood per cubic metre than softwood lumber or plywood. Consequently, OSB, PB and MDF sequester as much, or more, carbon than an equivalent volume of softwood lumber or plywood despite being more energy intensive to manufacture.

Figure 7-2 Cradle-to-gate global warming potential and net carbon balance



8 SUMMARY INTERNATIONAL COMPARISONS OF ENERGY INTENSITY



8 SUMMARY OF INTERNATIONAL COMPARISONS OF ENERGY INTENSITY

This chapter compares the manufacturing energy intensity of Canadian wood products with similar products produced in the United States – Canada's largest wood products trading partner. Energy intensity comparisons are also presented for Scandinavian and South American production for several wood product commodities, where comparable data exist.

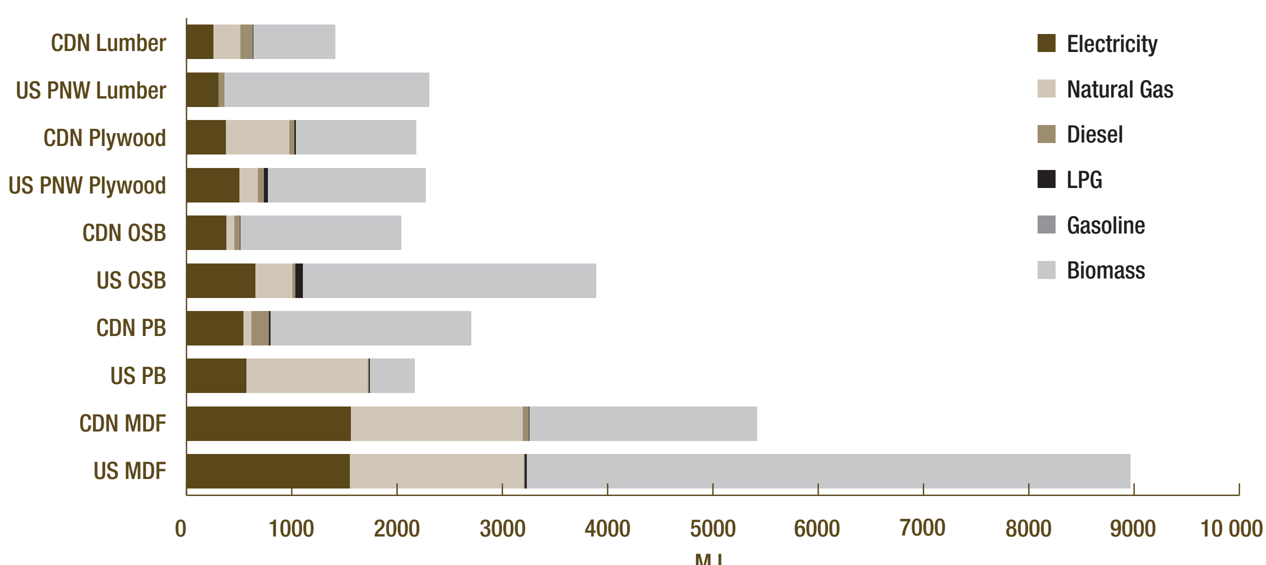
Figure 8-1 provides a comparison of manufacturing energy use for the five commodities relative to similar products produced in the United States, by fuel type. The data for these comparisons come from the Consortium for Research on Renewable Industrial Materials (CORRIM) – www.corrim.org).

CORRIM has undertaken life-cycle assessment studies of United States wood products since 2004. Although CORRIM employs a similar methodology as that applied in this study, methodological differences do exist. For example, system boundaries do not necessarily match and different fuel heating values have been used across CORRIM and this study. For these and other reasons, the comparisons provided in Figure 8-1 have been developed by adjusting product profiles in either this study or in the CORRIM work to better align and focus on gross manufacturing energy use.

The following list includes some of the adjustments:

- Resource extraction and transportation effects are removed or ignored, unless otherwise indeterminable.
- Electricity use was adjusted to report it on an equivalent megajoule basis (i.e. the comparison uses a conversion factor of 3.6 MJ per kWh consumed rather than a primary energy value for electricity).
- Fossil fuel use is limited to direct combustion effects.
- The heating value for biomass fuel has been adjusted to be the same (15.8 MJ/kg) for both countries.

Figure 8-1 Manufacturing energy use in Canada and the United States by fuel type



Sources: Various CORRIM reports (www.corrim.org).

With the exception of plywood and PB, the comparative manufacturing energy use values show that gross energy use in Canada is generally lower than in the United States. Canadian softwood lumber production uses slightly less purchased electricity and biomass energy, but more natural gas and diesel fuel than lumber production in the United States Pacific Northwest (PNW). That is, United States lumber production is less reliant on natural gas and uses more biomass-derived energy in its place – something that Canadian mills may want to mimic to lessen their reliance on fossil fuels.

Canadian softwood plywood mills are more reliant on natural gas than those in the PNW. Considering the difference in natural gas and biomass use between Canadian and United States plywood plants, one can infer that PNW mills are generating and/or utilizing their process heat more efficiently than Canadian plants, while Canadian plants generally use less purchased electricity per unit of production.

The manufacture of Canadian OSB is a third less energy intensive than in the United States Southeast. Canadian mills have an energy use efficiency advantage across all major fuel types – electricity, natural gas and biomass. One major qualifier affecting this comparison may be the difference in the resource processed by the two regions. In Canada, most OSB mills process aspen, which is less dense than the southern yellow pine used in the United States Southeast. Because southern yellow pine has a higher density and is a more resinous wood, it is both more difficult (energy intensive) to mechanically process (greater electricity use) and to dry (more process heat use).

Canadian and United States PB mills use almost the identical amount of electricity in the production of 1 m^3 of PB. While Canadian mills use more biomass than natural gas, they use proportionally more biomass than their United States counterparts use natural gas. Particle drying is the most energy-intensive aspect of PB manufacture and appears to be the major difference between Canadian and United States PB manufacture and is something that Canadian PB mills may want to investigate further.

Canadian and United States MDF plants are very similar in their use of electricity and natural gas. They differ in biomass energy, with Canadian mills using only half as much as United States MDF mills. While some of this difference may be explained by resource attributes or moisture contents of incoming material, this statistic does indicate that Canadian mills seem to be managing their biomass energy use better than their United States counterparts.

Table 8-1 provides additional information on energy use for the production of wood products in other countries. The table focuses on South American and Scandinavian regions, a cross-section of products, and fuel input types.

Energy use in forest operations (i.e. harvesting and transportation) is slightly lower in South America and Scandinavia compared with Canada (265 MJ/m^3). Much of this difference can probably be explained by the hauling distance faced by mills in Canada relative to the distance traveled in the other two regions. Relative to South America, Canadian manufacturing energy use is either comparable or lower for the products reported on. In particular, both electricity and biomass heat use is generally lower in Canadian manufacturing.

Dimension lumber manufacture in Scandinavia is almost identical to that of Canadian mills. Scandinavian mills use slightly more electricity and biomass fuels, but fewer fossil fuels in their production of softwood lumber. Reconstituted panel production (e.g. OSB, PB and MDF) in Scandinavia is also of the same order of magnitude as that of Canadian mills. Plywood manufacture is considerably less energy intensive in Canada than in Scandinavia – by almost half.

Table 8-1 Energy use in South America and Northern Europe by product

Forest products sector	Region	Renewable heat (MJ/m³)	Electric power (MJ/m³)	Fossil fuel	Total energy (MJ/m³)
Forest operations	Chile and South America	0	0.8	208.5	209.3
Forest operations	Canada (this study)	0	0.2	265.8	266.0
Dimension lumber	Chile and South America	2767	833.0	214.0	3814.0
Dimension lumber	Canada (this study)	775	359.0	380.0	1514.0
Fiberboard and particleboard	Chile and South America	2773	1052.0	294.0	4119.0
Particleboard	Canada (this study)	1890	757.0	294.0	2941.0
Plywood board	Chile	3908	951.0	86.0	4944.0
Plywood	Canada (this study)	1144	61.0	730.0	1935.0
Forest operations	Sweden	0	6.1	171.9	178.0
Forest operations	Canada (this study)	0	0.2	265.8	266.0
Dimension lumber	Norway, Finland and Sweden	1062	312.0	91.0	1465.0
Dimension lumber	Canada (this study)	775	359.0	380.0	1514.0
Fiberboard and particleboard	Northern Europe	2092	1468.0	298.0	3857.0
Particleboard	Canada (this study)	1890	757.0	294.0	2941.0
Plywood board	Finland and Sweden	2862	1049.0	487.0	4398.0
Plywood	Canada (this study)	1144	61.0	730.0	1935.0

Sources: Various – see References section – International Studies.

9 ENERGY USE REDUCTION POTENTIAL IN WOOD PRODUCT MANUFACTURING

9 ENERGY USE REDUCTION POTENTIAL IN WOOD PRODUCT MANUFACTURING

This chapter describes energy use reduction opportunities in wood product manufacturing. As noted previously in this report, the softwood lumber industry accounts for almost half of the energy used in the wood products sector. This report also notes that two-thirds of energy used in the manufacture of softwood lumber is used during the kiln drying stage of the manufacturing cycle. Therefore, this chapter focuses primarily on kiln drying of softwood lumber, because even a small improvement in kiln drying applied across the softwood lumber industry has the potential to markedly improve the energy use footprint of the entire wood products industry.

9.1 Kiln drying of softwood lumber

There are many types of commercial lumber drying systems used in Canada. The flow chart in Figure 9-1 provides a breakdown of these technologies by operating system and operating temperature.

In the softwood dimension lumber sector, most kilns are in the heat-and-vent category, in both the conventional and high temperature subcategories. These systems have been popular because of their relatively low initial cost, ease of operation and maintenance, and adaptability to various fuel sources. The following section describes the current situation in this industry sector and the opportunities for improved energy efficiency.

Energy usage in drying

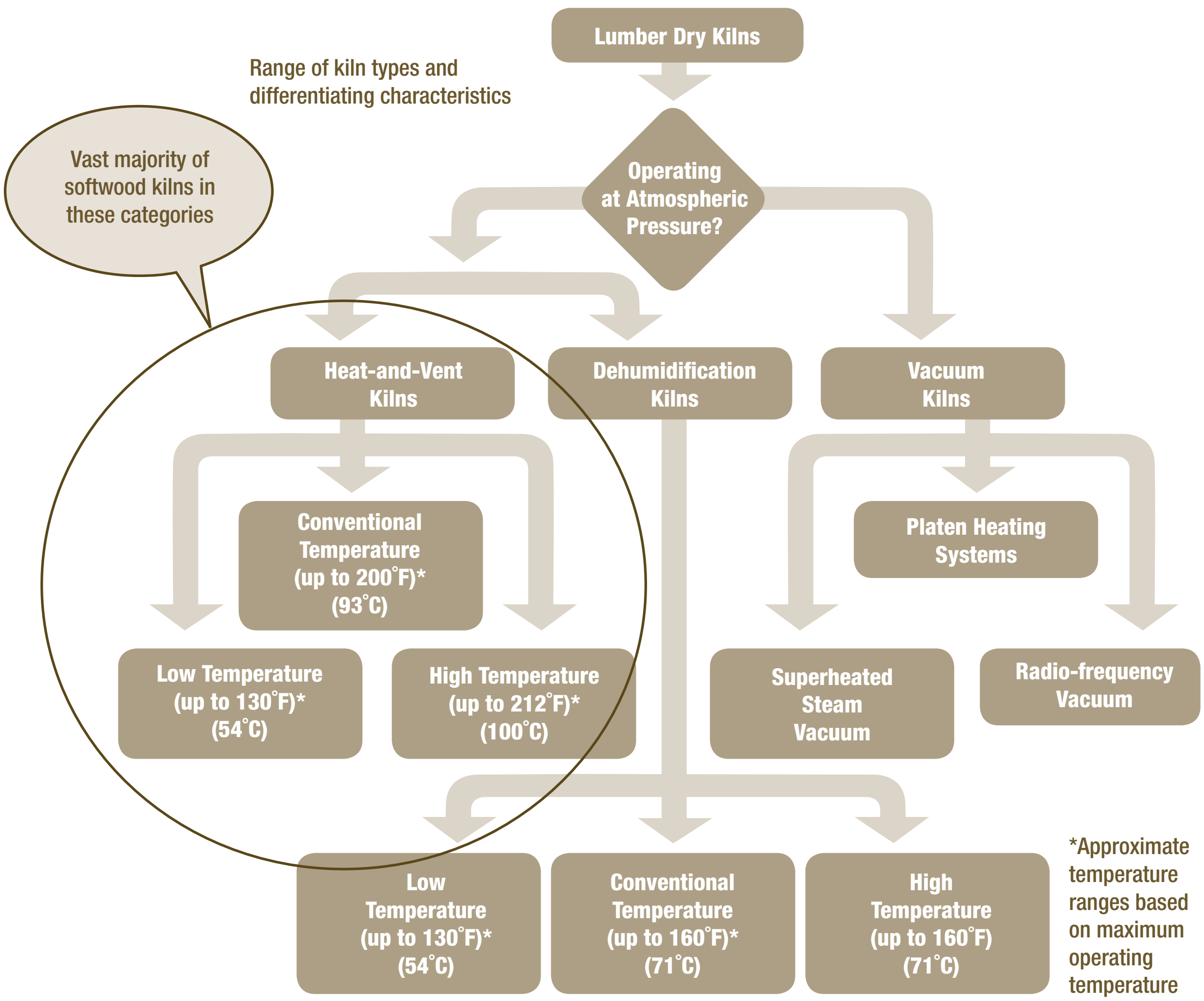
Drying uses 70 percent or more of the energy needed to transform logs into lumber (66 percent in this study). This number will vary depending on factors such as initial moisture content (MC), final MC requirements and the sizes of lumber produced. Regardless of the precise number, the drying process requires the most energy in lumber production.

The manner in which heat is introduced, used, and, in some cases, re-used in the process is one of the factors that differentiates the various kiln systems. The amount of electricity and thermal energy used varies considerably by drying system. Heat-and-vent kilns, including both conventional and high-temperature equipment, are the predominant technology used for drying softwood construction-grade lumber in Canada.

Both electrical and thermal energy are used in heat-and-vent lumber dryers. Electrical energy drives motors primarily for circulating air within the kiln, and to a lesser extent, motors for delivering the energy to the kiln (e.g. pumps circulating hot oil). A much larger proportion of the energy is used to generate heat for the drying process.

To put things into perspective, the electrical energy used to power the kiln fans is only about 4 percent of the thermal energy requirements for drying SPF dimension lumber. Although electrical energy consumption is low in comparison to thermal energy requirements, it is typically purchased energy and is a significant component of the operating costs. For this reason, various electrical energy saving opportunities will be presented later in this chapter.

Figure 9-1 An overview of types of lumber dry kilns used in Canada



Thermal energy breakdown

Various models have been developed for estimating kiln energy consumption by examining the components of the thermal energy load individually. It is useful to review the general breakdown in thermal energy use to help identify and evaluate the potential of energy saving opportunities.

Thermal energy is used in many areas during the drying of lumber. However, the three categories that use most of the energy are

- heating and evaporating the water to be removed: 50 to 70 percent
- replacing heat losses (walls, roof and floor): 15 to 30 percent
- raising the temperature and relative humidity of the incoming air: 10 to 20 percent

There are numerous reasons for the variability in each of these energy use constituents. For example, the second item (heat losses through the walls, roof, and floor) will be higher when drying times are longer. The initial and final moisture content of the lumber largely influence the first item, the heat required to evaporate the water to be removed.

As mentioned previously, some knowledge of how energy is used helps identify the potential for energy savings. Much of the energy "lost" from a heat-and-vent kiln is in high-humidity air, which poses some challenges as well as opportunities for recovering energy.

Although insulating a kiln operating at high temperature may seem like a logical way to improve energy use, it is not the best option. In some instances, doubling the amount of insulation may result in only a 5 to 7 percent reduction in energy use. A cost-benefit analysis is needed to determine if the significant costs associated with doubling the insulation can be justified.

Thermal energy requirements

A recent FPInnovations publication on drying SPF (Garrahan, P. 2008. *Drying Spruce-Pine-Fir Lumber*) lists thermal energy requirements for drying the individual species within this species group. Thermal energy requirements vary from 0.65 to 1.38 GJ/m^3. Spruce and pine are closer to the low end of this range, and balsam and subalpine fir are at the top end of the range.

Because these species are often dried in a mixture that has more spruce and pine than fir, the weighted average thermal energy requirement for SPF is presented at 0.67 GJ/m^3. The calculations are based on kilns and energy systems in good condition and material starting at the typical green moisture content for the species considered. Any changes in either of these assumptions can vary the energy requirements considerably.

Extrapolating the unit energy consumption data from the previous paragraph to a typical SPF sawmill/drying operation provides an estimate of the energy requirements. For a mill producing 150 million board feet (354 000 m^3) of kiln-dried SPF lumber, the estimated annual thermal energy requirements are approximately 237 TJ.

An important consideration in designing energy systems for lumber drying is that the energy demands vary throughout the drying cycle. Although the drying temperature typically increases from the start to the end of the cycle, the thermal energy demand decreases. The highest energy demand is always at the start of the cycle, at a point in the process when the wood still contains free (liquid) water that is close to the surface of the boards and evaporates readily. The drying rate will be its fastest at this point in the cycle, and this is the drying rate that has the greatest impact on energy demand.

The change in energy demand from the start to the end of the cycle requires careful planning when sizing the energy system but also provides some opportunity for energy efficiency through implementation of energy management practices as summarized in the following section.

Opportunities to improve energy efficiency of heat-and-vent (conventional) dry kilns

This section is relevant to heat-and-vent (conventional) kilns, but many of the recommendations regarding a more efficient overall drying process are equally relevant to other drying systems. Regardless of the type of energy used, there will be both economic and environmental benefits from making a drying system more energy efficient.

The following actions can reduce energy consumption in existing kilns, and are explained in detail in *Drying Spruce-Pine-Fir Lumber*:

- If kiln conditions are difficult to maintain or a lot of steam or water spray is being used to maintain the wet-bulb temperature, the kiln may have leaks.
- If drying times are longer than expected, consider improving kiln insulation.
- Heat losses through the kiln vents can be reduced by using air-to-air heat exchangers to pre-heat the incoming air.
- Avoid over-drying the lumber, which can have a significant effect on both drying time and energy consumption.
- Consider pre-sorting material to supply a more uniform product to the kiln and thereby reduce final MC variability. A more uniform product mix will reduce average drying time and improve final MC uniformity, resulting in less over-dried material. Over-drying even a small portion of the load increases energy consumption and contributes to higher levels of drying degradation.
- Improve uniformity of temperature and airflow in the kiln. A more uniform drying environment will result in a more uniform final MC, and this may result in a shorter drying time or eliminate the need for an equalization treatment.
- Increase reliance on air drying or install forced-air drying systems (fans located outside to push air through the lumber loads) as a pre-treatment before final kiln drying. Removing some or most of the free (liquid) water can reduce the energy requirements at the kiln by 50 percent or more. Better tools to monitor drying rate and economic analysis of benefits may encourage more mills to pursue this option.
- Implement better energy monitoring tools on kilns to allow operators to evaluate the impact of their actions on energy consumption. This practice could include comparing one drying schedule against another or evaluating the impact of pre- or post-drying lumber sorting strategies.
- Improvements in efficiency for electrical energy consumption can be realized through
    - implementing variable speed drives to reduce fan speed at non-critical times
    - conducting an audit of the airflow equipment to determine optimum operating parameters and identify inefficient equipment

More detail on each of these points is provided in Garrahan (2008).

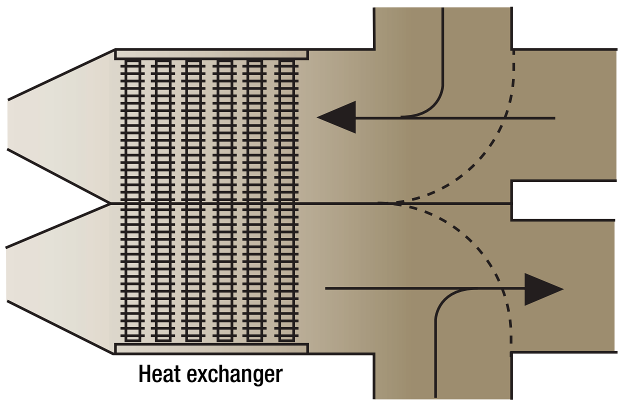
Application of heat exchangers to lumber drying kilns

From the list above, the application of heat exchangers has been selected as the technology to provide further detail about how this technology can be applied and the magnitude of energy efficiency attainable.

Figure 9-2 illustrates exhaust air from a kiln being used to pre-heat make-up air before it enters the kiln. The same or similar technology can be applied to all other drying processes in wood product manufacturing in which exhaust heat is not typically captured.

In tests conducted on a research-scale kiln at Forintek, a heat-pipe type of heat exchanger consistently raised the temperature of the incoming air to within 10°F (5.5°C) of the operating temperature of the kiln. The maximum amount of energy that can be recovered with an air-to-air heat exchanger is the heat required to warm the fresh air from the outside temperature to the operating temperature of the kiln. This value corresponds to the kiln vent losses and can vary from 10 to 20 percent of the total energy requirements. The energy in the exiting air stream represents the energy used to heat and evaporate moisture in the wood and can vary from 50 to 70 percent of the total energy requirements.

Figure 9-2 Typical airflow arrangement through an air-to-air heat exchanger installed between the outlet and inlet vents on a heat-and-vent kiln



Therefore, even with an efficient heat exchanger, there is a theoretical limit to how much energy can be recovered in this process. This theoretical limit in energy savings is about 8 percent for drying SPF. In practice, however, many mills have reported higher energy savings, from 15 to 25 percent. This higher level of energy savings is likely due to several side benefits of installing a heat exchanger. First, the kiln generally becomes more air tight, reducing leakage around doors and vents. Second, injection of heated air helps maintain a more uniform temperature in the kiln, which in turn means more uniform drying and less over-dried lumber.

After the incoming air is heated, there is still a lot of energy remaining in the exiting air stream. This warm moist air could potentially be passed through another heat exchange system to serve some other heating need, such as pre-heating boiler water or space heating requirements.

The use of air-to-air heat exchangers is not a new concept. However, in the past, the economics of the process have not been attractive enough to generate widespread acceptance. For installing extra insulation, the economic feasibility will depend largely on the type and cost of fuel being used. Another factor that can potentially motivate a mill to consider using heat exchangers is the benefit of freeing up more energy to fuel an additional kiln or avoiding problems with meeting peak demand. These situations are more likely to develop in larger mills with multiple kilns.

Opportunities for conversion to biomass energy

One fuel advantage in the wood products industry is easy access to wood by-products from the sawmilling process, either at no cost or very minimal cost. Most of the conventional drying systems and many of the non-conventional systems offer at least some capacity to inject heat from burning wood fibre or bark. In heat-and-vent kilns, this heat could form the major portion of the energy required.

However, even in dehumidification and vacuum drying systems, there is often the opportunity to supply part of the thermal energy requirements from a combustion system that can be fuelled with conventional fossil fuels or with by-products from the sawmill or planer mill. There are many small and large-scale biomass systems available that can be adapted easily to fit wood-drying applications. Burning wood residues also has an environmental advantage over burning fossil fuels in that it is typically viewed as being "carbon neutral." The subject of energy self-sufficiency and reducing the industry's "carbon footprint" are key motivations for seeking out such technology, and lumber drying is the logical place to look for opportunities.

Wood biomass has been used in this industry sector for many years in the following ways:

- hog-fuel fired boilers producing steam or hot oil to heat kilns
- hog-fuel fired boilers producing steam for a co-generation system with secondary steam supplied to the kilns
- direct-fired burners using planer shavings or similar fuel that have been reduced in a hammer mill to allow burning in suspension. The combustion gases are injected directly into the kiln.

Recent advances in technology provide the option to use a wider range of biomass, with greater efficiencies and different heating arrangements. The following are examples of available technologies:

- direct-fired burners that can operate with green fuel
- wood gasification systems that produce a clean combustion gas that can be injected directly into the kiln
- wood gasification systems to fuel a hot oil or steam system that in turn could be linked with a co-generation system

Kiln drying technologies

The material presented to this point has been about opportunities relevant to existing wood drying operations. There are, however, existing and developing technologies that could be chosen for new drying operations to minimize their energy requirements. Examples include the following:

- In Scandinavia and the United States, continuous-flow dry kilns have been used for many years. Recent design changes have made these systems more energy efficient by taking hot, humid air from one part of the process and injecting it into another zone to provide heating and humidification needs. There are no studies documenting the magnitude of energy savings but one kiln manufacturer estimated it at 15 percent or more.

  The interesting concept employed here is that energy is re-used within the process rather than going through a heat exchange process, which would inherently be less efficient. It is possible that the savings associated with this concept could be more significant than the estimate provided here.
- Dehumidification drying utilizes a heat pump to produce a more "closed system" in drying. Energy expended for evaporating moisture is recaptured by the heat pump. This technology has been used for many years in the hardwood and value-added sectors. Energy savings can be as high as 50 percent over a conventional heat-and-vent kiln. Economic savings are not as high as in other solutions because most of the energy input to this system is electrical. At least one manufacturer is developing a high-temperature heat pump that would make dehumidification drying available to a wider area of the lumber drying sector.
- Improved fan designs and changes to kiln geometry may help achieve further efficiencies in the need for electrical energy.

9.2 Panel manufacturing energy use reduction opportunities

Wood drying is the largest use of energy in composite panel plants, and biomass is the primary source of energy. Adhesives that can tolerate higher moisture content such as isocyanate (MDI) could present a huge energy savings for all composite mills. However, MDI is expensive. Ongoing research into finding cheaper and more moisture-tolerant adhesives is needed.

Drying is a big energy factor in these mills. Most mills produce only the boards they need for the orders they have and do not like to keep much inventory. Mills find that they must switch thicknesses to meet their order requirements. Ideally, thinner boards requiring a lower press temperature are produced first, and then the press temperature is gradually raised to accommodate thicker boards. If the schedule has to be altered to go from a thick to a thin product, much time and heat energy is lost because equipment is idle, waiting for it to cool down. A large press can take several hours to cool to the temperature required to produce thin board. For this reason, most mills try to avoid last minute orders requiring many thickness changes. A better system of scheduling or inventory control would provide energy savings.

Although composite panel mills try to use all their waste by-products, there is still some material remaining that could be used for cogeneration. There is also a trend developing with the secondary manufacturers who use these materials, especially those who use PB, MDF and hardwood plywood. Trimmings from these mills have traditionally gone in the garbage or landfill. Environmental concerns are now affecting this practice. The trend is that more and more secondary manufacturers are asking the panel mills to take these trimmings back. Some of these materials can be recycled, but those that cannot be recycled could be burned to generate electrical power.

A good example of this recycling is the co-generation facility at Calstock, Ontario, which uses a combination of waste heat from the Trans-Canada Natural Gas Pipeline and burned wood trimmings from nearby mills to produce electricity that is then sold to the Ontario power grid.

The following subsections describe additional energy saving technologies and practices relevant to each panel type.

Oriented strand board mills

The biggest consumers of electric energy in OSB mills are the waferizers and other machine motors associated with the preparation of the strands, including debarkers and slashers. The next largest consumers of electrical energy are the fans in the drying system and the pump motors for the press hydraulics and thermal oil for the press heating system. In some mills, the electrical energy consumed by the press hydraulics and platen heating system is almost equal to the energy consumed by the mat formers and forming line. Fossil fuels are used mainly for forklifts and yard machines and sometimes as backup or supplementary systems for drying and building heat. The thermal oil systems used for press and building heat and direct-fired dryers are the biggest consumers of biomass energy.

Many OSB mills are compelled to use certain hardwood species such as maple or birch, which require more energy at the waferizer than the aspen normally used in the manufacture of OSB. Reducing the use of maple and birch, or studying additional ponding or pre-treatment, could result in significant electrical energy savings at the waferizer and could increase furnish yield by reducing material of undesirable sizes (fines) and unusable furnish fractions. This would also create a saving in expensive resin consumption.

Not all mills practice good log yard management. Logs should be sorted as received so that raw material arrives at the ponds and waferizers at the ideal moisture content, i.e. older logs should be used first. This practice saves waferizer energy and maximizes usable raw material furnish. Excessively high moisture content logs will increase the energy demand on the log ponds and strand drying systems. Over-dry raw material increases waferizer energy demand and increases the generation of undesirable undersized strands.

It is recommended that mills track their seasonal green end log moisture content along with corresponding waferizer and dryer power consumption and fines generation, so that this relationship can be confirmed and quantified for their specific operation.

The waferizer uses a significant amount of electrical energy, and as the waferizer knives dull, the amperage or current draw also increases until it reaches a certain level. At that time, the machine is stopped and sharp knives are installed. The knife rotation may be needed once or twice during a 12-hour shift, depending on the log species, how well the log is conditioned and whether the log is frozen. Proper log yard management and log conditioning can be of benefit in this process. More frequent knife rotation should be considered.

Mills should also investigate the possibility of developing a hybrid hydraulic/electrical starting system for the waferizer motor as a possible saving for high demand charges from electrical power suppliers.

Some OSB mills lose heat from exposed log conditioning ponds. It is recommended that, where possible, a cover be put over the pond to reduce heat loss.

Some mills use plastic drop curtains over the jack chain where logs enter the mill from the ponds to avoid loss of heat to the outside in winter. We recommend the same practice for the roll-up doors over the warehouse. Heat is lost each time a roll-up door is opened for incoming and outgoing trucks. Plastic drop curtains that easily move aside to allow truck passage would help. Plant walls and roofs may also require additional insulation.

Sander motors are one of the biggest consumers of electrical energy. Some OSB mills still have to skip sand boards that are “over thick.” Optimized forming lines and press controls would produce boards closer to the target thickness and reduce sand off, thereby reducing electrical consumption at the sander and saving raw material, resin and the energy used to process the excess sand off.

Often equipment is kept running when no material is being processed. The installation of more electric “eyes” to shut off machine motors when not in use may prove to be a saving. Similarly, oversized electric machine motors are sometimes used; new motors of the correct horsepower with variable speed drives should be considered.

Infrared pre-heaters are used in PB and MDF production. It is possible that these same pre-heaters could be used before the OSB press, which could result in shorter press cycles and lower energy costs. These pre-heaters could also be installed over conveyers leading to the wet bin. This practice could significantly reduce energy requirements for dryers, especially during winter months.

Mat pre-heaters have been designed for continuous presses using an air/steam mix. These presses are used mainly for the production of thick MDF or PB. Continuous presses are installed in only a few OSB mills. By preheating the mat from 30°C to 70°C, production capacity may be increased between 30 and 50 percent depending on panel thickness.

Recent US Environmental Protection Agency (EPA) MACT regulations (Maximum Achievable Control Technology) affecting press, dryer, boiler and burner emissions may eventually may affect Canadian provinces. These regulations, coupled with proposed Canada-wide standards for particulates and ozone levels may require OSB producers and all composite mills to make significant changes to their pressing and drying processes, which may have large positive or negative impacts on energy consumption.

There is considerable potential for a heat recovery system in OSB mills. Up to 50 percent of the energy used by dryers is exhausted into the atmosphere. A closed-loop drying system has recently been installed in a European OSB mill. By using a new drying method based on vaporisation, and recovering exhaust gases, volatile organic compound emissions were reduced by more than 95 percent. The incineration of particulate matter from exhaust gases has also resulted in a reduction in consumption of natural gas of about 6 m^3 per cubic metre of OSB produced, a 12 percent reduction on thermal energy consumption.

Particleboard mills

Machine motors, particularly related to forming and pressing, and the sander are the biggest users of electric energy in PB production. Heating of thermal oil, drying, and building heat are the main uses listed for biomass fuel consumption, and fossil fuels are used for yard handling plus some dryer and building heat.

Surface finish quality and thickness tolerance are two of the most important attributes of PB. These attributes are achieved by sanding off the surface of the board up to 0.03 inches from each side in some older mills. Most panel sanders have multiple heads to allow for different sanding paper grits to produce a smooth surface finish. A typical mill reported the sanders requiring 2770 horsepower, provided by 228 motors. Newer mills with modern forming lines and continuous presses are able to produce boards much closer to target thickness, requiring only 0.01 in. to be sanded off on each side, saving considerable electric energy at the sander and also attaining significant savings in glue and raw material cost.

Some survey participants reported heat loss from thermal oil burners and stacks. Recycled heat from these burners is recycled through furnish dryers in some mills. This recycling can cause problems because the fly ash from the burner can raise the alkalinity of the raw furnish, which subsequently interferes with the urea formaldehyde resin bonding system. It is recommended that PB mills consider installing cyclones to remove burner fly ash particulates and install heat exchangers where possible to reduce heat loss. Heat exchangers can also be used to reduce pollution from the dryer exhaust stacks. Particulates are considered a critical air contaminant by Environment Canada.

One mill surveyed uses an infrared pre-heater system for preheating the PB formed mat before pressing. This practice reduces press times and allows for faster production.

PB and MDF plants are always operated under negative ambient air pressures. This method removes formaldehyde derived from the board glue from the ambient air to meet workplace air quality regulations. Operating under negative pressure releases a lot of heat from the building, especially in winter. Heat recovery air exchanger systems could have an effect similar to an infrared pre-heater and should be investigated. It is recommend that mills look at the feasibility and energy potential saving of air exchange units to recover heat otherwise lost to the environment, from the building, the dryer and the hot press area.

Raw material for PB and MDF is commonly stored uncovered outside the plant, exposed to the elements. A few mills in Canada have the luxury of a covered raw material storage room. The advantage of covered storage is a lower furnish MC entering the plant process, which can lead to significant savings at the dryer. Shorter drying time also reduces particle break-up and the production of excess undesirable fine material.

MDF mills

The pressurized refiner is the largest user of electrical energy in MDF plants, followed by the sander and other conveying machine motors. Biomass is used mainly for thermal oil heat, drying and building heat. Fossil fuels are also reported as being used for drying, building heat and log handling.

Reducing the horsepower consumed by the refiners would have the greatest impact on MDF electrical energy consumption. For panel sizing, wax is added at the refiner stage to help reduce refiner plate friction. Refiner plate and refiner operating pressures should also be monitored as another method of reducing energy by lowering friction. Additional pre-treatment before refining may also contribute to energy reduction at the refiner. Certain species require more energy to refine. Elimination or reduction of these species and/or some sort of unique species pre-treatment may also save energy at the refiner. A study on the use of hybrid hydraulic/electric starting systems for the refiner motor may also reduce peak high-demand electrical power.

Similar to PB, MDF requires a very smooth surface. Mills with newer continuous presses produce boards with less thickness variation and thus less board sand off is required, which can result in considerable electrical energy savings at the sander.

MDF mills in North America use exclusively “flash tube” dryers that are usually fuelled by thermal oil and heated by biomass. These dryers are well-insulated but still lose heat to the environment. Some sections of the dryers pass through the mill and provide heat, but this is an uncommon practice due to fire safety concerns. These mills are also operated under negative pressure to reduce formaldehyde levels in the ambient air in the mill. There is considerable potential for a heat recovery system in MDF mills, which could reduce biomass consumption.

10 REFERENCES

10 REFERENCES

1. Nyboer, J. 2009. *A Review of Energy Consumption and related Data in the Canadian Wood Products Industry* – various years. Canadian Industrial Energy End-use Data and Analysis Centre, Simon Fraser University, Vancouver, B.C. for Canadian Industry Program for Energy Conservation, Forest Products Association of Canada, www.cieedac.sfu.ca
2. Intergovernmental Panel on Climate Change. 2006. *Guidelines for National Greenhouse Gas Inventories,* www.ipcc.ch/ipccreports
3. Intergovernmental Panel on Climate Change. 2003. *Good Practice Guidance for Land Use, Land Use Change and Forestry*, www.ipcc.ch/ipccreports
4. Intergovernmental Panel on Climate Change. 2000. *Land Use, Land Use Change and Forestry*, www.ipcc.ch/ipccreports
5. Athena Institute. 2008. *A cradle-to-gate life cycle assessment of Canadian softwood plywood sheathing*. Prepared for FPInnovations, Forintek Division, Vancouver, B.C.
6. Athena Institute. 2008. *A cradle-to-gate life cycle assessment of Canadian Oriented Strand Board sheathing*. Prepared for FPInnovations, Forintek Division, Vancouver, B.C.
7. U.S. Life-Cycle Inventory Database. www.nrel.gov/lci – accessed in 2007 and 2008
8. Garrahan, P. 2008. *Drying Spruce-Pine-Fir Lumber*. By FPInnovations for Natural Resources Canada. Special Publication –SP-527E:167pp
9. Nielson, R, W., J. Dobie, and D.M. Wright, *Conversion Factors for the Forestry Products Industry in Western Canada*, Forintek Canada Corp, 1985.

Consortium for Research on Renewable Industrial Materials (CORRIM) Reports

1. Meil, J. and J. Wilson, J. O'Connor, and J. Dangerfield. 2007. *An assessment of wood product processing technology advancements between the CORRIM I and II studies*. Forest Products Journal 57:7/8, July/August 2007.
2. Wilson, J. 2007. *Forests, Carbon and Climate Change-Exploring the Role of Trees in Reducing Atmospheric Carbon*. A Special Report From the Oregon Forest Resources Institute. OFRI, Portland, Oregon. p. 13.
3. Milota, M., C. West, and I. Hartley. 2005. *Gate-to-gate Life-Cycle Inventory of Softwood Lumber Production*. Wood Fiber Sci. Vol 37 Dec. 2005: p47-57.
4. Wilson, J. and E. Sakimoto. 2005. *Gate-to-gate Life-Cycle Inventory of Softwood Plywood Production*. Wood Fiber Sci. Vol 37 Dec. 2005: p58-73.
5. Kline, D. 2005. *Gate-to-gate Life-Cycle Inventory of Oriented Strand Board Production*. Wood Fiber Sci. Vol 37 Dec. 2005: p74-84.
6. Wilson, J. 2008. Medium Density Fiberboard (MDF): *A Life Cycle Inventory of Manufacturing Panels from Resource through Product*. CORRIM Phase II Final Report. 69pp.
7. Wilson, J. 2008. Particleboard: *A Life Cycle Inventory of Manufacturing Panels from Resource through Product*. CORRIM Phase II Final Report

Other international reports

1. Arauco, 2006, *Declaración de Impacto Ambiental: Proceso de Elaboración de Tablero Contrachapado*. www.e-seia.cl. Nueva Aldea, Chile.
2. Aserraderos JCE S.A.. 2006. *Declaración de Impacto Ambiental: Planta Remanufactura Aserradero JCE*. www.e-seia.cl. Bio Bio, Chile.
3. CMPC Maderas S.A.. 2004. *Declaración de Impacto Ambiental: Ampliación de la Planta Mulchén, CMPC Maderas S.A.* www.e-seia.cl. Bio Bio, Chile.
4. CMPC Maderas S.A.. 2005. *Declaración de Impacto Ambiental: Planta Contrachapados*. www.e-seia.cl. Araucania, Chile.
5. Forestal Santa Elena Ltd. 2005. *Declaración de Impacto Ambiental: Planta de Secado y Remanufactura de Maderas Forestal Santa Elena*. www.e-seia.cl. Angol, Malleco, Chile.
6. Forestal Santa Elena Ltd. 2006. *Declaración de Impacto Ambiental: Regularización de Modificaciones y Ampliación de Forestal Santa Elena Ltda. - Planta Nueva Imperial*. www.e-seia.cl. Nueva Imperial, Cautin, Chile.
7. Frühwald A. and J. Hasch. 1999. *Life Cycle Assessment of Particleboards and Fibreboards*. www.oekobilanzen-holz.org. In Proceedings of the 2nd European Wood-Based Panel Symposium, Hannover, Germany, September 8-10.
8. Industrial Energy Efficiency Network. 1998. *Norwegian Industrial Energy Efficiency Network 1998*. http://ies.lbl.gov/iespubs/norwegian1998.pdf. IEEN, Norway.
9. Industrias Rio Itata II S.A.. 2008. *Declaración de Impacto Ambiental: Ampliación Planta Paneles Río Itata*. www.e-seia.cl. Trehuaco, Bio Bio, Chile.
10. Lindholm E-L. 1997. *Energy Use in Swedish Forestry and its Environmental Impact* (Licentiate thesis 004). SLU, Department of Biometry and Engineering, Uppsala, Sweden.
11. Louisiana Pacific Chile S.A. 2006. *Declaración de Impacto Ambiental: Planta elaboradora de tableros de fibra orientada OSB*. www.e-seia.cl. Lautaro, Cautín, Chile.
12. Louisiana Pacific Chile S.A. 1999. *Declaración de Impacto Ambiental: Reconstrucción y Modificación Planta de Tableros Panguipulli*. www.e-seia.cl. Panguipulli, Valdivia, Chile.
13. Masisa S.A. 2003. *Reporte de Sustentabilidad 2002–2003*. www.masisa.com.as Condes, Santiago, Chile.
14. Masisa S.A. 2005. *Reporte de Sustentabilidad 2004–2005.* www.masisa.com. Las Condes, Santiago, Chile.
15. Masisa S.A. 2005. *Declaración de Impacto Ambiental: Nueva Línea de MDF en Masisa S.A., Planta Cabrero*. www.e-seia.cl. Cabrero, Bio Bio, Chile.
16. Masonite AB. 1999. *Environmental building product declaration: Hardboard, Oil tempered hardboard, Mediumboard and Structural hardboard*. www.masonite.se. Rundvik, Sweden.
17. Masonite Chile S.A. 2002. *Declaración de Impacto Ambiental: Ampliación de planta de tableros para fabricación de puertas moldeadas*. www.e-seia.cl. Cabrero, Bio Bio, Chile.
18. Paneles Santa Elena S.A. 2006. *Declaración de Impacto Ambiental: Planta Paneles Contrachapados*. www.e-seia.cl. Angol, Malleco, Chile.

19. Polincay Export Ltd. 2006. *Declaración de Impacto Ambiental: Paneles Polincay La Union*. www.e-seia.cl. La Colina, Santiago, Chile.
20. Rivela B., M.T. Moreira, and G. Feijoo. 2007. *Life Cycle Inventory of Medium Density Fibreboard*. Int J LCA 12(3):143-150.
21. Stora Enso Timber Swedish Sawmills. 2004. *EMAS Statement: Interim Statement 2004*. www.storaenso.com/timber. Falun, Sweden.
22. Stora Enso Timber Finnish Sawmills. 2005. *EMAS Statement: Interim Statement 200*5. www.storaenso.com/timber. Porvoo, Finland.
23. Svenska Cellulosa Aktiebolaget. 2004. *Environmental and Social Report 2004*. www.sca.com. Stockholm, Sweden.
24. Terranova S.A. 2003. *Reporte de Sustentabilidad 2002-2003*. www.terranova.com. Las Condes, Santiago, Chile.
25. UPM. 2004. *Corporate responsibility report 2004*. www.upm-kymmene.com/en/. Helsinki, Finland.
26. Vanerply AB. 2001. *Environmental declaration: The Nordic Timber Industry*. www.vanerply.se/en/. Otterbäcken, Sweden.
27. WISA. 2004. *Life Cycle Assessment of WISA-Form Birch* www.wisa.fi. Lahti, Finland.

APPENDICES

APPENDIX 1: INHERENT HEATING VALUES AND GLOBAL WARNING POTENTIAL OF FUELS

		Fuel combustion		Fuel precombustion		Total energy and GWP	
Mobile sources	**Basis**	MJ	CO_2e kg	MJ	CO_2e kg	MJ	CO_2e kg
Diesel comb. truck	tkm	1.05254	0.081	0.16279	0.013	1.215	0.094
Diesel rail	tkm	0.25061	0.019	0.03876	0.003	0.289	0.022
Gasoline truck	tkm	2.03432	0.139	0.29728	0.025	2.332	0.164
RFO water	tkm	0.20557	0.016	0.03189	0.003	0.237	0.019
Jet fuel (kerosene)	tkm	0.79032	0.053	0.11715	0.009	0.907	0.062
Industrial heat processes							
Anthracite coal	kg	28.90946	2.883	0.80972	0.677	29.719	3.560
Bit/subbit coal	kg	24.76128	2.783	1.28946	0.157	26.051	2.940
Lignite coal	kg	15.01247	2.304	1.46594	0.126	16.478	2.430
Biomass	kg	15.80000	1.840	–	–	15.800	1.840
Diesel	L	38.66215	2.730	5.97966	0.470	44.642	3.200
Distillate fuel oil	L	38.66215	2.730	5.97966	0.470	44.642	3.200
Gasoline	L	34.87120	2.341	5.09578	0.419	39.967	2.760
LPG	L	26.62030	1.767	3.73801	0.293	30.358	2.060
Natural gas	m^3	38.84866	2.019	3.42582	0.411	42.274	2.430
Residual fuel oil	L	41.72836	3.269	6.47331	0.511	48.202	3.780
Electricity							
Canadian electricity	MJ primary energy/delivered kWh (includes 6.8% line losses)					5.065	0.283
B.C. electricity	MJ primary energy/delivered kWh (includes 6.4% line losses)					0.586	0.034
Electricity primary energy values account for primary fuel conversion efficiency and line losses.							
GWP includes all anthropogenic sources of greenhouse gases (CO_2, CH_4, N_20, CFCs, PFCs and SF_6).							
Sources: US LCI Database (www.nrel.gov/lci)							
Athena Institute data files (www.athenasmi.org), Environment Canada Greenhouse Gas Inventory (2006)							

APPENDIX 2: SPECIES DISTRIBUTION AND THE AVERAGE WOOD DENSITIES IN CANADA

Main species	Western Canada	Species	Basic Density (kg/m^3)*	Eastern Canada	Basic density (kg/m^3)
Spruce	B.C., Alta.: white and black with some Engelmann in limited areas	white	360	Ont., Que.: white and black	360
		black	406		406
		average density	383		383
Pine	B.C.: lodgepole Alta.: lodgepole with an insignificant proportion of jack pine	lodgepole	409	Ont., Que.: jack	421
Fir	B.C.: subalpine Alta.: subalpine and some balsam	subalpine	329	Ont., Que.: balsam	335
		balsam	335		
		average density	332		
Douglas fir		coastal	450		–
Larch		western	450		–
Poplar		balsam	–		337
Birch		white	–		506

* See Nielson, R. W.; Dobie, J.; Wright, D. M.: “Conversion Factors for the Forestry Products Industry in Western Canada,” Forintek Canada Corp, 1985.

APPENDIX 3: CUBIC METRE CONVERSION FACTORS PER Mfbm LUMBER

Nominal dimensions (inch)	Surfaced dry	Surfaced green	Rough green
	Conversion factor* (m^3/Mfbm)		
2x2	1.3272	1.4401	2.380
1x4	1.5486	1.6418	2.333
1x6	1.6222	1.7284	2.318
2x4	1.5486	1.6418	2.380
2x6	1.6222	1.7284	2.364
2x8	1.6038	1.7284	2.368
2x10	1.6369	1.7513	2.371
2x12	1.6590	1.7666	2.372
1x3	1.4747	1.5746	2.318
2x3	1.4747	1.5746	2.364
3x4	1.7205	1.7952	2.364
6x8	1.9099	1.9966	2.371
3x3	1.7205	1.7952	2.349
4x4	1.8066	1.8717	2.380

* Nielson, R. W.; Dobie, J.; Wright, D. M.: "Conversion Factors for the Forestry Products Industry in Western Canada," Forintek Canada Corp, 1985.