CORRIM: Phase I Final Report

Module D

SOFTWOOD PLYWOOD MANUFACTURING

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EXECUTIVE SUMMARY

The objective of this study is to develop a life cycle inventory (LCI) for the production of softwood plywood as manufactured in the Pacific Northwest (Oregon and Washington) and the Southeast (Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, and Texas). Softwood plywood is considered a structural panel product, and is used for roof, wall and floor sheathing and sub-flooring in residential and commercial construction. Wood species used for veneers to make plywood in the Pacific Northwest include Douglas fir, western hemlock, and some spruce and western larch, whereas wood species used to make plywood in the Southeast include loblolly and slash pine (referred to as Southern Pine). Plywood plants were surveyed in these two regions to obtain a record of all inputs and outputs associated with the production process. Input data collected included material transportation distances and the use of wood, bark, electricity, fuel and resin. Output data quantified plywood product, co-products of chips, trimmings, clippings, bark, and sawdust, as well as emissions to land, water and air. The analysis is a gate-to-gate LCI for the production of softwood plywood, with transportation data provided for delivery of logs, bark, veneer, and resin resources. The LCI data was provided to the US LCI Database project for inclusion in their database, and was used by ATHENA™ and CORRIM to develop resource-to-residential construction LCIs (cradle-to-gate) for this report. A critical outside review was conducted of the process and data analysis to ensure compliance with CORRIM and ISO 14040 protocol.

In addition to the LCI assessment, this study also involved a sensitivity analysis of the type of fuel used for heat generation. This assessment examined tradeoffs between use of wood/bark hogged fuel and natural gas. A carbon balance of wood material inputs and outputs was performed to track carbon through the process. Carbon storage is important since it makes it unavailable for formation of carbon dioxide (CO_2), the major atmospheric greenhouse gas. A cost analysis of plywood production, completed as a part of this study effort, is also reported herein.

Five plywood manufacturing plants in the Pacific Northwest (PNW) and five plants in the Southeast (SE) were surveyed. The surveyed plants produced 1.23 billion square feet (MMMSF) 3/8-inch basis in the PNW and 1.38 billion square feet (MMMSF) 3/8-inch basis in the Southeast in 2000, representing 27% and 14% of total production in the PNW and SE, respectively.

A unit process approach was taken in modeling the LCI of manufacturing plywood. The plywood process was defined in terms of six unit processes—bucking and debarking, block conditioning, peeling and clipping, drying, lay-up and pressing, and trimming and sawing. The rationale for this approach is that this type of model would be useful in analyzing ways to improve process efficiency, optimize operations, and finding means to reduce environmental impacts. These things cannot be achieved using a simple "black-box" approach. With the recent attention given to conservation of raw materials, awareness of price volatility and increases in the cost of electricity and fuel, and the substantial cost of emissions mitigation, it has become imperative to address these concerns. The LCI data presented would be useful as a benchmark to assess environmental performance and economic feasibility of process improvements.

As expected, the major use of electricity and heat (generated with fuel) were the drying and pressing sub-unit processes and to a lesser extent the conditioning process. The same was true of emissions. All inputs and outputs were determined per thousand square feet (MSF) 3/8-inch basis of plywood. The PNW used 1.40E+06 Btu of heat in processing, of which 90% was from wood and bark hogged fuel with the other 10% from natural gas. Similarly the SE used 1.84E+06 Btu of heat—89% from hogged fuel and 11% from natural gas. The greater use of heat in the Southeast is due to the need to remove a greater amount of moisture from the veneer. The ability of the plywood industry to generate a major portion of its heat needs from the combustion of hogged fuel instead of natural gas provides a significant benefit. If a plant producing about 290,000 MSF 3/8-inch annually replaced the hogged fuel with an equivalent quantity of natural gas, at $0.26 per therm (100,000 Btu), a PNW plant would have an additional natural gas bill of $137,309, and the SE plant would have an additional $183,363 bill. The electricity use per MSF 3/8-inch basis of plywood is 138.9 kWh for the PNW and 122.0 kWh for the SE. As such, the electricity bills for the same annual production of 290,000 MSF 3/8-inch basis would be substantial; at $0.0425 and $0.047 per kWh, respectively, the annual bills would be about $1.7 million and $1.6 million respectively. With the projected cost increases of both natural gas and electricity, means to become more energy efficient will receive more attention.

The PNW and the SE had wood recoveries of 51% and 50% respectively as determined by the output of wood in the form of plywood as a percentage by weight of the wood input to the manufacturing facilities in the form of logs. For the PNW 65.6 $ft.^3$ (1,788 lb oven-dry) of wood in log form plus 20.6 lbs of purchased veneer were required to produce 1.0 MSF 3/8-inch basis of plywood, while for the SE 66.0 $ft.^3$ (2080 lb oven-dry) of wood in log form and 18.5 lb of purchased veneer were required. The quantity of bark generated during the debarking process based on the dry weight of bark to dry weight of wood was 5.5% (99 lb) and 6.0% (124 lb) for the PNW and SE, respectively.

Emissions and emissions mitigation are becoming increasingly important in terms of plant operations and manufacturing costs. Emissions are presented for two cases: 1) total emissions for the entire plywood manufacturing process, including those associated with the production and delivery of fuels, electricity, and resin; and 2) site emissions, those associated with the plywood manufacturing process only. Burdens, or allocations of emissions, were assigned to products and co-products on a mass basis. Emissions reported for plywood had a burden on a mass-based allocation of 51.1% and 49.6% for the PNW and SE, respectively. Approximately half the emissions were assigned to the plywood and the other half to the co-products of peeler core, chips, clippings, trimmings, veneer (green and dry), bark, and sawdust based on their weight percentage. Bark and wood waste used for hogged fuel within the plant were not allocated any emissions. Carbon dioxide (CO_2), a greenhouse gas of international interest, is generated by combustion of fuels. Since a major portion of the heat generation for the production of plywood was based upon hogged fuel; this type of fuel contributed 97% of the total CO_2 emissions from the plant. However, this impact is negated or greatly lessened by the growing of trees that remove CO_2 from the atmosphere. CO_2 values were obtained from EPA reports.

The quality of the data is considered very good. Based on the amount of data for the five plants from each region, a comparison of values between plants established the validity of the data. Additional data analysis (i.e., mass and energy balances), as well as regional comparisons, further supported the integrity of our findings. The unit process approach for modeling the LCI of plywood should prove useful for modeling other similar processes such as laminated veneer lumber (LVL) production, which uses green and dry veneer to produce product. The model would also be valuable as a tool to optimize operations, and the LCI data could be used as a benchmark to assess improvements.

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1.0 PACIFIC NORTHWEST SOFTWOOD PLYWOOD

1.1 INTRODUCTION

Softwood plywood has had a long tradition as a structural building material for both commercial and residential construction. Plywood is used as roof, wall and floor sheathing, and for sub-flooring in home construction. Although plywood comes in a variety of grades and thickness, its production is based on a one thousand square feet (MSF) of 3/8-inch basis equivalence—industry refers to this as M 3/8. In SI units, it is on a one thousand square meters (MSM) of 9-mm basis. Plywood is made from various species in the Pacific Northwest region; Douglas-fir and western hemlock dominate, with other species such as spruce and western larch also used. This report focuses on production practices in Oregon and Washington. The size of production facilities in the region range from 50,000 to 450,000 MSF 3/8-inch basis annually. This study collected data from representative plants that would be considered in the upper portion of this range. The total annual softwood plywood production for the region was 4,686,000 MSF 3/8-inch in 2000 (APA 2001), representing 27% of all US plywood production (17,475,000 MSF 3/8-inch basis) and 13% of all structural panel production (29,381,000 MSF 3/8-inch basis) (APA 2001). The region produces enough panels, if it were all sheathing, to build 754,000 homes annually (NAHB 2001 — 6.212 MSF 3/8 sheathing per home). Panels are normally produced in 4-x 8-foot sheets.

To conduct the survey of plywood manufacturers, five plants were identified based on their production capability and representativeness of the industry. All five plants provided data for 2000 in terms of plywood and co-products production, raw materials, electricity and fuel use, and emissions. The five plywood producers surveyed represent 26% of the region's production. Total annual production from producers surveyed was 1,233,424 MSF 3/8-inch basis.

This report documents the life cycle inventory (LCI) of manufacturing structural plywood based on resources from the Pacific Northwest softwood region. The output of this report, a gate-to-gate analysis plus transportation data for delivery of materials, will be used to conduct a cradle-to-residential building life cycle analysis (LCA) of structural building materials by CORRIM. This report considers those impacts associated solely with the manufacture of softwood plywood, documenting all inputs and outputs and their impact. Primary data was collected through a survey of plywood manufacturers, while secondary data was obtained for impacts associated with the manufacture and delivery of electricity and all fuels (Franklin Associates 2001; Pre´ Consultants 2001; USDOE 2000), CO_2 and press emissions (EPA 2001), and the production of phenol-formaldehyde resin (ATHENA™ 1993). For a cradle-to-gate analysis this data would need to be combined with the impacts for the resource module that generated logs and bark, and the transportation impacts for delivery of logs, bark, veneer, and resin to the plywood plants.

The scope of this report encompasses production of softwood plywood in the Pacific Northwest region (Oregon and Washington) including raw material transport (mileage data provided) to the production facility (commonly referred to as a gate-to-gate analysis). This report is confined to transportation of logs and resin materials to the manufacturing site, and production of phenol-formaldehyde resin, electricity, natural gas, plywood and its co-products. A critical review of this LCI process and analysis was conducted to ensure compliance with CORRIM and ISO 14040 protocol.

1.1.1 Unit Process Approach

The plywood process was broken down into six unit processes rather than examining the process as a "black box." The rationale for taking this approach is that a unit type of model would be most useful in analyzing ways to improve process efficiency, optimize operations, and reduce environmental impacts. Furthermore, data in this format could be used as a benchmark to document process improvements. In addition, this approach allows unit processes developed for one process to be used for modeling other processes. For instance, the peeling and drying unit processes could be used as input for green and dry veneer, respectively, into a laminated veneer lumber (LVL) life cycle inventory analysis (LCI). The unit processes used to model softwood plywood production are shown in Figure 1.1.

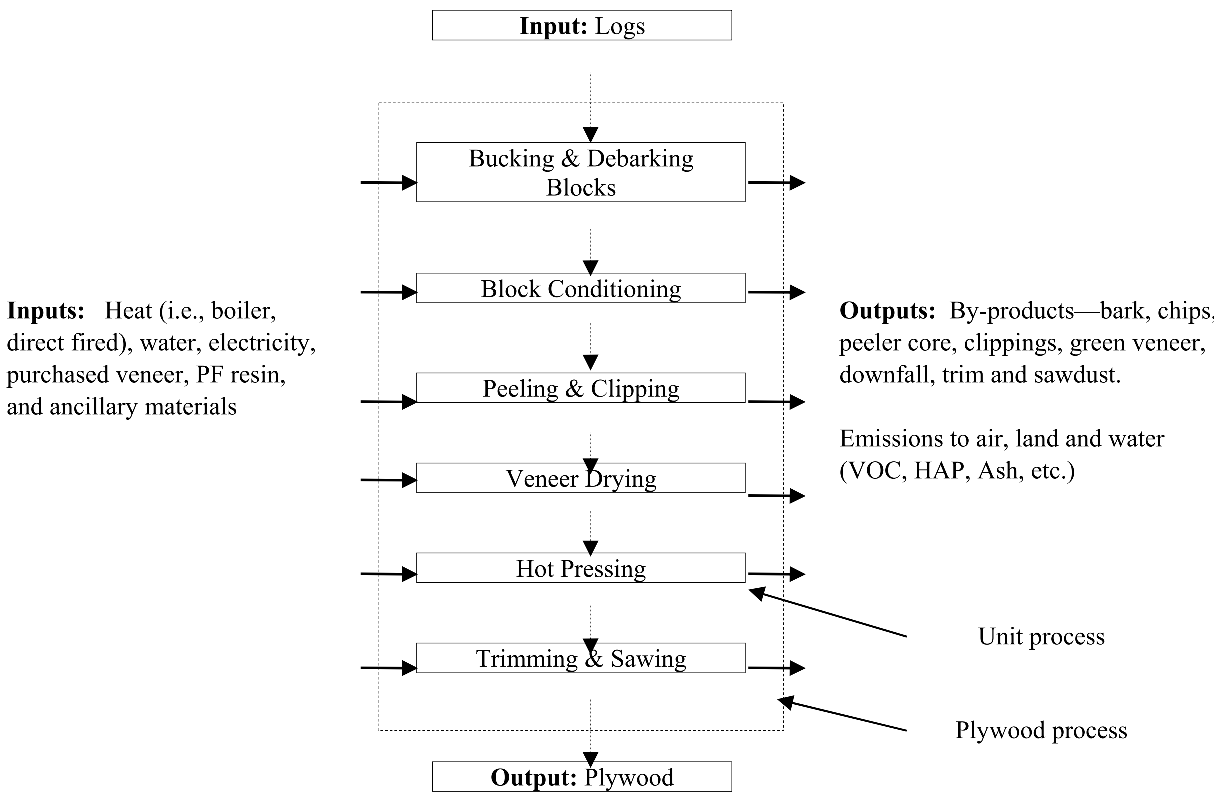


Figure 1.1. Unit process approach to the modeling of the plywood manufacturing process.

Description of unit processes:

1. Debarking: includes debarking and bucking logs—cutting to length—to make blocks for peeling; possible co-products include bark and some wood waste,

2. Conditioning: heating the blocks with either hot water or steam to condition—increase temperature and moisture content—the blocks for peeling,

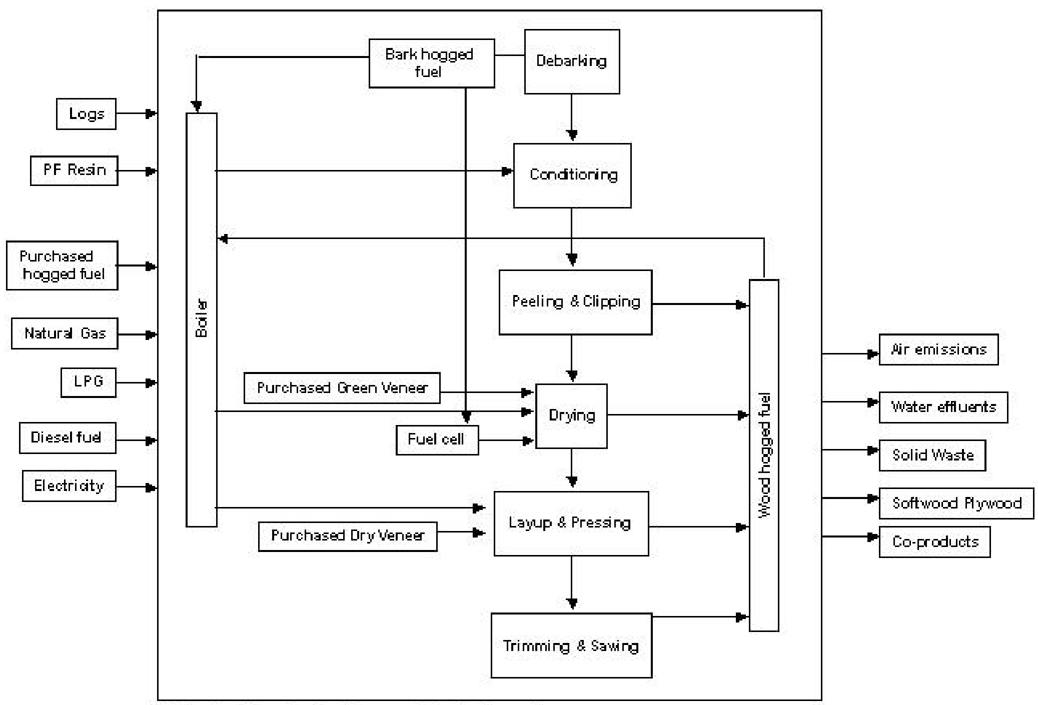
3. Peeling and Clipping: blocks are peeled in the lathe to make veneer, clipped to size, and sorted by moisture content (which is a function of the percentage of sapwood and heartwood in the sheet) in preparation for drying; co-products include round-up wood, peeler cores, veneer clippings and trim,

4. Veneer Drying: veneers are dried in "continuous dryers" to 3-5% moisture content. Various heat sources are used for the drying. This process center includes redrying, a practice where 10-20% of the veneer processed through the dryer is still too wet, so it is redried or set aside for conditioning. Co-products include veneer downfall and other wood waste,

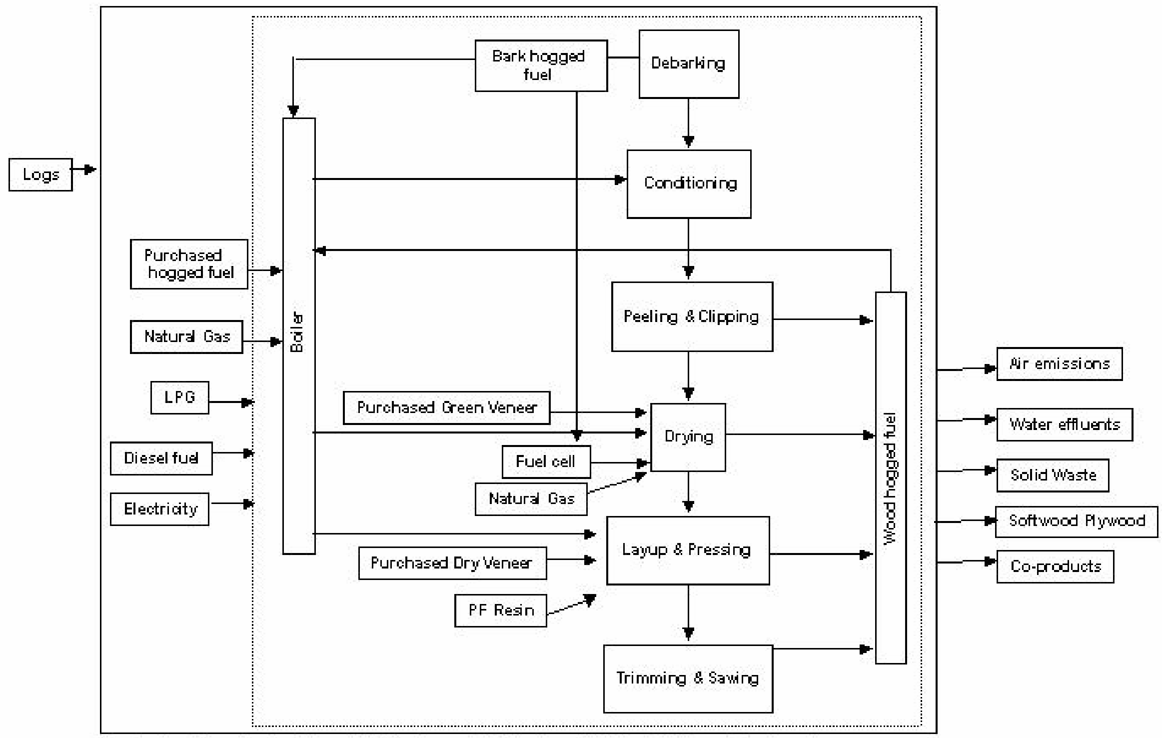
5. Lay-up and Pressing: veneers are coated with phenol-formaldehyde resin and composed into panels for hot pressing; heat and pressure are used to cure the resin, thereby bonding the veneers to make plywood,

6. Trimming and Sawing: plywood panels coming out of the press are sawn to appropriate dimensions. Co-products include plywood trim and sawdust.

Bark and some wood waste are used as fuel to fire boilers and fuel cells that supply heat to various unit processes—conditioning, drying and hot pressing—in the manufacturing process. As such, the bark and other wood waste when used as "hogged fuel" to generate heat are considered within the system boundary for the LCI analysis. Excluded from the study were the production of catalyst, fillers, and extenders used in resins, and the growth and harvesting of the trees. The boiler, although not considered as a unit process, was analyzed as a separate operation within the system boundary. Figure 1.2 provides an overview of the entire system boundary used to model the plywood process, two conditions are examined: A) considering site generated emissions and B) considering site and off-site emissions.



A) System Boundary for site generated emissions only



B) System Boundary for Site and Off-site Generated Emissions which include those for fuels, resin, purchased veneer and hogged fuel, and electricity, but do not include emissions for delivery of logs, resin, and purchased veneer, nor for production of logs

Figure 1.2. System Boundary and Unit Processes Used to Model the Plywood Manufacturing Process: a) for Site Generated Emissions Only, and b) for Site and Off-site Emissions.
Notes: Co-product flows are not included in the sketch.

1.1.2 Materials Flow

Those materials considered in the LCI analysis included those listed in Table 1.1. Input materials considered were logs (includes wood and bark), dry and green veneer, and phenol-formaldehyde resin. Outputs were plywood and co-products consisting of peeler core, chips, clippings, trimmings, veneer (green and dry), bark, wood waste, and sawdust. All flow analyses of wood and bark in the process were determined on an oven-dry weight basis. Only for energy calculations were bark and hogged fuel considered green (with moisture) at 50% moisture content wet-basis, all other weights are at an oven dry condition. To derive the wood and bark weights and to determine how much water was “dried” from the wood and bark, the following assumptions were made: bark was at 50% moisture content (MC) on a wet-basis, the wood was at 60% MC for sapwood and 25% MC for heartwood—both on an oven-dry basis, and dry veneer and wood waste were at 7% MC on an oven-dry basis.

Table 1.1. Listing of Input Materials, Products, and Co-products for Producing Plywood.

Input Materials	Co-products Produced	Products
Logs	Bark	Plywood
Green veneer	Chips, green	
Dry veneer	Peeler cores	
Phenol-formaldehyde resin	Clippings, green	
	Veneer, dry	
	Veneer downfall, dry	
	Plywood trimmings, dry	
	Sawdust, dry	

1.1.3 Transportation

Delivery of the input materials was by truck. The one-way delivery distances for logs, veneer, and resin are given in Table 1.2. The impacts of delivering materials is not considered in this module, rather the data is used by CORRIM and ATHENA™ when conducting resource through residential construction LCAs presented in Module J.

Table 1.2. Pacific Northwest Delivery Distance (one-way) for Plywood Production.

Material	Delivery Distance (miles)
Logs (roundwood)	60
Bark on logs	60
Purchased Veneer	75
Purchased hogged fuel	55
Resin	122

1.1.4 Wood Density

The weight of the input wood was determined by using the log volume data in Scribner scale and converting to cubic feet (ft^3) of wood using the appropriate conversion factor as given by Briggs (1994). A final conversion was then made from ft^3 to mass (lb) by multiplying by the average weighted densities as determined by their percentage use as given by the survey, and the densities for these species as provided in the Wood Handbook (1999). The average wood density used was 27.26 lb/ft^3 oven-dry, wet volume for the mix of Douglas-fir, spruce, hemlock-fir, and western larch as given by the survey (Table 1.3).

Table 1.3. Average Density of Wood Species Used to Calculate Mass of Wood from Logs.

Wood Species	Percentage Use in Survey	Density[1]	Weighted Average Density	
	%	lb/ft^3	lb/ft^3	kg/m^3
Douglas fir[2]	67.6	28.08	18.98	304.20
Sitka spruce	11.6	23.09	2.68	42.92
Western Hemlock-Fir	16.8	26.21	4.40	70.56
Western larch	4.0	30.00	1.20	19.20
Total	100		27.26	436.88

Sources: [1] Wood density values are from Wood Handbook: Wood as an Engineering Material (1999).
[2] Coastal West

1.1.5 Assumptions

The data collection, analysis, and assumptions followed protocols as defined in "Consortium for Research on Renewable Industrial Materials (CORRIM)--Research Guidelines for Life Cycle Inventories" dated April 18, 2001 and ISO 14040. Additional considerations include:

- A critical review was conducted of the process and data analysis to ensure compliance with CORRIM and ISO 14040 protocol.

- Data quality was found to be high based upon comparisons between plants, and on mass and heat balances. Data was also compared between regions and was found to be consistent when accounting for the higher density and moisture content of wood species for the southeast region.

- LCI data for site generated emissions considered only those emissions at the manufacturing process, thus giving a gate-to-gate LCI; to provide a cradle-to-gate LCI the reader would need to include the environmental impact of the growing and harvesting of the trees for logs, the transportation of logs, resin, purchased veneer and hogged fuel to the mill. LCI data for site and off-site emissions are also considered, but exclude burdens for logs and transportation of logs, resin, and purchased veneer and hogged fuel to the mill.

- All data from the mill survey taken in 2000 was weight averaged for the five plants based on the individual production of each plant in comparison to the total production for the year.

- The purchase dry and wet veneers, come with the same allocated burdens, as if produced in the plant since they use the same unit process models. The addition burden for transportation of the veneers is handled separately using the delivery mileage data.

- A mass-allocation process was used for assigning burdens.

- Co-products were defined as any materials that were sold outside the system boundary.

- 100% of diesel fuel use was assigned to debarking and bucking to address fuel use by yard log loaders.

- 20% of liquid propane gas (LPG) was assigned to each of the five sub-unit processes from Conditioning through Trimming and Sawing to account for fuel use by forklift trucks within the plant.Density values for the wood species used to make the plywood were obtained from Wood Handbook—Wood as an Engineering Material (1999), and based on their weighted percentage of use as reported by manufacturers; the weighted average density was calculated to be 27.26 lb/ft^3 oven-dry, wet volume.

- Log inputs were provided in thousand board feet (Mbf) in Scribner scale and converted to ft^3.

- All conversion units for forestry and forest products type conversions were taken from Forest Products Measurements and Conversion Factors, with special emphasis on the US Pacific Northwest (Briggs 1994).

- Unaccounted wood mass of 7.5% was established by the difference between reported input and output wood material flows (see Table 1.5 for material balance analysis); since there was a similar weight difference between hogged fuel and bark, much of the difference may have been the unaccounted for wood that was hogged for fuel. The unaccounted wood was treated as a co-product for the mass-based allocation of environmental burdens.

- SimaPro 5.0.9, a software package designed for analyzing the environmental impact of products during their whole life cycle, was used to perform the life cycle analysis. Developed in the Netherlands by PRé Consultants B.V., SimaPro5 contains a US database for a number of materials, including paper products, fuels, and chemicals. Franklin Associates (FAL) provides an additional US database.

1.2 PRODUCT YIELDS

The input to produce a thousand square feet (MSF) 3/8-inch basis consists of 65.6 cubic foot (ft^3) or 1,788 lb of wood from logs (based on volume and wood densities given in Table 1.3) and 20.6 lb of purchased veneer. These inputs yield 916 lb of oven-dry plywood (wood only) and 191.5 lb of oven-dry hogged fuel that is about half bark (the survey had a second category for bark where plants reported 99 lb oven-dry bark which appears to have been also included in the hogged fuel reported value). See Table 1.4 for a listing of all inputs and outputs.

Table 1.4. Inputs to Produce 1.0 MSF (3/8-in) and 1.0 m^3 Plywood in the Pacific Northwest.[1/]

PNW Plywood – INPUTS Materials[2/]	Units	MSF 3/8-in Basis	SI Units	m^3
Roundwood	ft^3	6.56E+01	m^3	2.10E+00
	lb	1.79E+03	kg	9.18E+02
Phenol-formaldehyde adhesive	lb	1.59E+01	kg	8.15E+00
Extender and fillers	lb	8.90E+00	kg	4.56E+00
Catalyst[3/]	lb	1.11E+00	kg	5.69E-01
Soda Ash[3/]	lb	3.30E-01	kg	1.69E-01
Bark[4/]	lb	9.90E+01	kg	5.07E+01
Purchased				
Dry veneer	lb	6.40E+00	kg	3.28E+00
Green veneer	lb	1.42E+01	kg	7.28E+00
Electrical Use				
Electricity	kWh	1.39E+02	MJ	5.65E+02
Fuel Use				
Hogged Fuel (produced)	lb	1.92E+02	kg	9.84E+01
Hogged Fuel (purchased)	lb	1.70E+01	kg	8.71E+00
Wood waste	lb	5.00E-01	kg	2.56E-01
Liquid propane gas	gal	3.59E-01	L	1.54E+00
Natural gas	ft^3	1.63E+02	m^3	8.36E+01
Diesel	gal	3.95E-01	L	1.69E+00
Water Use				
Municipal water source	gal	8.28E+01	L	3.54E+02
Well water source	gal	2.94E+01	L	1.26E+02
Recycled water source	gal	3.00E-01	L	1.28E+00

Notes: 1/ All information comes from primary survey data collected in 2000 for plant site only
2/ All materials are given as an oven-dry basis or solids weights
3/ These materials were not included in the SimaPro LCI analysis; excluded based on the 2% rule
4/ Oven-dry weight. Assumed to be 50% moisture content on wet-basis in survey data.

A complete wood mass balance is given in Table 1.5. Bark was not considered in the wood flow. The percentage by weight of bark based on the weight of wood from the processed logs was most likely 10% if all the hogged fuel generated within the plant was bark; however when only the reported bark weight was considered then the amount of bark was 5.5%, and the remainder of the fuel would be from wood residues. From these values it appears that at least half of the hogged fuel was bark.

The difference between the total wood input and output is 137 lb, which was labeled as the "unaccounted for wood." The unaccounted for wood amounted to 7.5% of the total wood input, which is reasonably close for a survey of this type. The percentage of recovery of wood in terms of wood input as logs and output as plywood is 51%—defined as the weight of wood in plywood expressed as a percentage of the total weight of input wood from the logs. This is a very good efficiency for an industry that has had to use smaller and smaller diameter logs to produce veneer. The smaller diameter logs make it more challenging to maintain a high recovery value. Most of the remaining 49% of wood material went into co-products and, as defined, were sold outside the plant.

Some of the 137 lb of unaccounted wood may have been included in the reported hogged fuel value. The plants reported that they produced 191.5 lb of hogged fuel; however, only 99 lb of this was specifically reported as bark from the debarking unit process. The difference may be bark, but more likely it is wood waste that had been hogged for fuel from various unit processes.

Table 1.5. Wood Mass Balance for Plywood Production in the Pacific Northwest Region per 1.0 MSF 3/8-in Basis.

Inputs	lb/MSF 3/8-in Basis	kg/m^3
Round wood (logs)	1,788[1]	917
Purchased dry veneer	6	3.1
Purchased green veneer	14	7.2
Total	1,809	927

Outputs	lb/MSF 3/8-in Basis	kg/m^3
Plywood (wood only)	916[2]	470
Wood chips	425	218
Peeler core	95	49
Green clippings	31	16
Veneer downfall	3.4	1.7
Panel trim	107	55
Sawdust	9.6	4.9
Wood waste to boiler	0.25	0.13
Sold wood waste	21	11
Sold dry veneer	63	32
Unaccounted for wood	137[3]	704
Total	1,809	927

[1] Based on Douglas-fir, spruce, western hemlock and western larch weighted average wood density of 27.26 lb/ft^3 for 65.6 ft. of wood in logs to produce MSF 3/8-in basis.
[2] Plywood (wood only) based on estimated weight of plywood, 991 lb, minus 80% of resin, filler, soda ash, and catalyst total use.
[3] 7.6% unaccounted for wood; a good portion of this was likely in the hogged fuel.
Note: All weights are at oven-dry or 100% solids.

1.3 MANUFACTURING ENERGY SUMMARY

1.3.1 Sources of Energy

Energy for the production of plywood comes from electricity, diesel, liquid propane gas (LPG), bark-hogged fuel, and steam. With the volatile and increasing fuel and electricity prices, this topic will attract considerable attention in the coming years as plants seek to maintain profitability by reducing costs. The electricity is used to operate the debarker, bucker, lathe, pneumatic and mechanical conveying equipment, fans, hydraulic pumps, saws, and a radio-frequency redryer (one plant only). Electricity was used in all processes. Diesel fuel use is attributed solely to log loaders in the "Debarking" sub-unit process. As such, all of the diesel use was assigned to this process. Forklift trucks used small amounts of LPG in one or more of the remaining five sub-unit processes. This fuel use was assigned evenly over the five sub-unit processes from "Conditioning" to "Trimming and Sawing;" as such, 20% of the LPG use was assigned to each of these operations.

1.3.2 Electricity Use Summary

The source of fuel used to generate the electricity used in the manufacturing process is very important in determining the type and amount of impact in the LCA. The breakdown of electricity for the Pacific Northwest by fuel source is given in Table 1.6. The source of this data is the US Department of Energy (DOE). In 2000 the dominant form of electricity generation in the region was hydro, representing 74.3% of the total, followed by natural gas at 12.3% and coal at 8.1%. In the SimaPro (LCA software) impact analysis, no impacts are associated with hydro-generated electricity; however, combusting of coal can contribute significant impact values.

Table 1.6. Electric Power Industry Generation of Electricity by Primary Energy Sources and State for the Pacific Northwest Region as Defined by the US Department of Energy.

Percentage Share, 2000[1]			
Fuel Source	**OR**	**WA**	**Average**
Coal	7.4	8.8	8.1
Petroleum	0.1	0.4	0.25
Natural Gas	17.1	7.5	12.3
Nuclear	0.0	7.9	3.95
Hydro	74.3	74.3	74.3
Others	1.1	1.1	1.1

[1] *Source*: Energy Information Administration/State Electric Profiles 2000, Department of Energy (2000). **http://www.eia.doe.gov/cneaf/electricity/st_profiles/toc.html**

The distribution of electricity use by unit process for the various plants was not obtained from the survey data. Rather it was extracted from data provided by the Oregon State University Energy Extension Office and a publication entitled Energy Use and Conservation in Oregon's Lumber and Wood Products Industry (Grist and Karmous 1988) of the Oregon Department of Energy. Table 1.7 provides a breakdown of electricity use by unit process. The dominant electricity use is for drying (36.7%) to operate the high velocity fans used in longitudinal, cross-flow and jet dryers (methods used to increase the heat and mass transfer rates during drying). Each of four other unit processes—debarking/bucking, peeling/clipping, lay-up/pressing, and trimming/sawing—each use approximately 15% of the total electricity. Conditioning used the least amount (7%).

Table 1.7. Electricity Distribution by Unit Process for Plywood Production in the Pacific Northwest.

Unit Process	kWh MSF 3/8-in Basis	Allocation %[1]
Debarking & bucking	17.2	12.4
Conditioning	9.6	6.9
Peeling & clipping	24.5	17.6
Drying	51.0	36.7
Lay-up & pressing	15.3	11.0
Trimming & sawing	21.4	15.4
Total	138.9	100.0

[1] *Source*: Ferrari, C.J. 2000. Life Cycle Assessment: Environmental modeling of plywood and laminated veneer lumber manufacturing. Table 24, Appendix D., page 111 – Distribution of electricity use by unit processes.

Notes: All values are given per 1.0 MSF 3/8-in basis of plywood.

1.4 FUEL UTILIZATION AS A HEAT SOURCE

All of the bark generated during debarking as well as other wood waste sources in the plants were combined with some purchased hogged fuel (approximately 10% of the total hogged fuel) to use as hogged fuel in either a boiler or a direct-fired fuel cell. Hogged fuel weight, following industry practice, was given as green weight and assumed to be at 50% moisture content on a wet-weight basis. As such the total hogged fuel burned, 405 lb at 50% moisture content on a wet basis, is 202.5 lb of oven-dry weight hogged fuel. The hogged fuel burned was determined by the 417 lb of total hogged fuel at 50% moisture content that were generated and purchased, minus the 12 lb of hogged fuel sold. Since this plant is a composite of five plants, there are both purchased and sold hogged fuel for the composite plant. Because of the small difference of the bark sold and purchased, and burden to produce the bark was not considered. However, transportation of bark would be considered in any cradle-to-gate LCI or LCA. A very small amount of "wood waste" was burned in the boiler. In addition to hogged fuel for heat generation, natural gas was also used. Natural gas was direct fired in dryers and also used as a fuel source for heat in a boiler. Hogged fuel consisting of bark and wood residuee was by far the dominant fuel source at 90% of the total energy. Natural gas represented only 10% of energy use. In addition to all of these inputs, there is a fraction of the hogged fuel that is sold outside of the mill. Hogged fuel that is sold represents about 4% of the total amount of hogged fuel used in plywood manufacturing. Table 1.8 provides a breakdown of heat energy use for the boilers by fuel source.

Table 1.8. Pacific Northwest Weighted Data Conversion of Boiler Inputs, Direct-Fired Inputs and Purchased Fuel into Heat Energy for 1.0 MSF 3/8-in Basis of Plywood.

Fuel Type	Input		Heat Energy Btu		Fuel Source %	
	Total	Breakdown	Total	Breakdown	Total	Breakdown
Hogged Fuel (lb)[1/2/]	2.03E+02		1.22E+06		90	
Self generated bark/wood for boiler		1.68E+02		1.01E+06		83
Purchased bark/wood for boiler		1.90E+01		1.15E+05		9
Self generated for fuel cell		1.58E+01		9.53E+04		8
Wood waste (lb)[1/2/]	2.50E-01		1.51E+03		0.11	
Natural gas (ft^3)[3/]	1.63E+02		1.33E+05		10	
Direct fired fuel cell		1.29E+02		1.04E+05		79
Boiler		3.48E+01		2.83E+04		21
Total			**1.35E+06**		**100**	

[1] Oven-dry weights; weight of green-hogged fuel (assumed to be 50% MC wet-basis, i.e., 202.5 lb oven dry is 405.0 lb green

[2] Weight of green hogged bark or wood waste multiplied by 4500 Btu/lb of green bark multiplied by 67% boiler efficiency

[3] Volume of natural gas multiplied by 1016 Btu/ft^3 of natural gas, 80% boiler efficiency—source ATHENA™

Three unit processes used hogged fuel and natural gas for heat—block conditioning, veneer drying, and hot pressing. Veneer drying used the dominant amount of energy for heating (75.5%), followed by hot pressing (14.8%) and conditioning (9.7%). The plants reported heat use for drying and pressing. To determine heat use for conditioning it was calculated by taking the total heat use for the plant (as determined by hogged bark/wood fuel used in the boiler to generate steam) and subtracting the reported heat use for drying and hot pressing. In summary, dryers used the dominant amount of electricity (36.7%) and overall energy (75.5%) compared to the total use for the three production centers. Table 1.9 provides a breakdown of heat use by sub-unit process and source.

Table 1.9. Boiler Energy Requirements for Conditioning, Drying, and Pressing Sub-unit Processes Used in Plywood Production in the Pacific Northwest. [1/]

MSF 3/8-in basis					
Fuel Inputs	Conditioning	Drying	Pressing	Total	Percent
	Btu/MSF 3/8-in Basis	Btu/MSF 3/8-in Basis	Btu/MSF 3/8-in Basis	Btu/MSF 3/8-in Basis	%
Hogged fuel[2/]	125,977	822,299	177,827	1,126,103	83.2
Fuel cell		95,274		95,274	7.0
Natural gas	4,875.3	104,493	23,401	132,770	9.8
Total	130,852	1,022,066	201,228	1,354,146	100.0
Percent %	9.7	75.5	14.8	100	

[1/] Heat inputs does not account for hogged fuel sold.

[2/] Hogged fuel values include self produced and purchased hogged fuel along with wood residue. Hogged fuel does not include fuel cell for the veneer dryers.

Boiler data in the LCI was determined by calculating the energy equivalence of the two fuel sources of hogged fuel and natural gas for the boiler and fuel cell,, then entering this data into either a specially written module for hogged fuel generated within the plant that is combusted in either the boiler or fuel cell, or for natural gas using the Franklin Database natural gas boiler. The boiler module written for hogged fuel used the Franklin Associates (FAL) data for wood boiler emissions which did not include a transportation burden for the delivery of hogged fuel to the plant. The fuel cell was similar to the wood boiler in that there were no transportation burdens associated with it since the fuel was generated in the plant. The natural gas fired boiler also used the FAL database but did include a production and transportation burden to the plant. For all fuel, whether wood residue, hogged fuel, or natural gas, emissions from the FAL database in the LCI analysis were used. Table 1.10 provides a comparison of emissions as generated by the FAL database to that of the weighted production data collected by the survey. All survey data, except for CO_2, was provided by the survey; CO_2 was calculated from EPA data on boiler emissions (EPA 1999). Although the emissions data for FAL and the CORRIM survey are similar in magnitude, there are differences. The difference between the FAL data and survey/EPA data is due to several factors. First, the FAL data represents all wood-fired boilers throughout the US and does not consider wood species or regional effects on the values. Secondly, the FAL database is based upon a much larger database. Consideration should be given to establishing a new database for hogged-fuel fired boilers based on the CORRIM survey data for the various manufacturing processes. The CORRIM database could include boiler data from modules for softwood plywood, softwood lumber, and oriented strand board (OSB) production.

Table 1.10. Survey Data on Air Emissions for Boilers as Output from SimaPro 5 (using the FAL[1] boiler data) Compared to Survey Data.

Air Emission	FAL Database[1] lb/MSF (3/8-in)	CORRIM Survey Data lb/MSF (3/8-in)
Acetaldehyde	3.96E-04	2.12E-03
Acrolien	N/R	1.50E-06
CO	1.80E+00	4.79E+00
CO_2[1/]	2.78E+02	3.76E+02[3/]
Formaldehyde	8.71E-04	4.61E-03
NO_X	2.05E-01	8.10E-01
Particulates	2.25E-02	5.39E-01
Particulates (PM10)	N/R	4.36E-01
Phenol	5.28E-03	2.91E-04
SO_2	1.03E-02	1.60E-01
VOC	N/R[2/]	3.18E-01

[1] Reference: SimaPro 5.0, 2001; Franklin Associates, FAL Database, 1998.
[2] N/R= Not reported in surveys.
[3] Calculated from EPA Wood Waste Combustion in Boilers, AP-42, Section 1.6, EPA, 1999.
Notes: Data represents total emissions based on weighted production data for boilers with no allocations or burdens to co-products.

1.5 DRYING EMISSIONS FOR PNW PLYWOOD PRODUCTION

Dryers are used to take the moisture content of green veneer from about 25-60% to 3-6% (oven-dry basis). Dryer temperatures are normally in the 300 to 365ºF range; however, the wood veneer does not experience this higher temperature until much of its moisture is evaporated near the output end of the dryer. Most emissions are generated at this time. One of the plants surveyed had a direct-fired natural gas dryer, and because of this, the emissions reported have components of CO, CO_2 (fossil), NO_x, and SO_2 that are not emitted from the steam heated dryers. One plant also used a fuel cell that combusted hogged fuel which exhausted into the dryer, resulting in emissions charged to the dryer, thus the CO_2 biomass.

Table 1.11. Emissions for Drying Veneer in the Pacific Northwest as Reported in Surveys.

Emission to Air[1]	Emissions from Dryer lb/MSF 3/8-in Basis	Emissions from Dryer kg/m^3
Acrolein	7.05E-07	3.61E-07
Acetaldehyde	1.11E-02	5.69E-03
CO	1.50E-01	7.69E-02
CO_2 (biomass)[2]	9.80E+00	5.02E+00
CO_2 (fossil)[2]	2.71E+00	1.39E+00
Formaldehyde	2.24E-02	1.15E-02
Methanol	3.44E-02	1.76E-02
NO_x	4.99E-02	2.56E-02
Particulates (PM10)	2.81E-01	1.44E-01
Particulates	3.16E-01	1.62E-01
Phenol	2.76E-03	1.41E-03
SO_2	1.10E-03	5.64E-04
VOC	6.28E-01	3.22E-01

[1] Air emission data as reported from surveys based on weighted production data .
[2] Calculated from EPA Plywood Manufacturing – Emission Factor Documentation, AP-42, Chapter 10, Table 10.5-2, 2001.
Notes: Data represents total emissions fordryers with no allocations or burdens to co-products.

1.6 PRESSING EMISSIONS FOR PNW PLYWOOD PRODUCTION

Hot pressing is done in the plywood process to provide intimate contact between veneers while the phenol-formaldehyde adhesive cures as a result of temperature in the 325-340^{o}F range. Emissions are generated from the wood as a result of the high temperatures and the adhesive curing.

Table 1.12. Emissions for Hot Pressing Plywood in the Pacific Northwest.

Emissions to Air	Emissions from Press lb/MSF 3/8-in Basis[1]	Emissions from Press kg/m^3
Acetaldehyde	4.19E-03	2.15E-03
Acetone	6.50E-03	3.33E-03
Alpha-pinene	9.80E-02	5.02E-02
Beta-pinene	3.80E-02	1.95E-02
Formaldehyde	1.90E-03	9.74E-04
Limonene	1.10E-02	5.64E-03
Methanol	1.39E-01	7.13E-02
Methyl ethyl ketone	8.70E-04	4.46E-04
Methyl isobutyl ketone	7.10E-04	3.64E-04
Particulates	1.20E-01	6.15E-02
Phenol	1.39E-03	7.13E-04
THC as carbon	2.10E-01	1.08E-01
VOC	2.49E-01	1.28E-01

[1] Calculated from EPA Plywood Manufacturing – Emission Factor Documentation, AP-42, Chapter 10, Table 10.5-6, 2001.
Notes: Data represents total emissions based on weighted production averages from dryer with no allocations to co-products.

1.7 ADHESIVE USE AND ENERGY/ELECTRICITY TO PRODUCE

Phenol-formaldehyde (phenolic) resin is the adhesive used in plywood production. The manufacture of phenolic resins is particularly energy intensive. The total energy requirement for the production of 15.88 lb of phenolic needed for MSF 3/8-inch basis plywood from the Pacific Northwest is 1.94E+05 BTUs. Electricity requirements for phenol-formaldehyde production per MSF 3/8-inch basis are 7% of the total electricity used to produce plywood in the Pacific Northwest region. The 15.88 lb of phenol-formaldehyde resin is comprised of 65% formaldehyde and 35% phenol by weight. All the materials, fuel, and electricity used to produce the phenol-formaldehyde resin are listed in Table 1.13. Total air emissions for the production of the 15.88 lb of phenol-formaldehyde resin are given in Table 1.14.

Table 1.13. Production Requirements[1] for the 15.88 lb of Phenol-formaldehyde Resin Needed to Manufacture 1.0 MSF 3/8-in Basis Plywood in the PNW.

PNW – PF Resin Inputs		
Material	**lb/MSF 3/8-in Basis**	**kg/m^3**
Formaldehyde	1.03E+01	5.28E+00
Phenol	5.56E+00	2.85E+00
Fuel Use	**Btu/MSF 3/8-in Basis**	**MJ/m^3**
Heavy oil	9.91E+03	1.18E+05
Gasoline	6.83E+01	8.14E+02
Natural gas	1.84E+05	2.19E+06
Electricity Use	**kWh/MSF 3/8-in Basis**	**MJ//m^3**
Electricity	1.02E+01	4.15E+01

[1] Data obtained from Raw Material Balances, Energy Profiles & Environmental Unit Factor Estimates: Structural Wood Products, ATHENA™, 1993.

Table 1.14. Air Emissions[1] for the Production of the 15.88 lb of Phenol-formaldehyde (PF) Resin Needed to Produce 1.0 MSF 3/8-in Plywood.

Emissions to Air	**PF Resin Production[1] lb/MSF 3/8-in Basis**	**Plywood Production[2] lb/MSF 3/8-in Basis**	**PF Resin Contribution to Plywood Production %**
Acrolein	2.93E-08	8.69E-07	3.37
Aldehydes	8.31E-05	3.79E-04	21.95
Ammonia	3.72E-05	4.45E-04	8.36
Be	9.35E-09	9.63E-08	9.71
Benzene	8.77E-06	5.28E-04	1.66
Cd	7.02E-08	4.43E-07	15.85
CO	8.19E-02	2.36E+00	3.48
CO_2 (fossil)	2.46E+01	7.32E+01	33.59
Cobalt	8.24E-08	6.31E-07	13.05
Cumene	7.41E-05	7.44E-05	99.69
Dichloromethane	1.17E-07	1.34E-06	8.70
Dioxin (TEQ)	1.56E-13	1.80E-12	8.67

Formaldehyde	1.68E-02	3.75E-02	44.88
HCl	1.47E-04	1.71E-03	8.60
HF	2.03E-05	2.36E-04	8.59
Hg	6.35E-08	6.88E-07	9.23
Kerosene	9.13E-07	1.08E-05	8.45
Metals	2.09E-06	9.06E-06	23.11
Methane	6.11E-02	1.96E-01	31.16
N-nitrodimethylamine	6.19E-09	7.19E-08	8.61
N2O	1.67E-05	1.93E-04	8.67
Non methane VOC	1.85E-01	8.13E-01	22.79
NO_X	3.22E-01	8.75E-01	36.76
Particulates (unspecified)	2.50E-03	2.51E-02	9.96
Phenol	2.17E-02	3.07E-02	70.69
Sb	3.19E-08	2.58E-07	12.38
Se	2.36E-07	2.63E-06	8.95
SO_X	3.12E-01	9.50E-01	32.87
Tetrachloroethene	2.81E-08	3.25E-07	8.66
Tetrachloromethane	5.81E-08	5.63E-07	10.32
Trichloroethene	2.77E-08	3.22E-07	8.60

[1] Data obtained from Raw Material Balances, Energy Profiles & Environmental Unit Factor Estimates: Structural Wood Products, ATHENA™, 1993. Includes all emissions from resource through resin production, it does not include emissions for delivery of resin to plant, this is handled separately.
[2] Includes all emissions for plywood and resin production, plus those emissions associated with the production and delivery of electricity and fuel, it does not include emissions for to generate the logs or to deliver materials to the plant, these are handled separately.

1.8 PROCESS RELATED EMISSIONS

The total emissions from each unit process can also be determined. Table 1.15 gives the emissions breakdown for the six processes. The values include the burdens in terms of emissions for the production of any electricity, fuel, and adhesive, in addition to that of the hogged fuel and wood. The total values for Tables 1.15 and 1.17 differ slightly due to rounding error as the values were accumulated from unit process to unit process. The allocation of all emissions to plywood was 51.1%; as such, to find total emissions, divide the emissions allocated to plywood by 0.511. The remainder of emissions (48.9%) was assigned to the co-products.

Table 1.15. Process Emissions for Plywood Production in the Pacific Northwest Region.

Substance	Debarking and Bucking	Log Conditioning	Veneer Peeling	Veneer Drying	Pressing	Sawing and Trimming	Total
				lb/MSF 3/8-in Basis			
Acetaldehyde		3.18E-05	0.00E+00	8.51E-03	3.41E-03	0.00E+00	1.20E-02
Acrolein	3.02E-08	1.65E-08	4.20E-08	6.53E-07	8.04E-08	5.51E-08	8.77E-07
CO	2.59E-02	1.49E-01	6.97E-03	1.48E+00	4.11E-01	9.44E-03	2.08E+00
CO_2 (fossil)	2.37E-03	2.76E+00	5.46E+00	1.78E+01	3.60E+01	7.26E+00	6.92E+01
CO_2 (biofuel)	8.73E+00	2.22E+01	1.71E-03	2.15E+02	4.85E+01	2.26E-03	2.94E+02
Formaldehyde	9.30E-03	7.03E-05	7.61E-07	1.74E-02	1.85E-02	1.00E-06	4.53E-02
Methane	2.47E-02	6.98E-03	1.34E-02	3.83E-02	1.28E-01	1.79E-02	2.29E-01
Methanol	0.00E+00	0.00E+00	0.00E+00	2.57E-02	1.10E-01	0.00E+00	1.36E-01
Non methane VOC	1.11E-01	9.28E-03	1.38E-02	3.53E-02	2.27E-01	1.90E-02	4.16E-01
Particulates	4.41E-04	1.85E-03	6.86E-03	2.53E-01	1.05E-01	7.93E-03	3.75E-01
Particulates (PM10)	2.41E-03	2.48E-04	4.06E-03	2.12E-01	2.16E-03	8.72E-03	2.30E-01
Particulates (unspecified)	0.00E+00	1.19E-03	2.98E-03	8.95E-03	5.86E-03	3.92E-03	2.29E-02
Phenol	1.00E-07	4.24E-04	1.10E-07	6.02E-03	2.37E-02	1.45E-07	3.02E-02
NOx	6.85E-03	3.16E-02	2.54E-02	2.58E-01	1.94E-01	3.47E-02	5.50E-01
SO_2	0.00E+00	0.00E+00	0.00E+00	8.24E-04	4.44E-06	0.00E+00	8.28E-04
SOx	4.80E-02	3.28E-02	5.85E-02	1.74E-01	6.64E-01	7.81E-02	1.06E+00
VOC				4.68E-01	1.98E-01	0.00E+00	6.67E-01

Notes: Data are allocated total emissions, which include emissions for the production and delivery of electricity and fuel, and the production of resin; it does not include emissions for production of logs, or for delivery of logs, bark, resin, purchased veneer to the plant, this is handled separately.

1.9 LIFE-CYCLE INVENTORY RESULTS FOR PLYWOOD PRODUCTION FROM THE PACIFIC NORTHWEST

Life-cycle inventory results for production of 1.0 MSF 3/8-inch of softwood plywood in the Pacific Northwest are given in Table 1.16 (inputs) and 1.17 (outputs). Results include all processes within the system boundary defined in Figure 1.2. Results were generated in SimaPro 5.0.9 version 5 Life-Cycle Assessment software with the Franklin Database employed for LCI on fuel use and electricity production burdens for their production. Emissions for production of the phenolic adhesive were obtained from ATHENA^{TM}. Other inputs and outputs were based on data from the manufacturing plant surveys.

Table 1.16. Life-cycle Inventory Inputs for Producing 1.0 MSF 3/8-in Basis of Plywood in the Pacific Northwest.

PNW Plywood – INPUTS				
Materials[1/]	**Units**	**Unit/ MSF 3/8-in Basis**	**SI Units**	**SI Unit/m^3**
Roundwood (logs)	lb	1.79E+03	kg	9.18E+02
Phenol-formaldehyde adhesive	lb	1.59E+01	kg	8.15E+00
Extender and fillers	lb	8.90E+00	kg	4.56E+00
Catalyst[2/]	lb	1.11E+00	kg	5.69E-01
Soda ash[2/]	lb	3.30E-01	kg	1.69E-01
Bark[3/4/]	lb	9.90E+01	kg	5.07E+01
Purchased				
Dry veneer	lb	6.40E+00	kg	3.28E+00
Green veneer	lb	1.42E+01	kg	7.28E+00
Electrical Use				
Electricity	kWh	1.39E+02	MJ	5.65E+02
Fuel Use[1/]				
Hogged fuel (produced)[3/4/]	lb	1.92E+02	kg	9.84E+01
Hogged fuel (purchased)[3/4/]	lb	1.70E+01	kg	8.71E+00
Wood waste[4/]	lb	2.50E-01	kg	1.28E-01
Liquid propane gas	gal	3.59E-01	L	1.54E+00
Natural gas	ft^3	1.63E+02	m^3	5.22E+00
Diesel	gal	3.95E-01	L	1.69E+00
Water Use				0.00E+00
Municipal water source	gal	8.28E+01	L	3.54E+02
Well water source	gal	2.94E+01	L	1.26E+02
Recycled water source	gal	3.00E-01	L	1.28E+00

[1] All wood, bark and other materials given as oven-dry weights.
[2] These materials were not included in the SimaPro LCI analysis; excluded based on the 2% rule.
[3] Bark weight included in the 'hogged fuel produced' weight.
[4] Bark, wood and hogged fuel when used for fuel assumed 50% MC wet basis for energy calculations.

Table 1.17. Life-cycle Inventory Results for 1.0 MSF 3/8-in Basis Plywood Production in the Pacific Northwest Region.

Raw Materials		
Substance	**lb/MSF 3/8 in**	**kg/m^3**
PNW bark on logs	4.68E+01	2.40E+01
PNW logs	9.27E+02	4.75E+02
		0.00E+00
Coal FAL	9.63E+00	4.94E+00
Crude oil FAL	1.14E+01	5.84E+00
Limestone	1.63E+00	8.36E-01
Natural gas FAL	2.58E+01	1.32E+01
Uranium FAL	5.01E-05	2.57E-05
Wood/wood wastes FAL	1.87E+01	9.59E+00

Electricity Use		
Substance	**kWh/MSF 3/8 in**	**MJ/m^3**
Electricity from other sources	1.12E+00	4.56E+00
Energy from hydropower	7.57E+01	3.08E+02

Energy Use		
Substance	**Btu/MSF 3/8 in**	**MJ/m^3**
Hogged fuel-fuel cell	7.13E+04	8.50E+05
Natural gas-fuel cell	7.81E+04	9.31E+05

Water Use		
Substance	**ft^3/MSF 3/8 in**	**m^3/m^3**
Municipal water source	5.80E+00	1.86E-01
Recycled water	2.31E-02	7.39E-04
Well water source	2.06E+00	6.59E-02

Emissions to Air		
Substance	**lb/MSF 3/8 in**	**kg/m^3**
Acetaldehyde	1.19E-02	6.10E-03
Acetone	5.11E-03	2.62E-03
Acrolein	8.75E-07	8.87E-04
Aldehydes	8.56E-04	1.23E-04
Alpha-pinene	7.69E-02	3.65E-07
Ammonia	4.85E-04	5.28E-02
As	1.26E-05	5.59E-06
Ba	5.82E-04	4.42E-03
Be	1.02E-07	6.10E-06
Benzene	4.86E-04	1.09E-01
Beta-pinene	2.99E-02	6.97E-02
Cd	5.69E-07	3.49E-04
Cl_2	1.03E-03	2.86E-04
CO	2.08E+00	6.10E-04
CO_2 (fossil)	7.78E+01	3.75E-08
CO_2 (biofuel)	2.85E+02	1.00E-04
Cobalt	7.44E-07	1.22E-03
Cr	7.44E-06	1.63E-04
Cumene	7.44E-05	4.20E-05
Dichloromethane	1.37E-06	1.69E-01
Dioxin (TEQ)	1.83E-12	3.33E-01
Fe	5.82E-04	1.17E-02
Formaldehyde	3.74E-02	1.95E-01
HCl	1.73E-03	1.16E-01
HF	2.40E-04	8.87E-04
Hg	7.13E-07	1.23E-04
K	1.03E-01	3.65E-07
Kerosene	1.09E-05	5.28E-02
Limonene	8.63E-03	5.59E-06
Metals	1.19E-05	4.42E-03
Methane	2.13E-01	6.10E-06
Methanol	1.36E-01	1.09E-01
Methyl ethyl ketone	6.81E-04	6.97E-02
Methyl i-butyl ketone	5.58E-04	3.49E-04
Mn	1.19E-03	2.86E-04
N-nitrodimethylamine	7.31E-08	6.10E-04
N_2O	1.96E-04	3.75E-08
Na	2.38E-03	1.00E-04
Naphthalene	3.18E-04	1.22E-03
Ni	8.19E-05	1.63E-04
Non methane VOC	3.29E-01	4.20E-05
Nox	6.50E-01	1.69E-01
Organic substances	2.28E-02	3.33E-01
Particulates	3.81E-01	1.17E-02
Particulates (PM10)	2.27E-01	1.95E-01
Particulates (unspecified)	2.52E-02	1.29E-02
Pb	1.60E-04	8.20E-05
Phenol	3.02E-02	1.55E-02
Sb	2.98E-07	1.53E-07
Se	2.71E-06	1.39E-06
SO_2	8.25E-04	4.23E-04
SOx	1.06E+00	5.43E-01
Tetrachloroethene	3.30E-07	1.69E-07
Tetrachloromethane	5.85E-07	3.00E-07
THC as carbon	1.65E-01	8.46E-02
Trichloroethene	3.27E-07	1.68E-07
VOC	6.69E-01	3.43E-01
Zn	5.82E-04	2.98E-04

Emissions to Water		
Substance	**lb/MSF 3/8 in**	**kg/m^3**
Acid as H+	1.23E-08	6.30E-09

B	9.19E-04	4.71E-04
BOD	1.44E-03	7.38E-04
Ca	1.03E-07	5.28E-08
Calcium ions	9.31E-06	4.77E-06
Cd	6.23E-05	3.19E-05
Chromate	4.43E-07	2.27E-07
Cl-	6.24E-02	3.20E-02
COD	1.67E-02	8.56E-03
Cr	6.23E-05	3.19E-05
Cyanide	9.31E-08	4.77E-08
Dissolved solids	1.38E+00	7.07E-01
Fe	1.35E-03	6.92E-04
Fluoride ions	4.36E-05	2.23E-05
H_2SO_4	2.30E-04	1.18E-04
Hg	4.89E-09	2.51E-09
Metallic ions	2.61E-04	1.34E-04
Mn	7.56E-04	3.88E-04
Na	1.73E-05	8.87E-06
NH_3	5.45E-05	2.79E-05
Nitrate	4.11E-06	2.11E-06
Oil	2.45E-02	1.26E-02
Other organics	4.08E-03	2.09E-03
Pb	2.24E-08	1.15E-08
Phenol	8.50E-07	4.36E-07
Phosphate	1.15E-04	5.89E-05
Sulphate	5.43E-02	2.78E-02
Suspended solids	3.27E-02	1.68E-02
Zn	2.16E-05	1.11E-05

Solid Waste Emissions

Substance	lb/MSF 3/8 in	kg/m^3
Solid waste	1.88E+01	9.64E+00

Nonmaterial Emissions

Substance	Ci/MSF 3/8 in	Bq/m^3
Radioactive substances to air	1.21E-05	5.06E+04

Notes: Data are allocated total emissions, which include emissions for the production and delivery of electricity and fuel, and the production of resin but not its delivery to plant.. Excludes burden for logs and their delivery.

It is also useful to examine those emissions solely attributed to the production of plywood. Table 1.18 provides output data for site-generated emissions from manufacturing plywood only; not included are emissions contributed by the production and delivery of resin, fuel, and electricity, and transportation of materials. Table 1.19 provides a summary comparison of the site-generated emissions to the total emissions that include those from the production and delivery of resin, fuel, and electricity, and transportation of materials.

Table 1.18. Life-cycle Inventory Results for Production of 1.0 MSF 3/8-in Basis Plywood in the Pacific Northwest.

Raw Materials		
Substance	**lb/MSF 3/8 in**	**kg/m^3**
PNW bark on logs	4.68E+01	2.40E+01
PNW logs	9.27E+02	4.75E+02
Phenol formaldehyde resin	1.25E+01	6.41E+00
Wood	1.86E+01	9.53E+00
Substance	**ft^3/MSF 3/8 in**	**m^3/m^3**
Distillate fuel oil (DFO)	2.74E-02	8.77E-04
Natural gas (vol)	4.19E+01	1.34E+00

Electricity		
Substance	**kWh/MSF 3/8 in**	**MJ/m^3**
Electricity from ATHENA™	9.38E+01	3.82E+02

Energy		
Substance	**Btu/MSF 3/8 in**	**MJ/m^3**
Hogged fuel direct fired	7.13E+04	8.50E+05
Natural gas direct fired	7.81E+04	9.31E+05

Water Use		
Substance	**ft^3/MSF 3/8 in**	**m^3/m^3**
Municipal Water Source	5.80E+00	1.86E-01
		0.00E+00
Recycled Water	2.31E-02	7.39E-04
Well Water Source	2.06E+00	6.59E-02

Emissions to Air		
Substance	**lb/MSF 3/8 in**	**kg/m^3**
Acetaldehyde	1.19E-02	6.10E-03
Acetone	5.11E-03	2.62E-03
Acrolein	5.28E-07	2.71E-07
Alpha-pinene	7.69E-02	3.94E-02
As	1.16E-05	5.95E-06
Ba	5.82E-04	2.98E-04
Benzene	4.76E-04	2.44E-04
Beta-pinene	2.99E-02	1.53E-02
Cl_2	1.03E-03	5.28E-04
CO	1.94E+00	9.94E-01
CO_2 (fossil)	1.20E+01	6.15E+00
CO_2 (biofuel)	2.85E+02	1.46E+02
Cr	6.08E-06	3.12E-06
Fe	5.82E-04	2.98E-04
Formaldehyde	2.06E-02	1.06E-02
K	1.03E-01	5.28E-02
Limonene	8.63E-03	4.42E-03
Methane	7.13E-05	3.65E-05
Methanol	1.36E-01	6.97E-02
Methyl ethyl ketone	6.81E-04	3.49E-04
Methyl i-butyl ketone	1.11E-02	5.69E-03
Mn	1.19E-03	6.10E-04
Na	2.38E-03	1.22E-03
Naphthalene	3.18E-04	1.63E-04
Ni	7.44E-05	3.81E-05
Non methane VOC	2.32E-02	1.19E-02
NO_X	3.79E-01	1.94E-01
Organic substances	2.19E-02	1.12E-02
Particulates	3.75E-01	1.92E-01
Particulates (PM10)	2.22E-01	1.14E-01
Pb	1.59E-04	8.15E-05
Phenol	8.44E-03	4.33E-03
SO_2	8.25E-04	4.23E-04
SO_X	1.80E-02	9.23E-03
THC as carbon	1.65E-01	8.46E-02
VOC	6.69E-01	3.43E-01
Zn	5.82E-04	2.98E-04

Emissions to Water		
Substance	**lb/MSF 3/8 in**	**kg/m^3**
BOD	5.69E-06	2.92E-06
COD	4.88E-04	2.50E-04

Dissolved solids	9.56E-04	4.90E-04
NH_3	1.10E-06	5.64E-07
Suspended solids	1.02E-03	5.23E-04

Solid Waste Emissions		
Substance	**lb/MSF 3/8 in**	**kg/m^3**
Solid waste	1.19E+01	6.10E+00

Source: SimaPro 5.0 LCI results

Notes: Results are for plywood production only [referred to as "site generated data"]; no emissions for production or transportation considered for fuel, electricity, resin and logs/bark. These are allocated emissions for plywood

Table 1.19. Summary of Life-Cycle Inventory Results for 1.0 MSF 3/8-in Basis Plywood Production in the Pacific Northwest Region—a Comparison of Total to Site-Generated Emissions.

Substance	**LCI Total lb/MSF 3/8-in Basis**	**LCI Site-Generated lb/MSF 3/8-in Basis**
Acetaldehyde	1.19E-02	1.19E-02
Acrolein	8.75E-07	5.28E-07
CO	2.08E+00	1.94E+00
CO_2 (fossil)	7.78E+01	1.20E+01
CO_2 (biofuel)	2.85E+02	2.85E+02
Formaldehyde	3.74E-02	2.06E-02
Methane	2.13E-01	7.13E-05
Methanol	1.36E-01	1.36E-01
Non methane VOC	3.29E-01	2.32E-02
NO_X	6.50E-01	3.79E-01
Particulates	3.81E-01	3.75E-01
Particulates (PM10)	2.27E-01	2.22E-01
Particulates (unspecified)	2.52E-02	0.00E 00
Phenol	3.02E-02	8.44E-03
SO_2	8.25E-04	8.25E-04
SO_X	1.06E+00	1.80E-02
VOC	6.69E-01	6.69E-01

Notes: Summary data for site-generated emissions for plywood production only; does not include production or transportation emissions for fuel, electricity and resin.

1.10 SENSITIVITY ANALYSIS

A sensitivity analysis was conducted to examine the effects of using different fuel sources for heat generation. Currently there are two fuel sources used, hogged fuel, which is comprised of bark and wood waste, and natural gas. This analysis used the plywood manufacturing model created in an LCI software program called SimaPro 5.0.9, using all natural gas and all self-produced hogged fuel for heat generation. Three scenarios were modeled: 1) comparing all natural gas versus the "as is" original plywood model, with no fuel changes and incorporating both natural gas and hogged fuel, 2) comparing using all self-produced hogged fuel versus the "as is" original plywood model, with no changes, and 3) comparing use of all natural gas versus all self-produced hogged fuel as a fuel for heat.

1.10.1 Sensitivity analysis of plywood manufacturing in the PNW

Sensitivity analyses were used to study the LCI model that represented plywood manufacturing. The analysis can be useful to understand how various process parameters contribute to environmental output factors. For instance, in plywood manufacturing, heat is used in several subunit processes, consuming hogged fuel and/or natural gas as fuel to generate the heat. Changing the fuel source, also referred to as fuel switching, can have a dramatic effect on the type and quantity of emissions into the environment. This sensitivity analysis was used to compare the effects of using all self produced hogged fuel—consisting of bark removed from the logs used to make veneer, and wood residue from production of plywood—or only natural gas as a fuel input. In the original model, fuel sources used for heat purposes included both natural gas and hogged fuel consisting of bark and wood residue.

The original PNW model that was based on survey data assumed 90.5% of the fuel in the form of hogged fuel, self produced and purchased, and 9.5% as natural gas. In actuality, most mills use only one or two types of fuel source, whereas, the original study resulted in an averaged model incorporating different fuel sources taken from primary survey information for five mills. There were three scenarios done for this "average mill." The first scenario used LCI results to compare fuel use of 100% natural gas versus the weighted average fuel use from the survey, referred to as the "as is" condition. The second scenario compared 100% self generated hogged fuel versus the "as is", and the third scenario compared 100% self generated hogged fuel versus 100% natural gas.

1.10.2 Sensitivity analysis results

Table 1.20 is a summary of the three scenarios, with a partial list of air emissions for the PNW (for a detailed listing see Appendix 2). In the first two scenarios, all natural gas versus "as is" and all self-produced hogged fuel versus "as is," a negative percentage difference number indicates that the assumed fuel source contributes fewer emissions than the "as is" plywood model. A positive percentage difference means that the "as is" or original model contributes lower emissions. In the third scenario, a negative number indicates that all natural gas contributes fewer emissions than all self-generated hogged fuel and a positive percentage number means that all self-produced hogged fuel contributes fewer emissions.

Table 1.20. Sensitivity Analysis Summary for the PNW. Fuel Use Comparison for Steam Production using Natural Gas, Hogged Fuel and "As Is" (original fuel distribution).

	All Natural Gas	All Hogged Fuel	As Is, Original Fuel Distribution	Scenario 1 All Natural Gas Difference[1/]	Scenario 2 All Hogged Fuel Difference[1/]	Scenario 3 Natural Gas versus Hogged Fuel Difference[1/]
Substance	**lb/MSF 3/8-in Basis**				**%**	
CO_2 (fossil)	1.71E+02	6.00E+01	7.78E+01	120	-23	185
CO_2 (biofuel)[2/]	4.85E-02	3.40E+02	2.85E+02	-100	20	-100
Methane	4.84E-01	1.67E-01	2.13E-01	127	-22	190
NO_X	9.63E-01	8.50E-01	6.50E-01	48	31	13
SO_2	8.25E-04	8.25E-04	8.25E-04	0	0	0
SO_X	2.49E+00	8.06E-01	1.06E+00	136	-24	209
Acetaldehyde	1.16E-02	1.20E-02	1.19E-02	-3	1	-4
Acrolein	8.75E-07	8.56E-07	8.75E-07	0	-2	2
Formaldehyde	3.66E-02	3.76E-02	3.74E-02	-2	1	-3
Methanol	1.36E-01	1.36E-01	1.36E-01	0	0	0
Phenol	2.49E-02	3.14E-02	3.02E-02	-18	4	-21
CO	5.12E-01	2.48E+00	2.08E+00	-75	19	-79
Particulates	3.65E-01	3.85E-01	3.81E-01	-4	1	-5
Particulates (PM10)	2.26E-01	2.26E-01	2.27E-01	0	0	0
Particulates (unspecified)	2.70E-02	2.39E-02	2.52E-02	7	-5	13
Non methane VOC	8.13E-01	3.64E-01	3.29E-01	147	11	123
VOC	6.69E-01	6.69E-01	6.69E-01	0	0	0

[1/] All comparisons are with the weighted fuel use as indicated in the mill survey.

[2/] CO_2 biomass and non-fossil (which comes from SimaPro database and is most likely biomass) collaborated.

Notes: Data are allocated emissions for plywood.

The following is a summary of the comparison results when fuel switching:

Carbon Dioxide (CO_2)

CO_2 fossil and biomass emissions are treated separately in LCI analyses; hogged fuel is a biomass fuel and natural gas is a fossil fuel. CO_2 biomass is treated separately because the carbon can be taken back up in biomass and oxygen released to the atmosphere through photosynthesis in growing trees. As such CO_2 biomass is assumed to have a neutral impact on the environment, while CO_2 fossil emissions cannot be readily replenished as natural gas.

Methane (CH_4)

Methane emissions increased by more than 100% when natural gas was used compared to all self-generated hogged fuel and the "as is" model. All self-produced hogged fuel contributed lower methane emissions than the all natural gas and the "as is" models.

Nitrogen Oxides (NO_X)

NO_X emissions in all three scenarios are higher than in the "as is" model, with natural gas having the highest emissions. Natural gas emitted 13 percent more NO_X emissions than hogged fuel.

SO_2 and SO_X

There is no difference in SO_2 emissions between various fuel sources used for heat generation, this occurs because it was reported in the survey for the dryers and does not change. SO_2 could have been included in the SO_X. The SO_X emissions are significantly higher when using natural gas.

VOC and Non Methane VOC

There is no difference in VOC emissions between fuel sources for heat generation, although, non methane VOC, is heavily influenced by natural gas combustion and is more than double those of scenarios 2 and 3. Hogged fuel use did not contribute any non-methane VOC. VOC emissions come from drying of veneer and also pressing emissions of plywood panel production.

HAP (hazardous air pollutants include acetaldehyde, acrolein, formaldehyde, methanol, and phenol)

HAP emissions are not influenced by fuel inputs since the drying of wood provides all HAP emissions. In this analysis, phenol was the only HAP that was influenced and it decreased when natural gas fuel was used.

Carbon Monoxide (CO)

Combustion of natural gas decreases CO emissions. When hogged fuel is used, CO emissions increased slightly compared to the "as is" model and were 78% higher than natural gas.

Particulates

Particulate emissions were affected little by fuel switching, indicating that both fuel sources contribute similar amounts of particulates. There was a slight indication that hogged fuel combustion generates more particulates than combustion of all natural gas (1% more) and the "as is" (4% more) models.

1.11 CARBON BALANCE FOR PNW PLYWOOD

1.11.1 Procedure

The element, carbon, was tracked "gate-to-gate" in the study of softwood plywood manufacturing. To track carbon, a checklist was devised to balance the inputs of carbon with the outputs to see if there was any carbon missing and to also follow carbon in the LCI of plywood, to see which product or emission carbon is assigned. This analysis followed carbon from the inputs of material, electricity and fuels to its production of plywood as a product, also its co-products and emissions into the environment. The percentage of carbon in wood was taken from a separate study done by R.A Birdsey, in 1994. The percentage was species specific and was manipulated to fit this study by allocating a percentage of the species used in the modeling of plywood manufacturing. Other carbon percentages in materials other than wood were either taken from the Merck Index (1989) or were calculated by using atomic masses of each element from the chemical formula.

1.11.2 Results

Table 1.21 describes the allocation of carbon percentages based on the species of wood; carbon comprises 51.23% of the total mass of wood material. Table 1.22 includes a list of inputs and outputs associated with plywood manufacturing. Values are based on an LCI of plywood only and thus the input of materials, electricity, and fuels are allocated to plywood, which is 51% by weight of the total outputs of materials. As a result, the inputs were also allocated so that 51% of the inputs by mass are used. Note that the result is that the carbon balance has a difference to the LCI of 2.7%.

Table 1.21. Percent of Carbon in Wood, Pacific Northwest

	Conversion Factor [1,2]	Species Weighted Allocation	Density lb/ ft^3	Roundwood ft^3	Roundwood lb	Carbon lb	Carbon %
Douglas–fir	15.11	0.676	28.08	65.6	1842.05	991.27	53.81
Spruce	9.8	0.116	23.088	65.6	1514.57	642.88	42.45
Hemlock	12.17	0.168	26.208	65.6	1719.24	798.35	46.44
Larch	14.26	0.04	29.952	65.6	1964.85	935.46	47.61
Weighted average	**13.97**	**1.0**	**27.26**	**65.6**[3]	**1788.34**	**916.18**	**51.23**

1/ Birdsey, R.A., 1994. Carbon storage and accumulation in US forest ecosystems. General Technical Report WO-59. Washington, DC. USDA-Forest Service.

2/ Skog, Kenneth E. and Geraldine A. Nicholson. Carbon cycling through wood products: The role of wood and paper products in carbon sequestration. FPJ. 48(7/8): 75-83.

3/ 65.6 ft^3 is the volume of wood needed to produce 1.0 MSF 3/8-inch basis of plywood and the co-products.

Table 1.22. Carbon Balance, PNW

PNW PLYWOOD – INPUTS			
Materials	**lb/MSF 3/8-in Basis**	**Carbon %**	**Carbon lb**
Roundwood	1.79E+03	51.23	9.16E+02
Bark	9.90E+01	51.23	5.07E+01
Purchased			
Dry veneer	6.43E+00	51.23	3.30E+00
Green veneer	1.42E+01	51.23	7.29E+00
Hogged fuel (minus bark sold)	1.10E+01	51.23	5.635E+00
Total	**1.92E+03**	51.23	**9.83E+02**

PNW PLYWOOD – OUTPUTS[1/]			
Emissions to Air			
Substance	**lb/MSF 3/8-in Basis**	**Carbon %**	**Carbon lb**
Acetaldehyde	1.19E-02	54.00	6.45E-03
Acetone	5.11E-03	64.27	3.29E-03
Acrolein	5.28E-07	65.00	3.43E-07
Alpha-pinene	7.69E-02	88.16	6.78E-02
Benzene	4.76E-04	92.25	4.39E-04
Beta-pinene	2.99E-02	88.16	2.63E-02
CO	1.94E+00	42.86	8.30E-01
CO_2 (biofuel)	2.85E+02	27.27	7.76E+01
Formaldehyde	2.06E-02	40.00	8.23E-03
Limonene	8.63E-03	88.16	7.60E-03
Methane	7.13E-05	75.00	5.34E-05
Methanol	1.36E-01	37.50	5.09E-02
Methyl ethyl ketone	6.81E-04	66.63	4.54E-04
Methyl i-butyl ketone	1.11E-02	71.94	8.01E-03
Naphthalene	3.18E-04	93.71	2.98E-04
Non methane VOC	2.32E-02	100.00	2.32E-02
Organic substances	2.19E-02	50.00	1.10E-02
Particulates	3.75E-01	51.23	1.92E-01
Particulates (PM10)	2.22E-01	51.23	1.14E-01
Phenol	8.44E-03	76.57	6.46E-03
THC as carbon	1.65E-01	100.00	1.65E-01
VOC	6.69E-01	100.00	6.69E-01

Solid Waste Emissions			
Substance	**lb/MSF 3/8-in basis**	**Carbon %**	**Carbon lb**
Solid waste	1.19E+01	51.23	6.08E+00
Subtotal	**3.12E+02**		**8.91E+01**
Plywood	9.37E+02	51.23	4.80E+02
Wood chips	4.25E+02	51.23	2.18E+02
Peeler core	9.51E+01	51.23	4.87E+01
Green clippings	3.10E+01	51.23	1.59E+01
Veneer downfall	3.40E+00	51.23	1.74E+00
Panel trim	1.07E+02	51.23	5.47E+01
Sawdust	9.63E+00	51.23	4.93E+00
Wood waste (sold)	2.10E+01	51.23	1.08E+01
Wood waste to boiler	2.50E-01	51.23	1.28E-01
Dry veneer (sold)	6.31E+01	51.23	3.23E+01
Total Output	**2.00E+03**		**9.56E+02**
DIFFERENCE %			**2.7**

[1/] Some of the emissions are due to the adhesive system used and was not included in the input.

1.12 COST ANALYSIS

A cost analysis was conducted for plywood production in the Pacific Northwest. The analysis took into account the total cost of purchased materials and energy, co-products, and fuels to obtain the cost to manufacture one MSF 3/8-inch basis of plywood. This value was then compared to the market price of a MSF 3/8-inch basis of plywood.

This analysis considered variable costs such as those associated with purchased electricity, hogged fuel, propane, natural gas and diesel fuel, logs, dry and green veneer, and phenol formaldehyde (PF) resin. It also examined fixed costs, including costs of capital, maintenance, labor, and overhead.

1.12.1 Production and Employees

A weighted average of production was obtained through primary surveys in the PNW and then plotted against the number of employees (Figure 1.2). After the slope of the graph was obtained, the weighted-average value of production was used to determine the number of employees. The manufacture of 290,268MSF 3/8-inch basis of plywood translates to 441 employees.

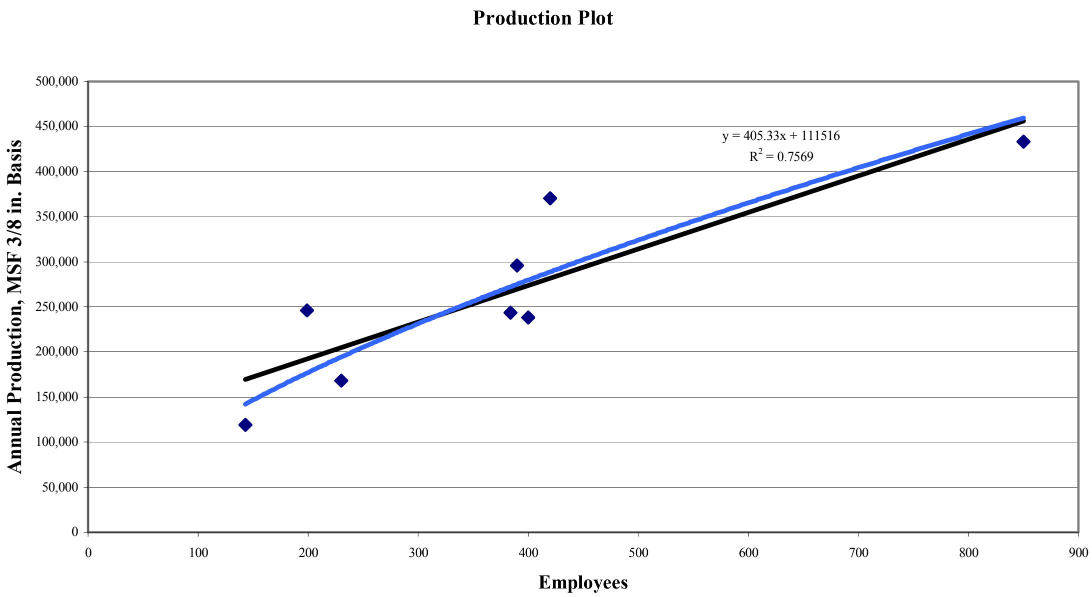


Figure 1.3. Annual Production vs. Number of Employees.

1.12.2 Variable Costs

Electricity prices vary from time to time and are influenced by the region of generation. For the Pacific Northwest the average price per kWh in 2001 was 4.25 cents, with a range of 3.60 to 5.90 cents per kWh. For natural gas, the price came from data taken in 1999. The reason why 3-year-old information is used is because data from the winter of 2000-2001 was unusually high, and therefore1999 data was used to represent current and expected price, however, based on recent forecasts, future prices could be much higher. As a result, the average price for a Dtherm (1,000,000 Btu) of natural gas is taken as $2.85, with a range of $2.20 to $4.70. Prices of wood material as logs and purchased green veneer came from Crow's Market Report, averaged over the year, 2002. Table 1.23 describes the variable cost on an annual basis and on a production basis of one MSF 3/8-inch.

Table 1.23. Variable Costs to Produce 1.0 MSF 3/8-in Basis of Plywood.

Variable Cost	Units	$/Unit	Units/Year	$/Year	Units/MSF	$/MSF
Energy Consumption						
Electricity	kWh	0.0425	40,318,280	1,713,527	138.90	5.90
Hogged fuel	lb	0.01	11,030,199	110,302	34.00	0.34
Liquid propane gas	gal	0.95	104,177	98,969	0.36	0.34
Natural gas	ft^3	0.0029	47,429,856	137,309	163.40	0.47
Diesel	gal	1.3	114,670	149,072	0.40	0.51
Materials						
Logs	bf	0.4741	81,878,910	38,822,067	282.08	133.75
Purchased dry veneer	M 3/8	193.51	2,192	424,080	7.55E-03	1.46
Purchased green veneer	M 3/8	170.47	4,847	826,344	1.67E-02	2.85
Resin	lb	0.45	4,609,462	2,074,258	15.88	7.15

1.12.3 Fixed Costs

Fixed costs are costs that are not dependent on production and can be a one-time annual cost. This analysis included fixed costs of capital, maintenance, labor and overhead. Table 1.24 details these fixed costs.

Table 1.24. Fixed Cost to Produce 1.0 MSF 3/8-in Basis of Plywood.

Fixed Cost	Units	$/unit	MSF/Year	$/Year	$/MSF
Capital	Annual	1,290,082	290,268	1,290,082	4.44
Maintenance	MSF	9	290,268	2,612,416	9.00
Labor	Annual	19,950,840	290,268	19,950,840	68.73
Overhead	MSF	10	290,268	2,902,684	10.00

The total cost, adding both variable and fixed cost, is equal to $244.95/MSF with the variable cost of energy and raw materials being $157.77 and the fixed cost coming to $92.18.

1.12.4 Energy and Co-products Sold

Fuels sold include hogged fuel and wood waste. Also sold are the co-products of wood chips, peeler core, green clippings, veneer downfall, panel trim, sawdust and dry veneer. These items are sold on a per ton oven dry weight basis. Table 1.25 lists the prices of these fuels and co-products.

Table 1.25. Sold Energy and Co-products Resulting from the Production of 1.0 MSF 3/8-in Basis of Plywood.

Sold	Unit	$/Unit	Units/Year	$/Year	Units/MSF 3/8-in Basis	$/MSF 3/8-in Basis
Sold Energy						
Hogged fuel	lb	0.01	4,673,321	46,733	16.1	0.16
Wood waste	lb	0.005	6,095,636	30,478	21	0.11
Sold Co-products						
Wood chips	lb	0.030	123,451,150	3,703,534	425.3	12.76
Peeler core	lb	0.015	27,604,525	414,068	95.1	1.43
Green clippings	lb	0.015	8,998,320	134,975	31	0.47
Veneer downfall	lb	0.015	998,523	14,978	3.44	0.05
Panel trim	lb	0.015	31,000,665	465,010	106.8	1.60
Sawdust	lb	0.015	2,795,285	41,929	9.63	0.14
Sold dry veneer	lb	0.227	18,316,348	4,160,673	63.1	14.33

The selling price of the hogged fuel sold is $10/green ton (which at 50% moisture content gives $20/ton oven-dry) and the price of wood waste is $10/ton OD (oven-dry) weight. The co-products peeler core, green clippings, veneer downfall and panel trim were assumed to be sold on a basis of $30/ton OD weight. Wood chips are mostly used for pulping and have a higher selling price, in this case equaling $60/ton OD weight. Dry veneer is sold to other plywood or LVL plants; in this case the selling price ($45-46/MSF of 1/10inch veneer) was determined by averaging the monthly price of veneer as reported in Crow's Market Report.

Total costs minus the sold energy and co-products, result in a net cost of $213.90 to produce one MSF 3/8-inch of plywood. Crow's Market Report, was used again to obtain the monthly average price for plywood 3/8-inch basis, CD grade (coastal) - $221.75/MSF. Subtracting the net cost to produce plywood from the selling price of plywood, results in a $7.85 margin per MSF 3/8-inch. The margin would differ for a production mix of different thicknesses of plywood.

2.0 SOUTHEAST SOFTWOOD PLYWOOD

2.1 INTRODUCTION

Softwood plywood has had a long tradition as a structural building material for both commercial and residential construction. Plywood is used as roof, wall and floor sheathing, and for subflooring in home construction. Although plywood comes in a variety of grades and thicknesses, its production is based on a thousand square feet (MSF) of 3/8-inch equivalence—industry refers to this as M 3/8. In SI units, it is on a one cubic meter (m^3). Plywood for the Southeast region is made from a group of wood species referred to as southern pine; the dominant species in this group are slash and loblolly pine. This report focuses on plywood production practices in a region consisting of Alabama, Georgia, Louisiana, Mississippi, Florida, Arkansas, and Texas. The size of production facilities in the region range from about 100,000 to 400,000 MSF 3/8-inch basis annually. This study collected data from representative plants that would be considered in the upper production capacity of this range. The total annual softwood plywood production for the region was 9,838,000 MSF 3/8-inch in 2000 (APA 2001), representing 56% of all US plywood production and 33% of all structural panel production including oriented strand board (OSB). The region produces enough panels if it were all sheathing, to build 1,583,000 homes annually (NAHB 2001—6.212 MSF sheathing per home). Panels are normally produced in 4- x 8-foot sheets.

To conduct the survey of plywood manufacturers, five plants were identified based on their production capability and representativeness of the industry. All five plants provided data for 2000 in terms of plywood and co-products production, raw materials, electricity and fuel use, and emissions. The five plywood producers surveyed represent 14% of the region's total production. Total annual production for producers surveyed was 1,383,642 MSF 3/8-inch basis.

This report documents the life cycle inventory (LCI) of manufacturing structural plywood based on resources from the Southeast softwood region. The output of this report, a gate-to-gate analysis plus transportation data for delivery of materials, will be used as an input to the life cycle analysis (LCA) of structural building materials by CORRIM in its cradle-to-residential building analysis. This report considers those impacts associated solely with the manufacture of softwood plywood, documenting all inputs and outputs and their impact. Primary data was collected by a survey of plywood manufacturers, while secondary data was obtained for impacts associated with the manufacture and delivery of electricity and all fuels (Franklin and Associates 2001; PRé Consultants 2001; USDOE 2000), CO_2 and press emissions (EPA 2001), and production of phenol-formaldehyde resin (ATHENA™ 1993). For cradle-to-gate analysis, this would data would need to be combined with the impacts for the resource module that generated logs, and bark, and the transportation impacts for delivery of logs, bark, veneer, and resin to the plywood plants.

The scope of this report encompasses production of softwood plywood from the Southeast region (Alabama, Georgia, Louisiana, Mississippi, Florida, Arkansas, and Texas) including raw material transport to the production facility (commonly referred to as a gate-to-gate analysis). This report is confined to transportation of logs and resin materials to the manufacturing site, production of phenol-formaldehyde resin, electricity, natural gas, plywood and its co-products. A critical review of this LCI process and analysis was conducted to ensure compliance with CORRIM and ISO 14040 protocol.

2.1.1 Unit Process Approach

The plywood process was broken down into six unit processes rather than examining the process as a "black box." The rationale for taking this approach is that this type of model would be most useful in analyzing ways to improve efficiency, optimize operations, and find means to reduce environmental impacts. Furthermore, data in this format could be used as a benchmark to document process improvements. In addition, this approach allows unit processes developed for one process to be used in modeling other processes. For instance, the peeling and drying unit processes could be used as input for green and dry veneer respectively into a laminated veneer lumber (LVL) process. The unit processes used to model softwood plywood production are shown in Figure 2.1.

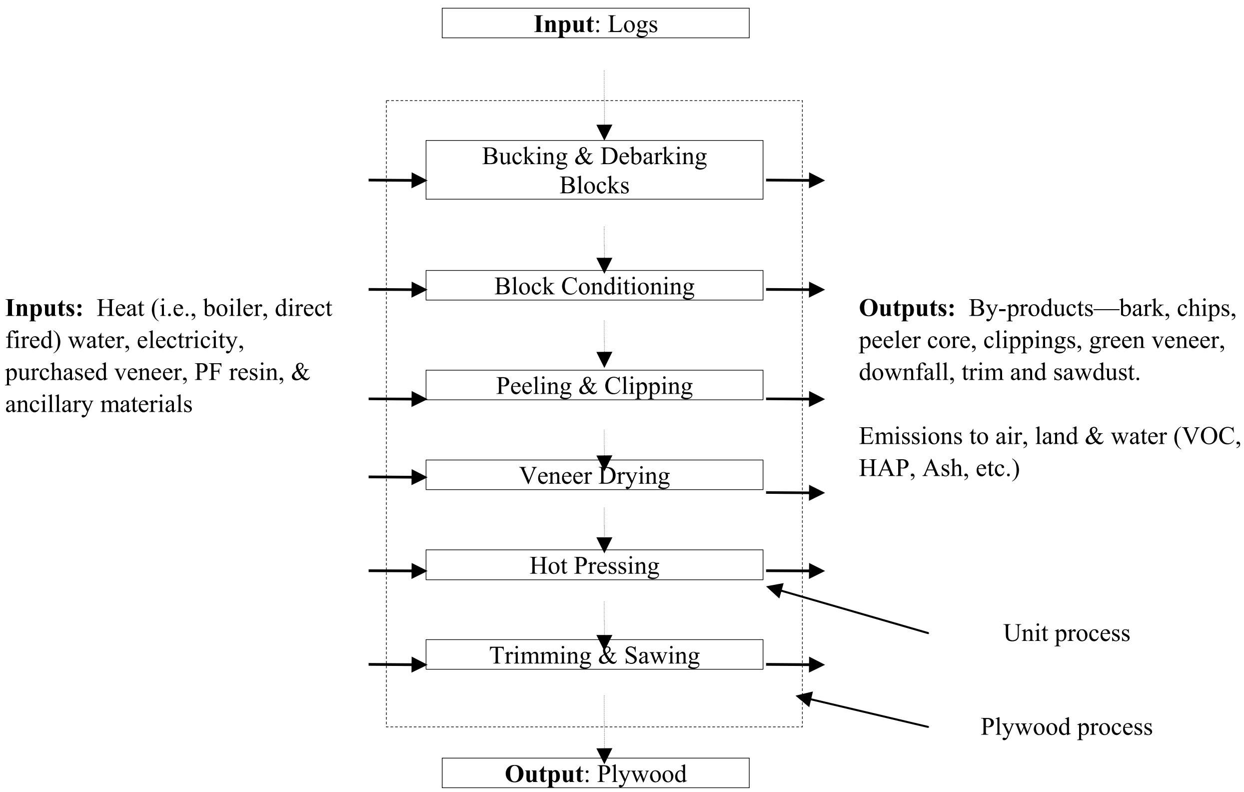


Figure 2.1. Unit Process approach to the modeling of the plywood manufacturing process.

Description of unit processes:

1. Debarking: includes debarking and bucking logs to make peeler blocks. Co-products include bark and some wood waste,

2. Conditioning: heating the blocks with either hot water or steam to condition the blocks for peeling,

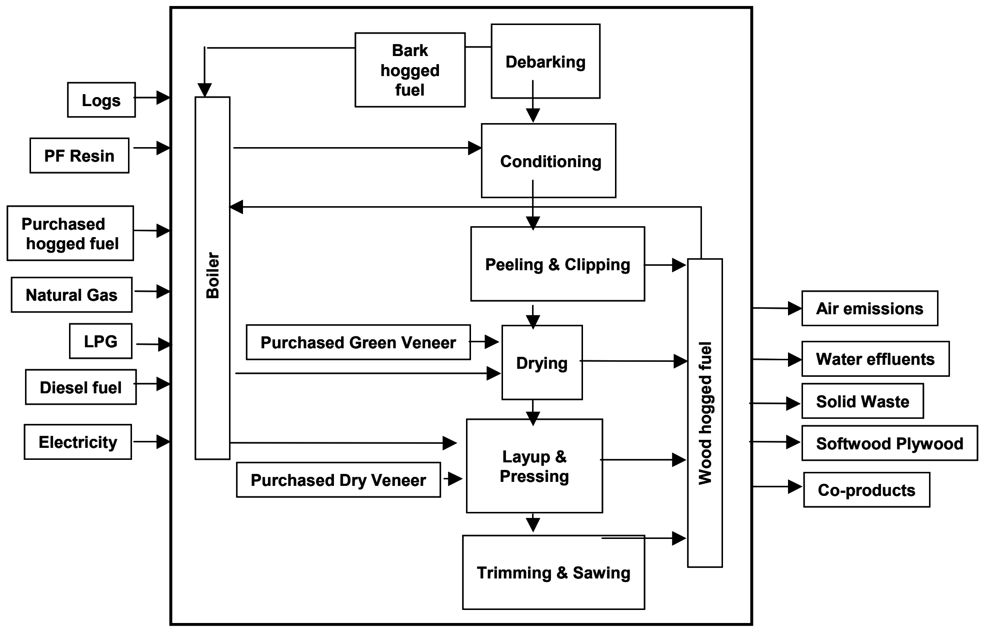
3. Peeling and Clipping: blocks are peeled in the lathe to make veneer, clipped to size, and sorted by moisture content (which is a function of the percentage of sapwood and heartwood in the sheet) in preparation for drying—co-products include round-up wood, peeler cores, veneer clippings and trim,

4. Veneer Drying: veneers are dried in "continuous dryers" to 3-8% moisture content; various heat sources are used for the drying. This center includes redrying, a practice where 10-20% of the veneer processed through the dryer is still too wet, so it is redried. Co-products include veneer downfall and other wood waste,

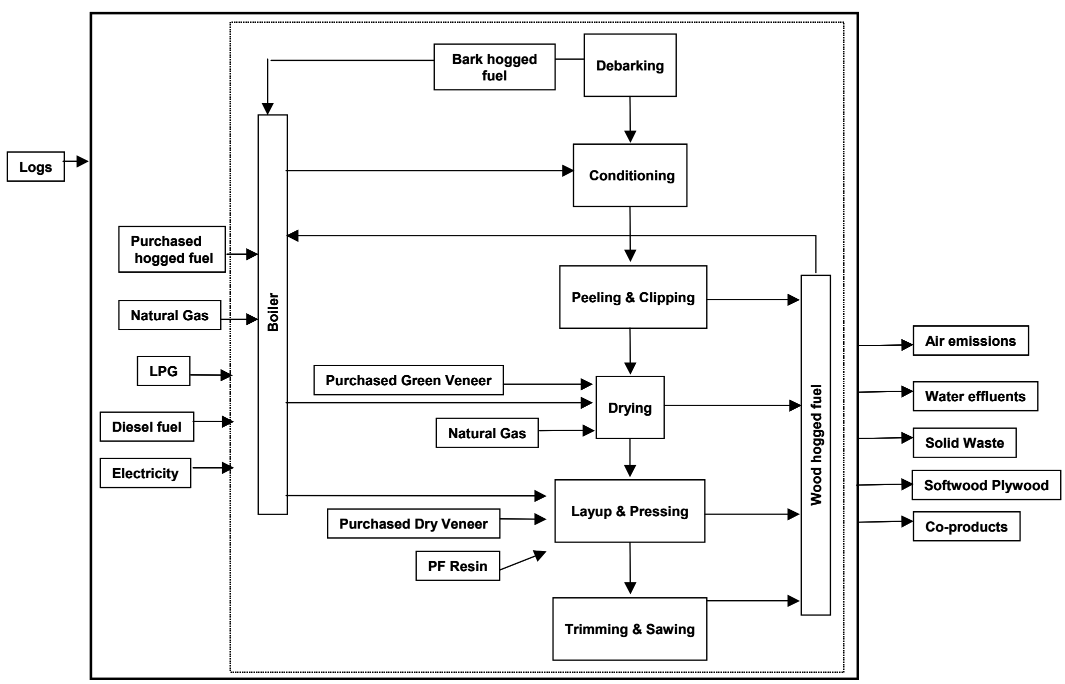
5. Lay-up and Pressing: veneers are coated with phenol-formaldehyde resin and composed into panels for hot pressing; heat and pressure are used to cure the resin, thereby bonding the veneers together to make plywood,

6. Trimming and Sawing: plywood panels coming out of the press are sawn to appropriate dimension. Co-products include plywood trim and sawdust.

Bark and some wood waste are used as fuel to fire boilers or fuel cells that supply heat to various unit processes—conditioning, drying and hot pressing—in the manufacturing process. As such, the bark and other wood waste when used as "hogged fuel" to generate heat are considered within the system boundary for the LCI analysis. Excluded from the study are the production of the catalyst, fillers, and extenders used in resins, the harvesting and growth of the trees, and the transportation of logs to the mill. The boiler, although not considered as a unit process, was analyzed as a separate operation within the system boundary. Figure 2.2 provides an overview of the entire system boundary used to model the plywood process.



A) System Boundary for site generated emissions only



B) System Boundary for Site and Off-site Generated Emissions which include those for fuels, resin, purchased veneer and hogged fuel, and electricity, but do not include emissions for delivery of logs, resin, and purchased veneer, nor for production of logs

Figure 2.2. System boundary and sub-unit processes used to model the plywood manufacturing process.
Notes: Not included in the sketch are the co-product flows.

2.1.2 Material Flows

Those materials considered in the LCI analysis included those listed in Table 2.1. Input materials considered were logs (includes wood and bark), green veneer, dry veneer, and phenol-formaldehyde resin. Outputs were plywood and co-products consisting of peeler core, chips, clippings, trimmings, veneer (green and dry), bark, and sawdust. All flow analyses of wood in the process were determined on an oven-dry weight basis. To derive the wood and bark weights and to determine how much water was "dried" from the wood and bark, the following assumptions were made: bark, as well as hogged fuel, was at 50% moisture content (MC) on a wet-basis, the wood was at an average of 100% MC oven-dry basis and mostly sapwood, and dry veneer and wood waste were at 7% MC on an oven-dry basis.

Table 2.1. Listing of Input materials, Products, and Co-products for Producing SE Plywood.

Input Materials	Co-products Produced	Products
Logs	Bark	Plywood
Green veneer	Chips, green	
Dry veneer	Peeler cores	
Phenol formaldehyde resin	Clippings, green	
	Veneer, dry	
	Plywood trimmings, dry	
	Sawdust, dry	

2.1.3 Transportation

Delivery of the input materials was by truck. The one-way delivery distances for logs, veneer, and resin are given in Table 2.2. The impacts of delivering materials is not considered in this module, rather the data is used by CORRIM and ATHENA™ when conducting resource through residential construction LCAs presented in Module J.

Table 2.2. Southeast Delivery Distance (One-Way) For Plywood Production.

Material	Delivery Distance (Miles)
Logs (roundwood)	97
Bark on logs	97
Purchased veneer	153
Purchased hogged fuel	64
Resin	98

2.1.4 Wood Density

The weight of the input wood was determined by using the log volume data in Doyle scale and converting to cubic feet (ft^3) of wood using the appropriate conversion factor as given by Briggs (1994). A final conversion was then made from ft^3 to mass (lb) by multiplying by the average weighted densities as determined by their percentage use as given by the survey, and the densities for these species as provided in the Wood Handbook (1999). The average wood density used was 31.51 lb/ft^3 oven-dry for the mix of loblolly and slash logs (Table 2.3).

Table 2.3. Average Density of Wood Species Used To Calculate the Mass of Wood From Logs.

Wood Species	Percentage Use in Survey[1]	Density[2]	
	%	lb/ft^3	kg/m^3
Loblolly	50	29.33	235
Slash	50	33.70	270
Average	100	31.51	505

[1] Assumed value.

[2] Wood density values are from Wood Handbook: Wood as an Engineering Material (1999).

2.1.5 Assumptions

The data collection, analysis, and assumptions followed protocols as defined in "Consortium for Research on Renewable Industrial Materials (CORRIM)—Research Guidelines for Life Cycle Inventories" dated April 18, 2001 and ISO 14040. Additional conditions include:

- A critical review was conducted of the process and data analysis to ensure compliance with CORRIM and ISO 14040 protocol.
- Data quality was found to be high based upon comparisons between plants, and on mass and heat balances. Data was also compared between regions and was found to be consistent when accounting for the lower density and moisture contents of wood species for the Pacific Northwest region.
- LCI data for site generated emissions considered only those emissions at the manufacturing process, thus giving a gate-to-gate LCI; to provide a cradle-to-gate LCI the reader would need to include the environmental impact of the growing and harvesting of the trees for logs, the transportation of logs, resin, purchased veneer and hogged fuel to the mill. LCI data for site and off-site emissions are also considered, but exclude burdens for logs and transportation of logs, resin, and purchased veneer and hogged fuel to the mill.
- All data from the mill survey taken in 2000 was weight averaged for the five plants based on the individual production of each plant in comparison to the total production for the year.
- The purchase dry and wet veneers, come with the same allocated burdens, as if produced in the plant since they use the same unit process models. The addition burden for transportation of the veneers is handled separately using the delivery mileage data.
- A mass-allocation process was used for assigning burdens.
- Co-products were defined as any materials that were sold outside the system boundary.
- 20% of liquid propane gas (LPG) was assigned to each of the five sub-unit processes from Conditioning through Trimming and Sawing to account for fuel use by forklift trucks within the plant.
- 100% of diesel fuel use was assigned to debarking and bucking to address fuel use by yard log loaders.
- Density values for the wood species used to make the plywood were obtained from Wood Handbook—Wood as an Engineering Material (1999), and based on their weighted percentage of use as reported by manufacturers; the weighted average density was calculated to be 31.51 lb/ft^3 oven-dry.
- Log inputs were provided in thousand board feet (Mbf) in Doyle scale and converted to ft^3.

- All conversion units for forestry and forest products type conversions were taken from Forest Products Measurements and Conversion Factors, with special Emphasis on the US Pacific Northwest (Briggs 1994).

- Unaccounted wood mass of 1.6% was established by the difference between reported input and output wood material flows (see Table 2.5 for material balance analysis). The unaccounted wood was treated as a co-product for the mass-based allocation of environmental burdens.

- SimaPro5, a software package designed for analyzing the environmental impact of products during their whole life cycle, was used to perform the life cycle analysis. Developed in the Netherlands by PRé Consultants B.V., SimaPro5 contains a US database for a number of materials, including paper products, fuels, and chemicals. Franklin Associates (FAL) provides an additional US database.

2.2 PRODUCT YIELDS

The input to produce a thousand square feet (MSF) 3/8-inch basis consists of 65.99 cubic foot (ft^3) or 2,079.5 lb of wood from logs (based on volume and wood densities given in Table 1.3), 10.4 lbs of green veneer and 8.07 lb of purchased dry veneer. These inputs yielded 1,083 lb of oven-dry plywood and 194 lb of oven-dry self produced hogged fuel that is mostly bark (the survey had a second category for bark where plants reported 124 lb oven-dry bark that appears to have been also included in the hogged fuel reported value. See Table 2.4 for a listing of all inputs and outputs.

Table 2.4. Inputs to Produce 1.0 MSF 3/8-in Basis of Plywood in the Southeast.

SE – Inputs				
INPUTS		**Unit/MSF 3/8-in Basis**		**SI Unit/m^3**
Materials[1/]	**Units**	**Weighted Average**	**SI Units**	**Weighted Average**
Roundwood	ft^3	6.60E+01	m^3	2.11E+00
	lb	2.08E+03	kg	1.07E+03
Phenol formaldehyde	lb	1.97E+01	kg	1.01E+01
Extender and fillers	lb	1.26E+01	kg	6.46E+00
Catalyst[2/]	lb	1.40E+00	kg	7.18E-01
Soda ash[2/]	lb	1.58E+00	kg	8.10E-01
Bark[3/]	lb	1.24E+02	kg	6.36E+01
Purchased				
Dry veneer	lb	8.07E+00	kg	4.14E+00
Green veneer	lb	1.04E+01	kg	5.33E+00
Electrical Use				
Electricity	kWh	1.22E+02	MJ	4.96E+02
Fuel				
Hog fuel (produced)[3/]	lb	1.94E+02	kg	9.94E+01
Hog fuel (purchased)[3/]	lb	4.58E+01	kg	2.35E+01
Wood waste[1/]	lb	6.07E+01	kg	3.11E+01
Liquid propane gas	gal	4.20E-01	L	1.80E+00
Natural gas	ft^3	2.42E+02	m^3	7.74E+00
Diesel	gal	2.70E-01	L	1.16E+00
Water Use				
Municipal water source	gal	3.05E+01	L	1.31E+02
Well water source	gal	9.30E+01	L	3.98E+02
Recycled water source	gal	8.20E-01	L	3.51E+00

[1] All materials are given as oven-dry or solids weights

[2] These materials were not included in the SimaPro LCI analysis; excluded based on the 2% rule

[3] Oven-dry weights were determined based on green weights assumed to be 50% moisture content on wet-basis.

A complete wood mass balance is given in Table 2.5. Bark was not considered in the wood flow. The percentage by weight of oven-dry bark based on the weight of oven-dry wood from the processed logs would be 9.7% if all the hogged fuel generated within the plant was bark, however if only the reported bark weight was considered then the amount of bark would be 5.9%. From these values it appears that 70 lb of the hogged fuel generated could be a mixture of bark and wood residue.

The difference between the total wood input and output is 2.64 lb, which was labeled as the "unaccounted for wood" and negative since more wood was output than input. The unaccounted wood amounts to only 0.1% of the total wood input. The percentage of recovery of wood in terms of wood input as logs and output as plywood is 50.2%—defined as the oven-dry weight of wood in plywood expressed as a percentage of the total oven-dry weight of input wood from the logs. This is a very good efficiency for an industry that has had to use smaller and smaller diameter logs to produce veneer. The smaller diameter logs make it more challenging to maintain a high recovery value.

The plants reported that they produced 194 lb of hogged fuel. However, only 124 lb of this was specifically reported as bark from the debarking unit process. Most likely the difference is bark, but it may also include some wood waste that had been hogged for fuel from various unit processes.

Table 2.5. Wood Mass Balance for Plywood Production in the Southeast Region per 1.0 MSF 3/8-in Basis.

Inputs	**lb/MSF 3/8-in Basis**	**kg/m³**
Round wood (logs)[1]	2079.5	1066
Purchased dry veneer	8.1	4.2
Purchased green veneer	10.4	5.3
Total	2098.0	1075

Outputs	**lb/MSF 3/8-in Basis**	**kg/m³**
Plywood (wood only)[2]	1055	541
Wood chips	645.2	331
Peeler core	112	57
Green clippings	172.7	89
Veneer downfall	0	0
Panel trim	60.6	31
Sawdust	4.2	2.2
Wood waste, sold	20.5	11
Wood waste (to boiler)	30.4	16
Sold dry veneer	0	0
Unaccounted for wood[3]	-2.64	-1.4
Total	2098.0	1075

1 Based on slash and loblolly logs using a weighted average wood density of 31.51 lb/ft³ for 65.99 ft³ of wood in logs to produce MSF 3/8-inch basis.
2 Plywood (wood only) based on estimated weight of plywood, 1083.2 lb, minus 80% of resin, filler, soda ash, and catalyst total use.
3 0.1% unaccounted for wood based on input weight.
Notes: All weights are on an oven-dry basis.

2.3 MANUFACTURING ENERGY SUMMARY

2.3.1 Sources of Energy

Energy for the production of plywood comes from electricity, diesel, liquid propane gas (LPG), bark-hogged fuel, and steam. With the recent dramatic cost increases for fuel and electricity, and the potential for greater cost increases, this topic will attract considerable attention in the coming years as plants seek to maintain profitability. The electricity is used to operate the debarker, bucker, lathe, pneumatic and mechanical conveying equipment, fans, hydraulic pumps, and saws. Electricity was used in all processes. Diesel fuel use is attributed solely to log loaders in the "Debarking" sub-unit process. As such, all of the diesel use was assigned to this process. Forklift trucks used small amounts of LPG in one or more of the remaining five sub-unit processes. This fuel use was assigned evenly over the five sub-unit processes from "Conditioning" to "Trimming and Sawing"; as such, 20% of the LPG use was assigned to each of these operations.

2.3.2 Electricity Use Summary

The source of fuel used to generate the electricity used in the manufacturing process is very important in determining the type and amount of impact in the LCA. The breakdown of electricity use in the Southeast by fuel source is given in Table 2.6. The source of this data is the US Department of Energy (USDOE 2000). In 2000, the dominant form of fuel source in the region was coal, representing 45.56% of the total, followed by natural gas at 23.03% and nuclear at 21.57%. In the SimaPro 5.0 analysis using the FAL database, combusting of coal contributes significant impact values, as does nuclear and petroleum, whereas natural gas and hydroelectric power contributes relatively less.

Table 2.6. Electric Power Industry Generation of Electricity by Primary Energy Sources and State for the Southeast Region as Defined by the US Department of Energy.

Percentage Share, 2000[1]								
Fuel	**AL**	**GA**	**LA**	**MS**	**FL**	**AR**	**TX**	**AVG**
Coal	61.90	64.80	25.60	37.00	37.90	54.70	37.00	45.56
Petroleum	0.20	1.30	2.30	7.90	18.50	0.50	0.70	4.49
Gas	4.30	2.70	49.60	22.50	22.70	7.80	51.60	23.03
Nuclear	25.20	26.40	17.60	28.50	16.90	26.50	9.90	21.57
Hydroelectric	4.70	1.90	0.60	0.00	0.00	5.40	0.20	1.83
Other	3.70	2.90	4.30	4.10	4.00	5.10	0.60	3.53

1 *Source*: Energy Information Administration/State Electric Profiles 2000, Department of Energy.
http://www.eia.doe.gov/cneaf/electricity/st_profiles/toc.html

The distribution of electricity use by unit process for the various plants was not obtained from the survey data. Rather it was extracted from data provided by outside sources as documented in Section 1.32 of the Pacific Northwest (PNW) plywood report (Grist and Karmous 1988). It was felt, in the absence of data for the Southeast, that the distribution of electricity by unit process would be comparable to data reported for the PNW. Table 2.7 provides a breakdown of electricity use by unit process. The dominant electricity use is for drying (36.7%) to operate the high velocity fans used in jet dryers (methods used to increase the heat and mass transfer rates during drying). Each of four other unit processes—debarking/ bucking, peeling/clipping, lay-up/pressing, and trimming/sawing—each use approximately 15% of the total electricity. Conditioning uses the least amount (7%).

Table 2.7. Electricity Allocation by Unit Process for Plywood Production in the Southeast.

Unit process	**kWh/MSF 3/8-in Basis**	**Allocation %[1]**
Debarking	15.1	12.4
Conditioning	8.4	6.9
Peeling & clipping	21.5	14.6
Veneer drying	44.8	36.7
Lay-up & pressing	13.4	11.0
Trimming & sawing	18.8	15.4
Total	122.0	100.0

Source: [1] Ferrari, C.J., 2000. Life Cycle Assessment: Environmental modeling of plywood and laminated veneer lumber manufacturing. Table 24, Appendix D., page 111 – Distribution of electricity use by sub-unit processes.
Notes: All values are given per 1.0 MSF 3/8-in basis of plywood.

2.4 HOGGED FUEL UTILIZATION

All of the bark generated during debarking as well as other waste sources in the plants were combined with some purchased hogged fuel (approximately 19% of the total hogged fuel which includes the wood waste burned) to use as hogged fuel in either a boiler or a direct-fired fuel cell. Hogged fuel weight, following industry practice, was reported in the surveys as green weight and assumed to be at 50% moisture content on a wet-weight basis. As such, the total hogged fuel burned is 479 lb at 50% moisture content on a wet basis, or 240 lb of oven-dry weight hogged fuel. A very small amount of wood waste, 30.4 lb oven-dry, was reported as burned in the boiler. In addition to hogged fuel for heat generation, natural gas was also used, representing 11.4% of the total heat generation. Hogged fuel and wood waste were by far the dominant fuel sources at 88.6% of the total energy for heat. Table 2.8 provides a breakdown of heat energy use for the boilers by fuel source.

Table 2.8. Southeast Weighted Data Conversion of Boiler Inputs into Heat Energy for 1.0 MSF 3/8-in Basis of Plywood.

Fuel Type	Input		Heat Energy Btu		Fuel Source %	
	Total	Breakdown	Total	Breakdown	Total	Breakdown
Hogged fuel (lb) [1, 2]	2.40E+02		1.44E+06		79	
Self generated – Wood boiler		1.94E+02		1.17E+06		81
Purchased – Wood boiler		4.58E+01		2.76E+05		19
Wood waste (lb) [1,2]	3.04E+01		1.86E+05		10	
Natural gas (ft^3) [3]	2.42E+02		2.09E+05		11	
Total			**1.84E+06**		**100**	

[1] Oven-dry weight based on assumed weight of green hogged fuel at 50% MC wet-basis.
[2] Energy calculations done on green weight of hogged fuel and wood waste multiplied by 4500 Btu/lb of green fuel multiplied by 67% efficiency for burning.
[3] Volume of natural gas multiplied by 1016 Btu/ft^3 of natural gas, 80% efficiency—source ATHENA™.

Three unit processes used hogged fuel and natural gas for heat—block conditioning, veneer drying, and hot pressing. Veneer drying used the dominant amount of energy for heating (77%), followed by hot pressing (13%) and conditioning (10%). The plants reported heat use for drying and pressing. To determine heat use for conditioning it was calculated by taking the total heat use for the plant (as determined by hogged and wood waste fuel used in the boiler to generate steam) and subtracting the reported steam use for drying and hot pressing. In summary, dryers used the dominant amount of electricity (36.7%) and overall energy (77%) compared to the total use for the three production centers. Table 2.9 provides a breakdown of heat use by sub-unit process and source.

Table 2.9. Boiler Energy Requirements for Conditioning, Drying, and Pressing Unit Processes Used in the Production of Plywood in the Southeast Region.

Fuel Inputs	Conditioning Btu/MSF 3/8-in Basis	Drying Btu/MSF 3/8-in Basis	Pressing Btu/MSF 3/8-in Basis	Total Btu/MSF 3/8-in Basis	Total %
Hogged fuel[1/]	168,010	1,135,802	225,758	1,529,570	88
Natural gas		209,271		209,271	12
Total	168,010	1,345,073	225,758	1,738,841	100
Percent	10	77	13	100	

[1/] Hogged fuel values include self-produced hogged fuel along with wood waste.

Boiler data in the LCI was determined by calculating the energy equivalence of the two fuel sources of hogged fuel and natural gas, then entering this data into a boiler module for hogged fuel generated within the plant, or in the Franklin Associates database for a natural gas fired boiler, respectively. The wood boiler database did not include a transportation burden for its delivery. The natural gas fired boiler used the FAL database that included a transportation burden to the plant. For all fuel, whether wood, hogged fuel, or natural gas, emissions from the FAL database in the LCI analysis were used. Table 2.10 provides a comparison of emissions as generated by the FAL database to that of the data collected by the survey. All survey data, except for CO_2, was provided by the survey; CO_2 was calculated from EPA data on boiler emissions (EPA 1999). Although the emissions data for FAL and the CORRIM survey are similar in magnitude, there are differences. The difference between the FAL data and survey/EPA data is due to several factors. First, the FAL data represents wood-fired boilers throughout the US and does not consider wood species or regional effects on the values. Secondly, the FAL database is based upon a much larger sampling. Consideration should be given to establishing a new database for hogged-fuel fired boilers based on the CORRIM survey data. The CORRIM database could include boiler data from other modules for softwood plywood, softwood lumber, and OSB. Transportation impacts for hogged fuel were not included in this emissions data, however, it would need to be considered whether self-generated or purchased in any cradle-to-gate LCI or LCA.

Table 2.10. Survey Data on Air Emissions for Boilers as Output from SimaPro 5 (Using the FAL[1] Boiler Data) Compared to Survey Data.

Emissions to Air	FAL Data[1] lb/MSF 3/8-in Basis	CORRIM Survey Data lb/MSF 3/8-in Basis
Acetaldehyde	5.80E-04	4.51E-04
Acrolien	N/R	4.06E-05
CO	2.63E+00	4.87E+00
CO_2	4.06E+02	6.41E+02[2]
Formaldehyde	1.27E-03	1.42E-03
Methanol	N/R	5.17E-03
NO_X	3.08E-01	1.14E+00
Particulates	3.30E-02	4.11E-01
Particulates PM10	N/R	1.72E-01
Phenol	7.73E-03	6.77E-06
SO_2	1.53E-02	2.30E-02
VOC	N/R	7.30E-02
Water vapor	N/R	2.36E+02

[1] Reference: SimaPro 5.0, 2001; Franklin and Associates, FAL Database, 1998.
[2] Calculated from EPA Wood Residue Combustion in Boilers, AP-42, Section 1.6, EPA, 2001.
Notes: Data represent total emissions based on weighted production data for the boilers with no allocation to co-products.
N/R= Not reported in surveys.

2.5 DRYING EMISSIONS FOR SOUTHEAST PLYWOOD PRODUCTION

Dryers are used to take the moisture content of green veneer from about 100% down to about 5% (oven-dry basis). Dryer temperatures are normally in the 340 to 380ºF range, however, the wood veneer does not experience this higher temperature until much of its moisture is evaporated near the output end of the dryer. Most emissions are generated at this time. One of the plants surveyed had a direct-fired natural gas dryer, and because of this the reported emissions have components of CO, CO_2 (fossil), NO_x, and SO_2 that would not be emitted from the steam heated dryers.

Table 2.11. Emissions for Drying Veneer in the Southeast as Reported in Surveys.

Emissions to Air [1/]	Emissions from Dryer lb/MSF 3/8-in Basis [1/]	Emissions from Dryer kg/m^3
Acrolien	6.76E-06	3.47E-06
Acetaldehyde	3.38E-04	1.73E-04
CO_2 (fossil)[2/]	2.04E+01	1.05E+01
CO	1.22E-01	6.25E-02
Formaldehyde	2.71E-04	1.39E-04
Methanol	7.21E-04	3.70E-04
NO_X	4.06E-02	2.08E-02
Particulates	7.35E-02	3.77E-02
PM10	2.09E-02	1.07E-02
Phenol	3.15E-04	1.61E-04
SO_2	8.21E-05	4.21E-05
VOC	7.61E-02	3.90E-02

[1] Air emission data based on weighted production data as reported from surveys.

[2] Natural gas, direct-fired dryer for one of the surveyed plants.

Notes: Data are total emissions; no burden or allocation to co-products.

2.6 PRESSING EMISSIONS SOUTHEAST PLYWOOD PRODUCTION

Hot pressing is done in the plywood process to provide intimate contact between veneers while the phenol-formaldehyde adhesive cures as a result of temperature in the 325-340ºF range. Emissions are generated from the wood as a result of the high temperatures, and the adhesive also generate emissions during cure.

Table 2.12. Emissions for Hot Pressing Plywood in the Southeast.

Emissions to Air	Emissions from Dryer lb/MSF 3/8-in Basis [1/]	Emissions from Dryer kg/m^3
Acetone	6.50E-03	3.33E-03
Acetaldehyde	4.20E-03	2.15E-03
Formaldehyde	1.90E-03	9.74E-04
Methanol	1.40E-01	7.18E-02
Methyl ethyl ketone	8.70E-04	4.46E-04
Particulate matter	1.78E-01	9.12E-02
Phenol	1.40E-03	7.18E-04
THC as carbon	2.10E-01	1.08E-01
VOC as propane	2.50E-01	1.28E-01
Water vapor	2.85E+01	1.46E+01

[1] Calculated from EPA Plywood Manufacturing – Emission Factor Documentation, AP-42, Chapter 10, Table 10.5-6, 2001.
Notes: Data are total emissions; no burden of allocation has been made to co-products.

2.7 ADHESIVE USE AND ENERGY/ELECTRICITY TO PRODUCE

Phenol-formaldehyde (phenolic) resin is the adhesive used in plywood production. The manufacture of phenolic resins is particularly energy intensive. The total energy requirement for the production of 19.68 lb of phenolic needed for MSF 3/8-inch basis plywood from the Southeast is 3.25E+05 Btu. Electricity requirements for phenol-formaldehyde production per MSF 3/8-inch basis are 10.4% of the total electricity used to produce plywood in the Southeast region. The 19.68 lb of phenol-formaldehyde resin is comprised of 65% formaldehyde and 35% phenol by weight. All the materials, fuel, and electricity used to produce the phenol-formaldehyde resin are listed in Table 2.13. Total air emissions for the production of the 19.68 lb of phenol-formaldehyde resin are given in Table 2.14.

Table 2.13. Production Requirements[1] for the 19.68 lb of Phenol-Formaldehyde Resin Needed to Manufacture 1.0 MSF 3/8-in Basis Plywood in the Southeast Region.

INPUTS		
Materials	**lb/MSF 3/8-in Basis**	**kg/m^3**
Formaldehyde	1.28E+01	3.02E+01
Phenol	6.89E+00	1.62E+01
Fuel Use	**Btu/MSF 3/8-in Basis**	**MJ/m^3**
Heavy oil	1.20E+04	1.43E+05
Gasoline	8.47E+04	1.01E+06
Natural gas	2.28E+05	2.72E+06
Electrical Use	**kWh/MSF 3/8-in Basis**	**MJ/m^3**
Electricity	1.27E+01	5.17E+01

[1] Data obtained from Raw Material Balances, Energy Profiles & Environmental Unit Factor Estimates: Structural Wood Products, ATHENA™, 1993.

Table 2.14. Air Emissions for the Production of the 19.68 lb of Phenol-Formaldehyde Resin Needed to Produce 1.0 MSF 3/8-in Basis Plywood in the Southeast Region.

Substance	PF Resin Production[1]	Total for Plywood Production[2]	PF Resin Contribution to Plywood Production
	lb/MSF 3/8-in Basis		%
Aldehydes	9.20E-04	1.48E-03	62.35
Ammonia	1.54E-04	8.94E-04	17.19
Be	7.68E-08	6.16E-07	12.46
Cd	7.44E-07	4.74E-06	15.69
CO	1.58E-01	3.14E+00	5.01
CO_2 (fossil)	5.17E+01	2.07E+02	24.97
Cobalt	7.98E-07	5.43E-06	14.70
Cr	1.04E-06	1.73E-05	6.03
Cumene	9.85E-05	1.03E-04	95.49
Dichloromethane	8.53E-07	7.56E-06	11.28
Dioxin (TEQ)	1.11E-12	9.94E-12	11.20
Formaldehyde	2.24E-02	2.76E-02	81.10
HCl	1.05E-03	9.38E-03	11.24
HF	1.46E-04	1.31E-03	11.16
Hg	4.91E-07	4.11E-06	11.95
Kerosene	6.42E-06	5.81E-05	11.05
Metals	1.00E-05	3.22E-05	31.20
Methane	1.68E-01	4.93E-01	34.19
N-nitrodimethylamine	4.44E-08	3.96E-07	11.21
N_2O	1.23E-04	1.09E-03	11.25
Ni	1.03E-05	1.79E-04	5.78
Non methane VOC	4.09E-01	6.24E-01	65.51
NO_X	5.05E-01	1.53E+00	33.12
Particulates (unspecified)	1.53E-02	1.33E-01	11.46
Phenol	2.89E-02	3.98E-02	72.58
Sb	3.03E-07	2.13E-06	14.27
Se	1.73E-06	1.48E-05	11.70
SO_X	8.37E-01	2.15E+00	38.93
Tetrachloroethene	2.04E-07	1.81E-06	11.25
Tetrachloromethane	5.77E-07	4.91E-06	11.75
Trichloroethene	1.99E-07	1.78E-06	11.21

[1] Data obtained from Raw Material Balances, Energy Profiles & Environmental Unit Factor Estimates: Structural Wood Products, ATHENA™, 1993. .   Includes all emissions from resource through resin production, it does not include emissions for delivery of resin to plant, this is handled separately.

[2] Includes all emissions for plywood and resin production, plus those emissions associated with the production and delivery of electricity and fuel, it does not include emissions for to generate the logs or to deliver materials to the plant, these are handled separately.

2.8 PROCESS RELATED EMISSIONS

The total emissions from each unit process can also be determined. Table 2.15 gives the emissions breakdown for the six unit processes. The values include the burdens in terms of emissions for the production of any electricity, fuel, and adhesive, in addition to that of the hogged fuel and wood. The total values for Tables 2.15 and 2.16 differ slightly due to rounding error as the values were accumulated from sub-unit process to sub-unit process. The allocation of all emissions to plywood was 48.49%; as such, to find total emissions, divide the emissions allocated to plywood by 0.4849. The reminder of emissions (51.55%) was assigned to the co-products.

Table 2.15. Process Emissions for Plywood Production in the Southeast Region.

	Bucking & Debarking	Log Conditioning	Peeling & Clipping	Veneer Drying	Lay up & Pressing	Trimming & Sawing	Total
Substance				**lb/MSF 3/8-in Basis**			
Acetaldehyde	0.00E+00	3.74E-05	0.00E+00	7.40E-04	3.63E-03	0.00E+00	4.41E-03
Acrolein	1.30E-07	7.32E-08	1.87E-07	6.45E-06	4.65E-07	2.76E-07	7.58E-06
CO	2.06E-02	1.75E-01	1.18E-02	2.21E+00	5.96E-01	1.78E-02	3.03E+00
CO_2 (fossil)	4.83E-03	6.78E+00	1.65E+01	6.49E+01	7.12E+01	2.45E+01	1.84E+02
CO_2 (biofuel)[1/]	1.44E+01	2.62E+01	5.96E-03	3.17E+02	6.50E+01	8.83E-03	4.23E+02
Formaldehyde	0.00E+00	8.27E-05	1.30E-06	1.24E-03	2.42E-02	1.92E-06	2.56E-02
Methane	2.44E-02	1.49E-02	3.58E-02	1.32E-01	2.11E-01	5.32E-02	4.71E-01
Methanol	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.18E-01	0.00E+00	1.18E-01
Non methane VOC	2.28E-02	1.10E-02	2.14E-02	7.20E-02	4.37E-01	3.26E-02	5.97E-01
NO_X	1.01E-01	5.00E-02	6.60E-02	5.09E-01	6.36E-01	9.95E-02	1.46E+00
Particulates	4.21E-03	2.16E-03	2.48E-05	8.82E-02	1.62E-01	2.76E-01	5.33E-01
Particulates (PM10)	1.98E-03	1.11E-03	2.85E-03	2.84E-02	6.40E-03	8.26E-02	1.23E-01
Particulates (unspecified)	9.33E-03	5.17E-03	1.32E-02	4.94E-02	3.04E-02	1.95E-02	1.27E-01
Phenol	3.32E-07	4.98E-04	4.58E-07	6.31E-03	3.13E-02	6.77E-07	3.81E-02
SO_2	0.00E+00	0.00E+00	0.00E+00	6.97E-05	4.82E-07	0.00E+00	7.02E-05
SO_X	1.00E-01	6.10E-02	1.42E-01	5.32E-01	1.00E+00	2.12E-01	2.05E+00
VOC	0.00E+00	0.00E+00	0.00E+00	6.46E-02	2.12E-01	0.00E+00	2.76E-01

[1] CO_2 biomass and non-fossil collaborated.

Notes: Data are allocated total emissions, which include emissions for the production and delivery of electricity and fuel, and the production of resin; it does not include emissions for production of logs, or for delivery of logs, bark, resin, purchased veneer to the plant, this is handled separately.

2.9 LIFE-CYCLE INVENTORY RESULTS FOR PLYWOOD PRODUCTION FROM THE SOUTHEAST REGION

Life-cycle inventory results for production of 1.0 MSF 3/8-inch of softwood plywood in the Southeast are given in Table 2.16 (inputs) and 2.17 (outputs). Results include all processes within the system boundary defined in Figure 2.2. Results were generated in SimaPro 5 Life-Cycle Assessment software with the Franklin Associates' database for fuel use and electricity production burdens. Emissions for production of the phenolic adhesive were obtained from ATHENA^{TM}. Other inputs and outputs were obtained from the surveyed plants.

Table 2.16. Life-Cycle Inventory Results for Producing 1.0 MSF 3/8-in Basis of Plywood in the Southeast Region.

SE Plywood – Inputs				
INPUTS		**Unit/MSF 3/8-in Basis**		**SI Unit/m^3**
Materials[1/]	**Units**	**Weighted Average**	**SI Units**	**Weighted Average**
Roundwood	ft^3	6.60E+01	m^3	2.11E+00
	lb	2.08E+03	kg	1.07E+03
Phenol formaldehyde	lb	1.97E+01	kg	1.01E+01
Extender and fillers	lb	1.26E+01	kg	6.46E+00
Catalyst[2/]	lb	1.40E+00	kg	7.18E-01
Soda ash[2/]	lb	1.58E+00	kg	8.10E-01
Bark[3/4/]	lb	1.24E+02	kg	6.36E+01
Purchased				
Dry veneer	lb	8.07E+00	kg	4.14E+00
Green veneer	lb	1.04E+01	kg	5.33E+00
Electrical Use				
Electricity	kWh	1.22E+02	MJ	4.96E+02
Fuel[1/]				
Hog fuel (produced)[3/4/]	lb	1.94E+02	kg	9.94E+01
Hog fuel (purchased)[3/4/]	lb	4.58E+01	kg	2.35E+01
Wood waste[4/]	lb	3.04E+01	kg	1.56E+01
Liquid propane gas	gal	4.20E-01	L	1.80E+00
Natural gas	ft^3	2.42E+02	m^3	7.74E+00
Diesel	gal	2.70E-01	L	1.16E+00
Water Use				
Municipal water source	gal	3.05E+01	L	1.31E+02
Well water source	gal	9.30E+01	L	3.98E+02
Recycled water source	gal	8.20E-01	L	3.51E+00

[1] All wood, bark and other materials given as oven-dry weights.
[2] These materials were not included in the SimaPro LCI analysis; excluded based on the 2% rule.
[3] Bark weight included in the hogged fuel produced weight.
[4] Bark, wood and hogged fuel when used for fuel assumed 50% MC wet basis for energy calculations.

Table 2.17. Life-Cycle Inventory Results for 1.0 MSF 3/8-inch Basis Plywood Production in the Southeast Region.

Raw Materials		
Substance	**lb/MSF 3/8 in**	**kg/m^3**
SE Bark from log	5.05E+01	2.59E+01
SE Logs	1.01E+03	5.18E+02 0.00E+00
Coal FAL	5.21E+01	2.67E+01
Crude oil FAL	1.84E+01	9.43E+00
Limestone	6.01E+00	3.08E+00
Natural gas FAL	3.83E+01	1.96E+01
Uranium FAL	2.65E-04	1.36E-04
Wood/wood wastes FAL	5.21E+01	2.67E+01

Electricity Use		
Substance	**kWh/MSF 3/8 in**	**MJ/m^3**
Electricity from other sources	3.58E+00	1.46E+01
Energy from hydro power	1.86E+00	7.57E+00

Energy Use		
Substance	**Btu/MSF 3/8 in**	**MJ/m^3**
Natural gas direct fired	1.85E+05	2.21E+06

Water Use		
Substance	**ft^3/MSF 3/8 in**	**m^3/m^3**
Municipal Water Source	2.01E+00	6.43E-02
Recycled Water Source	5.43E-02	1.74E-03
Well Water Source	6.15E+00	1.97E-01

Emissions to Air		
Substance	**lb/MSF 3/8 in**	**kg/m^3**
Acetaldehyde	4.61E-03	2.36E-03
Acetone	5.73E-03	2.94E-03
Acrolein	7.88E-06	4.04E-06
Aldehydes	1.48E-03	7.59E-04
Alpha-pinene	8.63E-02	4.42E-02
Ammonia	8.94E-04	4.58E-04
As	2.42E-05	1.24E-05
Ba	8.88E-04	4.55E-04
Be	6.16E-07	3.16E-07
Benzene	7.44E-04	3.81E-04
Beta-pinene	3.35E-02	1.72E-02
Cd	4.74E-06	2.43E-06
Cl2	1.58E-03	8.10E-04
CO	3.14E+00	1.61E+00
CO_2 (fossil)	2.07E+02	1.06E+02
CO_2 (biomass)	4.24E+02	2.17E+02
Cobalt	5.43E-06	2.78E-06
Cr	1.73E-05	8.87E-06
Cumene	1.03E-04	5.28E-05
Dichloromethane	7.56E-06	3.88E-06
Dioxin (TEQ)	9.94E-12	5.10E-12
Fe	8.88E-04	4.55E-04
Formaldehyde	2.76E-02	1.41E-02
HCl	9.38E-03	4.81E-03
HF	1.31E-03	6.72E-04
Hg	4.11E-06	2.11E-06
K	1.58E-01	8.10E-02
Kerosene	5.81E-05	2.98E-05
Limonene	9.69E-03	4.97E-03
Metals	3.22E-05	1.65E-05
Methane	4.93E-01	2.53E-01
Methanol	1.24E-01	6.36E-02
Methyl ethyl ketone	7.69E-04	3.94E-04
Methyl i-butyl ketone	6.25E-04	3.20E-04
Mn	1.83E-03	9.38E-04
n-nitrodimethylamine	3.96E-07	2.03E-07
N_2O	1.09E-03	5.59E-04
Na	3.64E-03	1.87E-03
Naphthalene	4.85E-04	2.49E-04
Ni	1.79E-04	9.18E-05
Non methane VOC	6.24E-01	3.20E-01
NOx	1.53E+00	7.84E-01

Organic substances	3.51E-02	1.80E-02
Particulates	5.71E-01	2.93E-01
Particulates (PM10)	1.33E-01	6.82E-02
Particulates (unspecified)	1.33E-01	6.82E-02
Pb	2.50E-04	1.28E-04
Phenol	3.98E-02	2.04E-02
Sb	2.13E-06	1.09E-06
Se	1.48E-05	7.59E-06
SO_2	7.31E-05	3.75E-05
SOx	2.15E+00	1.10E+00
Tetrachloroethene	1.81E-06	9.28E-07
Tetrachloromethane	4.91E-06	2.52E-06
THC as Carbon	1.85E-01	9.48E-02
Trichloroethene	1.78E-06	9.12E-07
VOC	2.88E-01	1.48E-01
Water vapor	5.08E+02	2.60E+02
Zn	8.88E-04	4.55E-04

Emissions to Water		
Substance	**lb/MSF 3/8 in**	**kg/m^3**
Acid as H+	1.94E-08	9.94E-09
B	5.21E-03	2.67E-03
BOD	2.09E-03	1.07E-03
Ca	1.43E-07	7.33E-08
Calcium ions	4.99E-05	2.56E-05
Cd	9.25E-05	4.74E-05
Chromate	3.74E-06	1.92E-06
Cl-	9.31E-02	4.77E-02
COD	2.04E-02	1.05E-02
Cr	9.25E-05	4.74E-05
Cyanide	1.38E-07	7.07E-08
Dissolved solids	2.03E+00	1.04E+00
Fe	7.31E-03	3.75E-03
Fluoride ions	2.32E-04	1.19E-04
H_2SO_4	1.31E-03	6.72E-04
Hg	7.25E-09	3.72E-09
Metallic ions	4.12E-04	2.11E-04
Mn	4.09E-03	2.10E-03
Na	9.19E-05	4.71E-05
NH_3	1.36E-04	6.97E-05
Nitrate	2.19E-05	1.12E-05
Oil	3.63E-02	1.86E-02
Other organics	6.81E-03	3.49E-03
Pb	3.53E-08	1.81E-08
Phenol	1.34E-06	6.87E-07
Phosphate	6.50E-04	3.33E-04
Sulphate	1.01E-01	5.18E-02
Suspended solids	9.81E-02	5.03E-02
Zn	3.21E-05	1.65E-05

Solid Waste Emissions		
Substance	**lb/MSF 3/8 in**	**kg/m3**
Solid waste	4.54E+01	2.33E+01

Nonmaterial Emissions		
Substance	**Ci/MSF 3/8 in**	**Bq/m^3**
Radioactive subst. to air	3.49E-05	1.46E+05

Notes: Data are allocated emissions and total emissions, which includes emissions for the production and delivery of electricity and fuel, and production of resin but not its delivery to plant. Excludes burden for logs and their delivery.

It is also useful to examine those emissions solely from the production of plywood, which is referred to as site emissions. Tables 2.18 and 2.19 provide output data for the plywood excluding the emissions contributed by the production of resin, fuel, electricity, logs, and transportation.

Table 2.18. Life-Cycle Inventory Results for Production of 1.0 MSF 3/8-inch Basis Plywood in the Southeast Region.

Raw Materials		
Substance	**lb/MSF 3/8 in**	**kg/m^3**
SE bark from log	5.05E+01	2.59E+01
SE logs	1.01E+03	5.18E+02
Phenol formaldehyde resin	1.73E+01	8.87E+00
Wood	5.18E+01	2.66E+01
Substance	**ft^3/MSF 3/8 in**	**m^3/m^3**
Distillate fuel oil (DFO)	1.76E-02	5.63E-04
LPG stand alone	5.56E-03	1.78E-04
Natural gas (vol)	2.73E+01	8.74E-01

Electricity Use		
Substance	**kWh/MSF 3/8 in**	**MJ/m^3**
Electricity from ATHENA™	9.03E+01	3.67E+02

Energy Use		
Substance	**Btu/MSF 3/8 in**	**MJ/m^3**
Natural gas direct fired	1.85E+05	2.21E+06

Water Use		
Substance	**ft^3/MSF 3/8 in**	**m^3/m^3**
Municipal water source	2.01E+00	6.43E-02
Recycled water source	5.43E-02	1.74E-03
Well water source	6.15E+00	1.97E-01

Emissions to Air		
Substance	**lb/MSF 3/8 in**	**kg/m^3**
Acetaldehyde	4.61E-03	2.36E-03
Acetone	5.73E-03	2.94E-03
Alpha-pinene	8.63E-02	4.42E-02
As	1.78E-05	9.12E-06
Ba	8.88E-04	4.55E-04

Benzene	7.25E-04	3.72E-04
Beta-pinene	3.35E-02	1.72E-02
Cl_2	1.58E-03	8.10E-04
CO	2.87E+00	1.47E+00
CO_2 (fossil)	1.01E+01	5.18E+00
CO_2 (biomass)	4.24E+02	2.17E+02
Cr	9.31E-06	4.77E-06
Fe	8.88E-04	4.55E-04
Formaldehyde	4.17E-03	2.14E-03
K	1.58E-01	8.10E-02
Limonene	9.69E-03	4.97E-03
Methane	9.50E-05	4.87E-05
Methanol	1.24E-01	6.36E-02
Methyl ethyl ketone	7.69E-04	3.94E-04
Methyl i-butyl ketone	6.25E-04	3.20E-04
Mn	1.82E-03	9.33E-04
Na	3.64E-03	1.87E-03
Naphthalene	4.85E-04	2.49E-04
Ni	1.13E-04	5.79E-05
Non methane VOC	5.19E-03	2.66E-03
NO_X	4.09E-01	2.10E-01
Organic substances	3.35E-02	1.72E-02
Particulates	5.64E-01	2.89E-01
Particulates (PM10)	1.05E-01	5.38E-02
Pb	2.43E-04	1.25E-04
Phenol	9.56E-03	4.90E-03
SO_2	7.31E-05	3.75E-05
SO_X	2.15E-02	1.10E-02
THC as Carbon	1.85E-01	9.48E-02
VOC	2.88E-01	1.48E-01
Zn	8.88E-04	4.55E-04

Emissions to water

Substance	**lb/MSF 3/8 in**	**kg/m^3**
BOD	7.63E-06	3.91E-06
COD	6.50E-04	3.33E-04
Dissolved solids	1.28E-03	6.56E-04
NH_3	1.47E-06	7.54E-07
Suspended solids	1.36E-03	6.97E-04

Solid Waste Emissions		
Substance	lb/MSF 3/8 in	kg/m^3
Solid waste	1.82E+01	9.33E+00

Source: taken from SimaPro 5.0 LCI

Notes: Results are for plywood production only [referred to as "site generated data"]; no emissions for production or transportation considered for fuel, electricity, resin, and logs/bark. It also doesn't include delivery emissions for purchased veneer or purchased hogged fuel. These are allocated emissions for plywood.

Table 2.19. Life-cycle Inventory Results for 1.0 MSF 3/8-in Basis Plywood Production from the Southeast region.

Substance	LCI Total lb/MSF 3/8-in Basis	LCI Site-Generated lb/MSF 3/8-in Basis
Acetaldehyde	4.61E-03	4.61E-03
Acrolein	7.88E-06	
CO	3.14E+00	2.87E+00
CO_2 (fossil)	2.07E+02	1.01E+01
CO_2 (biofuel)	4.24E+02	4.24E+02
Formaldehyde	2.76E-02	4.17E-03
Methane	4.93E-01	9.50E-05
Methanol	1.24E-01	1.24E-01
Non methane VOC	6.24E-01	5.19E-03
NO_X	1.53E+00	4.09E-01
Particulates	5.71E-01	5.64E-01
Particulates (PM10)	1.33E-01	1.05E-01
Particulates (unspecified)	1.33E-01	
Phenol	3.98E-02	9.56E-03
SO_2	7.31E-05	7.31E-05
SO_X	2.15E+00	2.15E-02
VOC	2.88E-01	2.88E-01

Notes: Table gives a comparison of the total LCI to the LCI of site generated emissions for plywood production only; does not include production and transportation emissions for fuel, electricity, and resin.)

2.10 SENSITIVITY ANALYSIS

A sensitivity analysis was conducted to examine the effects of using different fuel sources for heat generation. Currently there are two fuel sources used, hogged fuel, which is comprised of bark and wood waste, and natural gas. This analysis used the plywood manufacturing model created in an LCI software program called SimaPro version 5.0.009, using all natural gas and all self-produced hogged fuel for heat generation. Three scenarios were modeled: 1) comparing all natural gas versus the “as is” original plywood model, with no fuel changes and incorporating both natural gas and hogged fuel, 2) comparing the use of all self-produced hogged fuel versus the “as is” original plywood model, with no changes, and 3) comparing the use of all natural gas versus all self-produced hogged fuel as a fuel for heat.

2.10.1 Sensitivity analysis of plywood manufacturing in the SE region of the United States

Sensitivity analyses were used to study the LCI model that represented plywood manufacturing. The analysis can be useful to understand how various process parameters contribute to environmental output factors. For instance, in plywood manufacturing, heat is used in several unit processes, consuming hogged fuel and/or natural gas as fuel to generate the heat. Changing the fuel source can have dramatic effect on the type and quantity of emissions into the environment. This sensitivity analysis was used to compare the effects of using all self produced hogged fuel to natural gas as a fuel input. In the original model, fuel sources used for heat purposes included both natural gas and hogged fuel consisting of bark and wood waste.

The original SE model that was based on survey data had 89% of the fuel in the form of hogged fuel, self produced and purchased, and 11% as natural gas. In actuality, most mills use only one type of fuel source, whereas, the original study resulted in an averaged model incorporating different fuel sources taken from primary survey information. There were three scenarios done for the "average" mill. The first scenario used LCI results to compare fuel use of 100% natural gas only versus the weighted average fuel use from the survey, referred to as the “as is” condition. The second scenario compared 100% self generated hogged fuel versus the “as is”, and the third scenario compared 100% self generated hogged fuel versus 100% natural gas.

2.10.2 Sensitivity analysis results

Table 2.20 is a summary of the three scenarios, with a partial list of air emissions for the SE (for a detailed listing see Appendix 2). In the first two scenarios, all natural gas versus “as is” and all self-produced hogged fuel versus “as is,” a negative percentage difference number indicates that the assumed fuel source contributes fewer emissions than the “as is” plywood model. A positive percentage difference means that the “as is” or original model contributes fewer emissions. In the third scenario, a negative number indicates that all natural gas contributes fewer emissions than all self-generated hogged fuel and a positive percentage number means that all self-produced hogged fuel contributes fewer emissions.

Table 2.20. Sensitivity Analysis for the SE. Fuel Use Comparison for Steam Production, Analyzing Natural gas, Hogged Fuel and "As Is" (Original Fuel Distribution).

				Scenario 1	Scenario 2	Scenario 3
	Natural Gas	Hogged Fuel	"As is", Original Fuel Distribution	Natural Gas Difference[1/] %	Hogged Fuel Difference[1/] %	Natural gas versus Hogged Fuel Difference[1/] %
Substance			lb/MSF 3/8-in basis			
CO	8.06E-01	3.73E+00	3.14E+00	-74	19	-74
CO_2 (fossil)	3.95E+02	2.04E+02	2.07E+02	91	-1	91
CO_2 (biofuel)[2/]	1.20E-01	5.16E+02	4.24E+02	-100	22	-100
NOx	1.82E+00	1.58E+00	1.53E+00	19	3	19
SO_2	7.31E-05	7.31E-05	7.31E-05	0	0	0
SOx	5.06E+00	2.16E+00	2.15E+00	135	0	135
VOC	2.88E-01	2.88E-01	2.88E-01	0	0	0
Non methane VOC	1.39E+00	6.24E-01	6.24E-01	123	0	123
Acetaldehyde	4.00E-03	4.74E-03	4.61E-03	-13	3	-13
Acrolein	1.91E-06	1.88E-06	7.88E-06	-76	-76	-76
Formaldehyde	2.63E-02	2.79E-02	2.76E-02	-5	1	-5
Methane	1.04E+00	4.93E-01	4.93E-01	112	0	112
Methanol	1.24E-01	1.24E-01	1.24E-01	0	0	0
Phenol	3.17E-02	4.15E-02	3.98E-02	-20	4	-20
Particulates	5.50E-01	5.78E-01	5.71E-01	-4	1	-4
Particulates (PM10)	1.33E-01	1.33E-01	1.33E-01	0	0	0
Particulates (unspecified)	1.38E-01	1.33E-01	1.33E-01	4	0	4

[1/] All comparisons are with the weighted average fuel use as indicated in the mill survey.
[2/] CO_2 biomass and non-fossil (which comes from SimaPro database and is most likely biomass) collaborated
Notes: Data are allocated emissions for plywood.

Carbon Dioxide (CO_2)

CO_2 fossil and biomass emissions are treated differently in LCI analyses because hogged fuel is a biomass fuel, and natural gas, a fossil fuel. CO_2 biomass is treated separately because it can be taken back up in biomass through photosynthesis and assumed to have a neutral impact on the environment, while CO_2 fossil emissions cannot be readily replenished as natural gas.

The following is a summary of the comparison results when fuel switching:

Methane (CH_4)

Methane emissions increased by more than 100% when natural gas was used compared to the "as is" model. All self-produced hogged fuel contributed about the same methane emissions as the "as is" model.

Nitrogen Oxides (NO_X)

NO_X emissions in all three scenarios are higher than in the "as is" model, with natural gas having the highest emissions. Natural gas emitted 19% more NO_X emissions than hogged fuel.

SO_2 and SO_X

There is no difference in SO_2 emissions between various fuel sources use for heat generation it is the value that was reported in the plant survey for the dryers. However, SO_X emissions are significantly higher than when using natural gas rather than hogged fuel.

VOC and Non Methane VOC

There is no difference in VOC emissions between various fuel sources for heat generation, although, non methane VOC is heavily influenced by natural gas combustion and is more than double those of scenarios 2 and 3. Hogged fuel use does not contribute any non-methane VOC. VOC emissions come from drying of veneer and also pressing emissions of plywood panel production.

HAP (hazardous air pollutants which include acetaldehyde, acrolein, formaldehyde, methanol, and phenol)

Using natural gas as a heat source decreased HAP emissions, with the exception of methanol that was not influenced by fuel inputs. In this analysis, when switching to all self-produced hogged fuel, acrolein was the only HAP emission that decreased.

Carbon Monoxide (CO)

Combustion of natural gas decreases CO emissions. When hogged fuel was used, CO emissions increased compared to the "as is" model and were 74% higher than when using natural gas.

Particulates

Particulate emissions were affected little by fuel switching indicating that both fuel sources contribute similar amounts of particulates. There was a slight indication that hogged fuel combustion generates contributes more particulates than combustion of all natural gas (1% more) and the “as is” (4% more) models.

2.11 CARBON BALANCE FOR PLYWOOD IN THE SOUTHEAST

2.11.1 Procedure

The element, carbon, was tracked throughout the production of softwood plywood. To track carbon, a checklist was devised to balance the inputs of carbon with the outputs to see if there was any carbon missing and to also follow carbon in the LCI of plywood, to see which product or emission carbon is assigned to. This analysis followed carbon from the inputs of material, electricity and fuels to its production of plywood as a product, its co-products and emissions into the environment. The percentage of carbon in wood was taken from a separate study done by R.A Birdsey, in 1994. The percentage was species specific and was manipulated to fit this study by allocating a percentage of the species used in the modeling of plywood manufacturing. For the southeast specifically, Birdsey’s publication did not separate southern pine species. Other carbon percentages in materials other than wood material were either taken from the Merck Index (1989) or were calculated by using atomic masses of each element from the chemical formula.

Table 2.21. Percentage of carbon in wood, Southeast.

	Conversion factor (1,2)	Species allocation	Density lb/ft^3	Roundwood (3) ft^3	Roundwood lb	Carbon lb	Carbon (lb carbon /lb roundwood) %
SE S. Pine	16.9	1	31.51	65.99	2079.34	1115.23	53.63

1/ Birdsey, R.A., 1994. Carbon storage and accumulation in US forest ecosystems. General technical Report WO-59. Washington, DC. USDA Forest Services.
2/ Skog, Kenneth E. and Geraldine A. Nicholson. 1998. Carbon cycling through wood products: the role of wood and paper products in carbon sequestration. FPJ 48(7/8): 75-83.
3/ 65.99 ft3 is the volume of wood needed to produce a MSF of plywood and the co-products.

2.11.2 Results

Table 2.21 describes the allocation of carbon percentages based on the species of wood. Table 2.22 includes a list of inputs and a LCI of plywood manufacturing with a carbon percentage and weight of each item that included carbon. The LCI is for plywood only and so the input of materials, electricity, and fuels are allocated to plywood, which is 48.5% by weight of the total outputs of materials. As a result, the inputs are also allocated so that 48.5% of the inputs by mass are used. So, the inputs are allocated correctly to obtain a carbon balance that has a difference to the LCI of 4.1%.

Table 2.22. Carbon Balance, Southeast

SE PLYWOOD – INPUTS			
Materials	**lb/MSF 3/8-in Basis**	**Carbon %**	**Carbon lb**
Roundwood (w/o bark)	2.08E+03	53.63	1.12E+03
Bark	1.24E+02	53.63	6.65E+01
Purchased			
Dry veneer	8.07E+00	53.63	4.33E+00
Green veneer	1.04E+01	53.63	5.60E+00
Purchased hogged fuel	4.58E+01	53.63	2.46E+01
Total Inputs	**2.27E+03**		**1.22E+03**
SE PLYWOOD – OUTPUTS			
Substance	**lb/MSF 3/8-in Basis**	**Carbon %**	**Carbon lb**
Acetaldehyde	4.61E-03	54.00	2.49E-03
Acetone	5.73E-03	64.27	3.68E-03
Alpha-pinene	8.63E-02	88.16	7.60E-02
Benzene	7.25E-04	92.25	6.69E-04
Beta-pinene	3.35E-02	88.16	2.95E-02
CO	2.87E+00	42.86	1.23E+00
CO_2 (biofuel)	4.24E+02	27.27	1.16E+02
Formaldehyde	4.17E-03	40.00	1.67E-03
Limonene	9.69E-03	88.16	8.54E-03
Methane	9.50E-05	75.00	7.13E-05
Methanol	1.24E-01	37.50	4.64E-02
Methyl ethyl ketone	7.69E-04	66.63	5.12E-04
Methyl I-butyl ketone	6.25E-04	71.94	4.50E-04
Naphthalene	4.85E-04	93.71	4.54E-04
Non methane VOC	5.19E-03	100.00	5.19E-03
Organic substances	3.35E-02	50.00	1.68E-02
Particulates	5.64E-01	53.63	3.02E-01
Particulates (PM10)	1.05E-01	53.63	5.63E-02
Phenol	9.56E-03	76.57	7.32E-03
THC as carbon	1.85E-01	100.00	1.85E-01
VOC	2.88E-01	100.00	2.88E-01
Solid Wastes			
Substance	**lb/MSF 3/8-in Basis**	**Carbon %**	**Carbon lb**
Solid waste	1.82E+01	51.23	9.32E+00
Subtotal	**4.57E+02**		**1.30E+02**

Plywood	1.08E+03	53.63	5.79E+02
Wood chips	6.45E+02	53.63	3.46E+02
Peeler core	1.12E+02	53.63	6.01E+01
Green clipping	1.73E+02	53.63	9.28E+01
Panel trim	6.06E+01	53.63	3.25E+01
Sawdust	4.19E+00	53.63	2.25E+00
Wood waste, sold	2.05E+01	53.63	1.10E+01
Wood waste (to boiler)	3.04E+01	53.63	1.63E+01
Total Output	**2.58E+03**		**1.27E+03**
DIFFERENCE %			**4.1**

Carbon is an important issue related to global warming in terms of its relation to CO_2 emissions. The carbon balance completed in this study will be used to track carbon in CORRIM II assessment of wood products. Knowing where carbon is in its various paths from a log to different products and co-products is important to fully understand the flow of carbon in biomass. This study can be used to increase the understanding of the carbon cycle by having a benchmark of carbon mass values for plywood manufacturing.

2.12 COST ANALYSIS OF SOUTHEAST PLYWOOD

A cost analysis was conducted for plywood production in the Southeast. The analysis took into account the cost of purchased materials and energy less income from sales of co-products and fuels to obtain the cost to manufacture 1.0 MSF 3/8-inch basis of plywood. This value was then compared to market price of a MSF 3/8-inch basis of plywood.

This analysis considered variable costs such as those associated with purchased electricity, hogged fuel, propane, natural gas and diesel fuel, logs, dry and green veneer, and phenol formaldehyde (PF) resin. It also examined fixed costs, including costs of capital, maintenance, labor, and overhead.

2.12.1 Production and Employees

A weighted average of production was obtained through primary surveys in the Southeast and then plotted against the number of employees (Figure 2.3). After the slope of the graph was obtained the weighted average value of production was used to determine the number of employees.

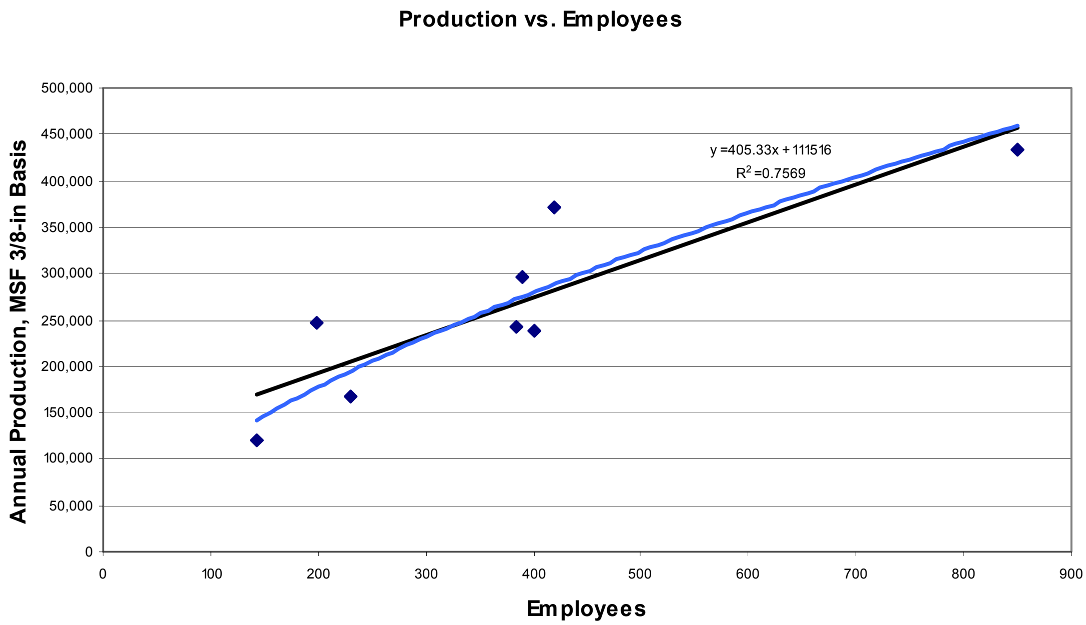


Figure 2.3. Annual Production vs. Number of Employees.

2.12.2 Variable Cost

Electricity prices vary from time to time and are influenced by the region of generation. For the Southeast, the average price per kWh in 2001 was 4.70 cents, with a range of 3.10 – 6.90 cents. For natural gas the price came from data taken in 1999. The reason 3-year-old information is used is because data from the winter of 2000-2001 was unusually high. As a result 1999 data was used to represent the current and expected price. The average price for natural gas/Dtherm was $2.60, with a range of $2.00-$4.90 (a Dtherm is equal to 1,000,000 Btu). Prices of wood material as logs and purchased green veneer came from Crow's Market Report, averaged for the year, 2002. Table 2.23 describes the variable cost on an annual basis and on a production basis of 1.0 MSF 3/8 inch.

Table 2.23. Variable Cost to Produce 1.0 MSF 3/8-in Basis of Plywood.

Variable Cost	Units	$/Unit	Units/Year	$/Year	Unit/MSF 3/8 in	$/MSF 3/8 in
Energy Consumption						
Electricity	kWh	0.047	34,958,355	1,643,043	122.04	5.74
Hogged fuel	lb	0.01	26,233,089	262,331	91.58	0.92
Liquid propane gas	gal	0.95	120,309	114,294	0.42	0.40
Natural gas	ft^3	2.64E-03	69,435,474	183,363	242.4	0.64
Gasoline	gal	1.35	48,697	65,740	0.17	0.23
Diesel	gal	1.27	77,341	97,837	0.27	0.34
Materials						
Logs	bf	0.45	73,892,896	32,882,339	257.96	114.79
Purchased dry veneer	M 3/8	193.51	2,346	453,976	8.19E-03	1.58
Purchased green veneer	M 3/8	170.47	3,036	517,606	1.06E-02	1.81
Resin	lb	0.45	5,637,335	2,536,801	19.68	8.86

2.12.3 Fixed Cost

Fixed costs are costs that are not dependent on production and can be a one-time annual cost. This analysis included fixed costs of capital, maintenance, labor and overhead. Table 2.24 details the fixed costs.

Table 2.24. Fixed Cost to Produce a MSF 3/8-in Basis of Plywood on an Annual Basis and on a MSF 3/8-in Basis.

Fixed Cost	Units	$/Unit	MSF 3/8-in Basis/Year	$/Year	$/MSF 3/8-in Basis
Capital	Annual			6,000,000	20.95
Interest on Capital	Annual			480,000	1.68
Maintenance	MSF	6	286,450	1,718,700	6.00
Labor	Annual	19,524,864		19,524,864	68.16
Overhead	MSF	10	286,450	2,864,500	10.00

The total cost adding both variable and fixed cost is equal to $242.09 per MSF 3/8-inch basis with the variable cost of energy and raw materials being $135.30 per MSF 3/8-inch basis and the fixed cost coming to $106.78 per MSF 3/8-inch basis.

2.12.4 Energy and Co-products Sold

Fuels sold include hogged fuel and wood waste. Also sold are the co-products wood chips, peeler core, green clippings, veneer downfall, panel trim, sawdust and dry veneer. These items are sold on a per ton oven dry weight basis. Table 2.25 lists the prices of these fuels and co-products sold.

Table 2.25. Energy and Co-products Sold in the Production of MSF 3/8-in Basis of Plywood.

Sold	Units	$/Unit	lb/Year	$/Year	MSF 3/8-in Basis	$/MSF 3/8-in Basis
Sold Energy						
Hogged fuel	lb	0.01	9,094,787	90,948	31.75	0.32
Wood waste	lb	0.005	5,866,495	29,332	20.48	0.10
Sold Co-products						
Wood chips	lb	0.03	184,814,659	5,544,440	645.19	19.36
Peeler core	lb	0.015	32,082,398	481,236	112	1.68
Green clippings	lb	0.015	49,481,369	742,221	172.74	2.59
Veneer downfall	lb	0.015	0.00	0.00	0	0.00
Panel trim	lb	0.015	17,350,275	260,254	60.57	0.91
Sawdust	lb	0.015	1,200,225	18,003	4.19	0.06
Dry veneer	lb	0.197	49,787	9,784	0.174	0.03

The selling price for hogged fuel is $10/green ton (50% moisture content) and the price for wood waste is $10/ton OD weight. Both of these prices were adjusted to a pound basis. For sold co-products, peeler core, green clippings, veneer downfall and panel trim was sold on a basis of $30/ton OD weight. Wood chips are mostly used for pulping and have a higher selling price at$60/ton OD weight. Similar to the sold energies, these two prices were converted to a pound basis. Dry veneer sold to other plywood or LVL plants has an averaged set price of $45.46/MSF 3/8-inch basis taken from Crow's Market Reports from 2002. The total amount of money obtained from selling the fuels and co-products are equal to $25.05/MSF 3/8-inch.

Taking the total cost and subtracting the sold energy and co-products, you come to the net cost equaling $217.03 to produce a MSF 3/8-inch basis of plywood. Crow's Market Report, publication has a price listing of 15/32-inch 3 ply, CD grade. For 2002, the price of plywood was averaged monthly and is equal to $214.67/MSF 3/8-inch basis of plywood. Subtracting the net cost to produce plywood by the selling price of plywood, results in a $ 2.37 loss per MSF 3/8-inch.

3.0 REFERENCES

APA—The Engineered Wood Association (APA). 2001. North America Structural Panel Production by Geography 2000. March, 1 p.

ATHENA™ Sustainable Materials Institute. 1993. Raw Material Balances, Energy Profiles and Environmental Unit Factor Estimates: Structural Wood Products. Forintek Canada Corp., Ottawa, Canada. March.

Birdsey, R.A. 1994. "Forest Products Measurements and Conversion Factors: with Special Emphasis on the US Pacific Northwest." College of Forest Resources, University of Washington. Seattle, WA. Institute of Forest Resources. Contribution No. 75. 161 p.

Briggs, David. 1994. Forest Products Measurements and Conversion Factors: with Special Emphasis on the US Pacific Northwest. College of Forest Resources, University of Washington. Seattle, Washington. Institute of Forest Resources. Contribution No. 75. 161 p.

Crow's Weekly Market Report for Lumber and Panel Products. 2002. CC Crows Publications, Inc. Portland, OR.

Ferrari, C.J. 2000. Life Cycle Assessment: Environmental Modeling of Plywood and Laminated Veneer Lumber Manufacturing. M.S. Thesis, Oregon State University. Corvallis, Oregon. Table 24, Appendix D. p.111.

Forest Products Laboratory. 1999. Wood Handbook: Wood as an Engineering Material. Gen. Tech. Rep. FPL-GTR-113. Madison, WI: U. S. Department of Agriculture, Forest Service, Forest Products Laboratory, 463 p.

Franklin Associates. 2001. The Franklin Associates Life Cycle Inventory Database. SimaPro5 Life-Cycle Assessment Software Package, version 36, 2001.

Franklin Associates. 2000. Wood Precombustion. SimaPro5 Life-Cycle Assessment Software Package, version 36, 2001.

Franklin Associates. 1998. Combustion of Wood in Industrial Boilers. SimaPro5 Life-Cycle Assessment Software Package, version 36, 2001.

Franklin Associates. 1998. Diesel Powered Industrial Equipment. SimaPro5 Life-Cycle Assessment Software Package, version 36, 2001.

Franklin Associates. 1998. Electricity from Coal. SimaPro5 Life-Cycle Assessment Software Package, version 36, 2001.

Franklin Associates. 1998. Electricity from DFO. SimaPro5 Life-Cycle Assessment Software Package, version 36, 2001.

Franklin Associates. 1998. Electricity from Hydropower. SimaPro5 Life-Cycle Assessment Software Package, version 36, 2001.

Franklin Associates. 1998. Electricity from Natural Gas. SimaPro5 Life-Cycle Assessment Software Package, version 36, 2001.

Franklin Associates. 1998. Electricity from Uranium. SimaPro5 Life-Cycle Assessment Software Package, version 36, 2001.

Franklin Associates. 1998. LPG Precombustion. SimaPro5 Life-Cycle Assessment Software Package, version 36, 2001.

Franklin Associates. 1998. Natural Gas Combustion in Industrial Boilers. SimaPro5 Life-Cycle Assessment Software Package, version 36, 2001.

Grist, C. and M. Karmous. 1988. Energy Use and Conservation in Oregon's Lumber and Wood Products Industry. Oregon Department of Energy, Salem Oregon.

Merck Index, Eleventh Edition. 1989. An Encyclopedia of Chemicals, Drugs, and Biologicals. Merck

National Association of Home Builders (NAHB). 2001. Material used in Building a 2085-Square-Foot Single Family Home. http://www.nahb.org/facts/economics/mub.html

PRé Consultants B.V. 2001. SimaPro5 Life-Cycle Assessment Software Package, version 36. Plotter 12, 3821 BB Amersfoort, The Netherlands. http://www.pre.nl/.

Skog, Kenneth E. and Geraldine A. Nicholson. 1998. Carbon cycling through wood products: the role of wood and paper products in carbon sequestration. FPJ 48(7/8): 75-83.

The Athena Sustainable Materials Institute (ATHENA™). 1993. Raw Material Balances, Energy Profiles and Environmental Unit Factor Estimates: Structural Wood Products. Forintek Canada Corp, Ottawa, Canada. March 1993.

United States Department of Energy (USDOE). 2000. State Electricity Profiles 2000. http://www.eia.doe.gov/cneaf/electricity/st_profiles/.

United States Environmental Protection Agency (EPA). 2001. Plywood Manufacturing. Chapter 10, Plywood and Composite Wood Products. AP-42.

United States Environmental Protection Agency (EPA). 1999. Wood Waste Combustion in Boilers. Chapter 1, External Combustion Sources AP-42.

APPENDIX 1: SOFTWOOD PLYWOOD MILL SURVEY

CORRIM SURVEY

The Consortium for Research on Renewable Industrial Materials (CORRIM II)

Softwood Plywood Mills

1-15-2001

The information from this survey will be used in a project by CORRIM II, a consortia comprised of universities, industry, and government groups. CORRIM is conducting a life-cycle assessment that will describe environmental influences of building materials and will focus our initial effort on structural building materials. CORRIM's objective is to acquire a database and produce life-cycle models of environmental performance for building materials. The database will be the basis for the scientific evaluation of feasible alternatives affecting the environmental releases and energy requirements of building materials through their life cycles. It is hoped that the output of the study will be used to competitively position wood in the marketplace over other types of building materials.

This CORRIM survey is designed specifically for softwood plywood mills. Questions will be concentrated on annual production, electricity production and usage, fuel use, material flows, and environmental emissions. We realize that you may not have all the information requested, especially when it comes to specific equipment/processing groups or what we call 'machine centers.' The data you are able to provide will be appreciated. Our intent is to maintain the confidentiality of the companies that supply the data for this survey.

Company: ______________________________

Facility Site (city, state): ______________________________

Should we have a follow-up question about the data, please provide the name and the following information for the contact in your company.

Name: ____________________ Title: ____________________

Telephone: ____________________ E-mail: ____________________

If you have questions about the survey, contact:
Eric Sakimoto
Graduate Research Assistant
Department of Forest Products
289 Richardson Hall
Oregon State University
Corvallis, OR 97331-5751
541-737-1299
eric.sakimoto@orst.edu

Annual Production (Please provide units of measurement if different than stated.)

1.	Plywood production in 1999 or 2000	MSF 3/8-inch basis	________
	Give production year		________
2.	Log volume consumption	BF	________
	Give log scale (i.e., Scribner, Doyle)		________
3.	Veneer		
	a. Purchased veneer:		
	i. Dry	MSF 3/8-inch basis	________
	ii. Green	MSF 3/8-inch basis	________
	b. Produced veneer:		
	i. Used in mill	MSF 3/8-inch basis	________
	ii. Sold	MSF 3/8-inch basis	________

Annual Energy Consumption (Please provide units of measurement if different.)

If you completed a 1999 Annual Fuel and Energy Survey for AF&PA, you may want to attach the survey and skip to the next section entitled "Other related information."

1.	Purchased electricity		KWH	________
2.	Purchased steam		lbs. (at temperature ^{o}F?)	________
	If you know fuel source used to generate steam, please state type, i.e. natural gas, hog fuel			________
3.	Coal		Tons	________
4.	Hog fuel	*Self-generated*	Tons	________
		Purchased	Tons	________
	Wood waste		Tons	________
	Residual fuel oil		42 Gal. Bbls.	________
	Distillate fuel oil		42 Gal. Bbls.	________
	Liquid propane gas		Gallons	________
	Natural gas		ft.^{3}	________
	Gasoline and kerosene		Gallons	________
	Diesel		Gallons	
	Other (Specify)			
	Less energy sold or transferred			
	a. Electricity		KWh	________
	b. Steam		lbs. (at temperature ^{o}F?)	________
	c. Hog fuel		Tons	________
	d. Wood waste		Tons	________

Note: please list fuel (i.e., propane, diesel, etc.) consumption in appropriate category above for use of fork lifts in yard and mill.

14. If you have a boiler, what is its heat source? Check appropriate box.

G Hogged fuel

G Oil

G Natural gas

G Other

Other Related Information on an annual basis

1. For dryer(s), check box for the heat source type and state the annual fuel consumption if known:

9	Steam	lbs.	____________
9	Natural gas direct-fired	$ft.^3$	____________
9	Hog fuel direct-fired	Tons (50% m.c.)	____________
9	Other (please specify)	________	____________

2. For dryer(s) specify the following:

- Type of dryer(s) (i.e. jet, longitudinal, cross flow) ____________
- How is dryer(s) heated (direct–such as a fuel cell, heat exchanger, etc.) ____________
- Do you recycle dryer exhaust, if so to where ____________

3. For dryer(s):

- Wood species dried and approximately percentage of total

wood species	% of total veneers	____________
wood species	% of total veneers	____________
wood species	% of total veneers	____________
Average moisture content into dryer	% ovendry basis	____________
Average moisture content out of dryer	% ovendry basis	____________
Percentage of redry	%	____________

4. For hot press(es), check box for heat source type and state the annual fuel consumption if known:

9 Steam lbs. ____________

9 Oil 42 gal. bbls. ____________

9 Electricity KWH ____________

9 Other ____________ ____________

5. Formulation and usage of resin, fillers, and other components.		
Component type	range % solids by weight	total annual use (lbs.) on a solids or wet basis–please state basis
phenol formaldehyde		
extender and filler		
catalyst (NaOH)		
water		
other (please specify)		

6. Annual water use (check source and give amount):

9 Municipal water source Gallons ____________

9 Well water source Gallons ____________

9 Recycled water Gallons ____________

7a. Transportation method and distance to deliver logs (check method(s)):

(note - if you only purchase veneer please skip to question 7b.)

Log delivery method % of Total

9 Truck ____________

9 Rail ____________

9 Other ____________

Total= 100%

Average distance to deliver logs Miles ____________

7b. Transportation method and distance to deliver veneer

Veneer delivery method — % of Total

9 Truck ____________

9 Rail ____________

9 Other ____________

Total= 100%

Average distance of delivery for veneer — Miles ____________

8. Transportation method used to deliver resin

9 Truck ____________

9 Rail ____________

9 Other ____________

Average distance to deliver resin to mill — Miles ____________

Annual Material Flow

This is a general material flow survey for plywood mills. This survey is designed to trace all wood components from the log that are generated during production. Please check box that pertains to your mill and answer related questions.

G **Debarking and Bucking**

1. Bark produced annually — Tons ____________

2. Wood chips produced — Tons ____________

G **Peeling and Chipping** (give unit used)

1.	Volume of peeler core	ft^3., pieces, etc.	________
2.	Green clippings	Tons	________

G **Veneer Dryer**

1.	Veneer downfall	Tons	________

G **Lay-up**

1.	Lay-up scrap	Tons	________
2.	Resin use	lbs	________

G **Sawing and Trimming**

1.	Panel trim	Tons	________
2.	Saw dust	Tons	________

Emission Control Device and Environmental Emission

The following is a chart of emission control devices and on page seven (7) is a listing of chemical compounds that are observed and/or permitted. Please fill in all information related to the control devices. Then list all compounds that are collected and known for the mill from all control device sources. If you recently applied for an air permit, use those numbers. Fill in all that apply and for which you have data. If you have more than five devices, please make a copy of this page and the next, change numbers from 1 to 6, i.e. ECD 1 to ECD 6, complete form and attach.

Emission Control Device (ECD) - Electricity, Fuel Usage and Emission Output

	ECD 1	ECD 2	ECD 3	ECD 4	ECD 5
Equipment type controlled (boiler, dryer, press, etc.)					
Type of device (i.e., RTO, RCO, Scrubber, WESP, cyclone, baghouse, etc.)					
Manufacturer and year installed					

ECD exhaust temperature (°F) and flow rate (acfm)					
Electricity use in % of total mill use or kWh, please state units					
Natural gas use in % of total mill use or ft.³, please state units					

Annual Emissions to Air (provide data for same device identified on prior page; please provide unit of measurement for each.)					
Organic Compound	**ECD 1**	**ECD 2**	**ECD 3**	**ECD 4**	**ECD 5**
Equipment type controlled (boiler, dryer, press, etc.)					
Units	**Tons/year**	**Tons/year**	**Tons/year**	**Tons/year**	**Tons/year**
CO_2					
CO					
NO_X					
SO_2					
VOC					
Particulate					
PM10					
Acrolien*					
Acetaldehyde*					
Propionaldehyde*					
Formaldehyde*					
Methanol*					
Phenol*					
Water Vapor					
*** HAPS; you may want to provide total HAPS rather than specific chemicals**					
Other (Please Specify					

Solid Emissions From All Known Sources (please provide units of measurement)		
Emission	**Quantity (i.e., tons, lbs.)**	**Method of disposal or end use (i.e., land fill, landscaping, sewer)**
Bark/wood waste		
Boiler ash and fly ash		
Recovered particulates from pollution abatement equipment		
Water (BOD, COD, suspended solids, etc.)		
Other (please specify)		

Machine Center Breakdown for Electricity and Fuel Use

Fill in all that apply and for which you have data. If you don't have a given machine center such as a co-generator, draw a line through that row and write none.

	Model/Type	**Annual Electricity Use**	**Fuel Use**
Machine Center	**Year Installed**	**Million KWH or % of Total Electricity Use for Mill**	**% of Total Use for Mill**
Boiler			
Co-generator			
Debarker			
Log conditioning			
Peeling and Clipping			
Dryer			
Lay-Up			
Press			
Trimming			

APPENDIX 2: SENSITIVITY ANALYSES

PNW Sensitivity Analysis LCI full – All Natural Gas versus Original Setup (90.5% Hogged Fuel; 9.5% Natural Gas).

All Natural Gas				90.5% Hogged Fuel 9.5% Natural Gas		
Substance	**lb/MSF 3/8-inch**	**kg/m^3**	**Difference %**	**Substance**	**lb/MSF 3/8-inch**	**kg/m^3**
Acetaldehyde	1.16E-02	5.95E-03	-3	Acetaldehyde	1.19E-02	6.10E-03
Acetone	5.11E-03	2.62E-03	0	Acetone	5.11E-03	2.62E-03
Acrolein	8.75E-07	4.49E-07	0	Acrolein	8.75E-07	4.49E-07
Aldehydes	1.10E-03	5.64E-04	28	Aldehydes	8.56E-04	4.39E-04
Alpha-pinene	7.69E-02	3.94E-02	0	Alpha-pinene	7.69E-02	3.94E-02
Ammonia	2.03E-04	1.04E-04	-58	Ammonia	4.85E-04	2.49E-04
As	1.03E-06	5.28E-07	-92	As	1.26E-05	6.46E-06
Ba			-100	Ba	5.82E-04	2.98E-04
Be	1.04E-07	5.33E-08	2	Be	1.02E-07	5.23E-08
Benzene	9.13E-06	4.68E-06	-98	Benzene	4.86E-04	2.49E-04
Beta-pinene	2.99E-02	1.53E-02	0	Beta-pinene	2.99E-02	1.53E-02
Cd	6.19E-07	3.17E-07	9	Cd	5.69E-07	2.92E-07
Cl_2	2.44E-06	1.25E-06	-100	Cl_2	1.03E-03	5.28E-04
CO	5.12E-01	2.62E-01	-75	CO	2.08E+00	1.07E+00
CO_2 (fossil)	1.71E+02	8.77E+01	120	CO_2 (fossil)	7.78E+01	3.99E+01
CO_2 (biomass)	4.85E-02	2.49E-02	-100	CO_2 (biomass)	2.85E+02	1.46E+02
Cobalt	7.88E-07	4.04E-07	6	Cobalt	7.44E-07	3.81E-07
Cr	1.32E-06	6.77E-07	-82	Cr	7.44E-06	3.81E-06
Cumene	7.44E-05	3.81E-05	0	Cumene	7.44E-05	3.81E-05
Dichloromethane	1.38E-06	7.07E-07	0	Dichloromethane	1.37E-06	7.02E-07
Dioxin (TEQ)	1.84E-12	9.43E-13	1	Dioxin (TEQ)	1.83E-12	9.38E-13
Fe			-100	Fe	5.82E-04	2.98E-04
Formaldehyde	3.66E-02	1.88E-02	-2	Formaldehyde	3.74E-02	1.92E-02
HCl	1.74E-03	8.92E-04	0	HCl	1.73E-03	8.87E-04
HF	2.41E-04	1.24E-04	0	HF	2.40E-04	1.23E-04
Hg	7.25E-07	3.72E-07	2	Hg	7.13E-07	3.65E-07
K			-100	K	1.03E-01	5.28E-02
Kerosene	9.81E-06	5.03E-06	-10	Kerosene	1.09E-05	5.59E-06
Limonene	8.63E-03	4.42E-03	0	Limonene	8.63E-03	4.42E-03
Metals	1.93E-05	9.89E-06	62	Metals	1.19E-05	6.10E-06
Methane	4.84E-01	2.48E-01	127	Methane	2.13E-01	1.09E-01
Methanol	1.36E-01	6.97E-02	0	Methanol	1.36E-01	6.97E-02

Methyl ethyl ketone	6.81E-04	3.49E-04	0	Methyl ethyl ketone	6.81E-04	3.49E-04
Methyl i-butyl ketone	5.58E-04	2.86E-04	0	Methyl i-butyl ketone	5.58E-04	2.86E-04
Mn	2.71E-06	1.39E-06	-100	Mn	1.19E-03	6.10E-04
N-nitrodimethylamine	7.31E-08	3.75E-08	0	N-nitrodimethylamine	7.31E-08	3.75E-08
N_2O	1.96E-04	1.00E-04	0	N_2O	1.96E-04	1.00E-04
Na			-100	Na	2.38E-03	1.22E-03
Naphthalene	7.63E-08	3.91E-08	-100	Naphthalene	3.18E-04	1.63E-04
Ni	8.88E-06	4.55E-06	-89	Ni	8.19E-05	4.20E-05
Non methane VOC	8.13E-01	4.17E-01	147	Non methane VOC	3.29E-01	1.69E-01
NO_X	9.63E-01	4.94E-01	48	NO_X	6.50E-01	3.33E-01
Organic substances	1.48E-03	7.59E-04	-94	Organic substances	2.28E-02	1.17E-02
Particulates	3.65E-01	1.87E-01	-4	Particulates	3.81E-01	1.95E-01
Particulates (PM10)	2.26E-01	1.16E-01	0	Particulates (PM10)	2.27E-01	1.16E-01
Particulates (unspecified)	2.70E-02	1.38E-02	7	Particulates (unspecified)	2.52E-02	1.29E-02
Pb	1.43E-06	7.33E-07	-99	Pb	1.60E-04	8.20E-05
Phenol	2.49E-02	1.28E-02	-18	Phenol	3.02E-02	1.55E-02
Sb	3.14E-07	1.61E-07	6	Sb	2.98E-07	1.53E-07
Se	2.64E-06	1.35E-06	-3	Se	2.71E-06	1.39E-06
SO_2	8.25E-04	4.23E-04	0	SO_2	8.25E-04	4.23E-04
SO_X	2.49E+00	1.28E+00	136	SO_X	1.06E+00	5.43E-01
Tetrachloroethene	3.31E-07	1.70E-07	0	Tetrachloroethene	3.30E-07	1.69E-07
Tetrachloromethane	5.54E-07	2.84E-07	-5	Tetrachloromethane	5.85E-07	3.00E-07
THC as carbon	1.65E-01	8.46E-02	0	THC as carbon	1.65E-01	8.46E-02
Trichloroethene	3.28E-07	1.68E-07	0	Trichloroethene	3.27E-07	1.68E-07
VOC	6.69E-01	3.43E-01	0	VOC	6.69E-01	3.43E-01
Zn			-100	Zn	5.82E-04	2.98E-04

PNW Sensitivity Analysis LCI full – All Hogged Fuel versus Original Setup (90.5% Hogged Fuel; 9.5% Natural Gas).

All Self-Generated Hogged Fuel				90.5% HOGGED FUEL 9.5% NATURAL GAS		
Substance	**lb/MSF 3/8-in**	**kg/m^3**	**Difference %**	**Substance**	**lb/MSF 3/8-in**	**kg/m^3**
Acetaldehyde	1.20E-02	6.15E-03	1	Acetaldehyde	1.19E-02	6.10E-03
Acetone	5.11E-03	2.62E-03	0	Acetone	5.11E-03	2.62E-03
Acrolein	8.56E-07	4.39E-07	-2	Acrolein	8.75E-07	4.49E-07
Aldehydes	8.13E-04	4.17E-04	-5	Aldehydes	8.56E-04	4.39E-04
Alpha-pinene	7.69E-02	3.94E-02	0	Alpha-pinene	7.69E-02	3.94E-02
Ammonia	1.96E-04	1.00E-04	-60	Ammonia	4.85E-04	2.49E-04
As	1.51E-05	7.74E-06	20	As	1.26E-05	6.46E-06
Ba	7.13E-04	3.65E-04	22	Ba	5.82E-04	2.98E-04
Be	9.25E-08	4.74E-08	-9	Be	1.02E-07	5.23E-08
Benzene	5.92E-04	3.03E-04	22	Benzene	4.86E-04	2.49E-04
Beta-pinene	2.99E-02	1.53E-02	0	Beta-pinene	2.99E-02	1.53E-02
Cd	3.96E-07	2.03E-07	-30	Cd	5.69E-07	2.92E-07
Cl_2	1.26E-03	6.46E-04	22	Cl_2	1.03E-03	5.28E-04
CO	2.48E+00	1.27E+00	19	CO	2.08E+00	1.07E+00
CO_2 (biomass)	3.40E+02	1.74E+02	28	CO_2 (biomass)	2.65E+02	1.36E+02
CO_2 (fossil)	6.00E+01	3.08E+01	-23	CO_2 (fossil)	7.78E+01	3.99E+01
Cobalt	5.79E-07	2.97E-07	-22	Cobalt	7.44E-07	3.81E-07
Cr	8.56E-06	4.39E-06	15	Cr	7.44E-06	3.81E-06
Cumene	7.44E-05	3.81E-05	0	Cumene	7.44E-05	3.81E-05
Dichloromethane	1.30E-06	6.66E-07	-5	Dichloromethane	1.37E-06	7.02E-07
Dioxin (TEQ)	1.75E-12	8.97E-13	-4	Dioxin (TEQ)	1.83E-12	9.38E-13
Fe	7.13E-04	3.65E-04	22	Fe	5.82E-04	2.98E-04
Formaldehyde	3.76E-02	1.93E-02	1	Formaldehyde	3.74E-02	1.92E-02
HCl	1.66E-03	8.51E-04	-4	HCl	1.73E-03	8.87E-04
HF	2.30E-04	1.18E-04	-4	HF	2.40E-04	1.23E-04
Hg	6.63E-07	3.40E-07	-7	Hg	7.13E-07	3.65E-07
K	1.26E-01	6.46E-02	22	K	1.03E-01	5.28E-02
Kerosene	9.44E-06	4.84E-06	-14	Kerosene	1.09E-05	5.59E-06
Limonene	8.63E-03	4.42E-03	0	Limonene	8.63E-03	4.42E-03
Metals	1.02E-05	5.23E-06	-14	Metals	1.19E-05	6.10E-06
Methane	1.67E-01	8.56E-02	-22	Methane	2.13E-01	1.09E-01
Methanol	1.36E-01	6.97E-02	0	Methanol	1.36E-01	6.97E-02
Methyl ethyl ketone	6.81E-04	3.49E-04	0	Methyl ethyl ketone	6.81E-04	3.49E-04
Methyl i-butyl ketone	5.58E-04	2.86E-04	0	Methyl i-butyl ketone	5.58E-04	2.86E-04
Mn	1.46E-03	7.48E-04	22	Mn	1.19E-03	6.10E-04

N-nitrodimethylamine	7.00E-08	3.59E-08	-4	N-nitrodimethylamine	7.31E-08	3.75E-08
N_2O	1.86E-04	9.53E-05	-5	N_2O	1.96E-04	1.00E-04
Na	2.91E-03	1.49E-03	22	Na	2.38E-03	1.22E-03
Naphthalene	3.88E-04	1.99E-04	22	Naphthalene	3.18E-04	1.63E-04
Ni	9.63E-05	4.94E-05	18	Ni	8.19E-05	4.20E-05
Non methane VOC	3.64E-01	1.87E-01	11	Non methane VOC	3.29E-01	1.69E-01
NO_X	8.50E-01	4.36E-01	31	NO_X	6.50E-01	3.33E-01
Organic substances	2.76E-02	1.41E-02	21	Organic substances	2.28E-02	1.17E-02
Particulates	3.85E-01	1.97E-01	1	Particulates	3.81E-01	1.95E-01
Particulates (PM10)	2.26E-01	1.16E-01	0	Particulates (PM10)	2.27E-01	1.16E-01
Particulates (unspecified)	2.39E-02	1.23E-02	-5	Particulates (unspecified)	2.52E-02	1.29E-02
Pb	1.96E-04	1.00E-04	22	Pb	1.60E-04	8.20E-05
Phenol	3.14E-02	1.61E-02	4	Phenol	3.02E-02	1.55E-02
Sb	2.41E-07	1.24E-07	-19	Sb	2.98E-07	1.53E-07
Se	2.46E-06	1.26E-06	-9	Se	2.71E-06	1.39E-06
SO_2	8.25E-04	4.23E-04	0	SO_2	8.25E-04	4.23E-04
SO_X	8.06E-01	4.13E-01	-24	SO_X	1.06E+00	5.43E-01
Tetrachloroethene	3.14E-07	1.61E-07	-5	Tetrachloroethene	3.30E-07	1.69E-07
Tetrachloromethane	4.63E-07	2.37E-07	-21	Tetrachloromethane	5.85E-07	3.00E-07
THC as carbon	1.65E-01	8.46E-02	0	THC as carbon	1.65E-01	8.46E-02
Trichloroethene	3.13E-07	1.60E-07	-4	Trichloroethene	3.27E-07	1.68E-07
VOC	6.69E-01	3.43E-01	0	VOC	6.69E-01	3.43E-01
Zn	7.13E-04	3.65E-04	22	Zn	5.82E-04	2.98E-04

PNW Sensitivity Analysis LCI full – All Hogged Fuel versus Natural Gas

All Natural Gas				All Self-Generated Hogged Fuel		
Substance	lb/MSF 3/8-in	kg/m^3	Difference %	Substance	lb/MSF 3/8-in	kg/m^3
Acetaldehyde	1.16E-02	5.95E-03	-4	Acetaldehyde	1.20E-02	6.15E-03
Acetone	5.11E-03	2.62E-03	0	Acetone	5.11E-03	2.62E-03
Acrolein	8.75E-07	4.49E-07	2	Acrolein	8.56E-07	4.39E-07
Aldehydes	1.10E-03	5.64E-04	35	Aldehydes	8.13E-04	4.17E-04
Alpha-pinene	7.69E-02	3.94E-02	0	Alpha-pinene	7.69E-02	3.94E-02
Ammonia	2.03E-04	1.04E-04	4	Ammonia	1.96E-04	1.00E-04
As	1.03E-06	5.28E-07	-93	As	1.51E-05	7.74E-06
Ba			-100	Ba	7.13E-04	3.65E-04
Be	1.04E-07	5.33E-08	12	Be	9.25E-08	4.74E-08
Benzene	9.13E-06	4.68E-06	-98	Benzene	5.92E-04	3.03E-04
Beta-pinene	2.99E-02	1.53E-02	0	Beta-pinene	2.99E-02	1.53E-02
Cd	6.19E-07	3.17E-07	57	Cd	3.96E-07	2.03E-07
Cl_2	2.44E-06	1.25E-06	-100	Cl_2	1.26E-03	6.46E-04
CO	5.12E-01	2.62E-01	-79	CO	2.48E+00	1.27E+00
CO_2 (biomass)	4.85E-02	2.49E-02	-100	CO_2 (biomass)	3.40E+02	1.74E+02
CO_2 (fossil)	1.71E+02	8.77E+01	185	CO_2 (fossil)	6.00E+01	3.08E+01
Cobalt	7.88E-07	4.04E-07	36	Cobalt	5.79E-07	2.97E-07
Cr	1.32E-06	6.77E-07	-85	Cr	8.56E-06	4.39E-06
Cumene	7.44E-05	3.81E-05	0	Cumene	7.44E-05	3.81E-05
Dichloromethane	1.38E-06	7.07E-07	6	Dichloromethane	1.30E-06	6.66E-07
Dioxin (TEQ)	1.84E-12	9.43E-13	5	Dioxin (TEQ)	1.75E-12	8.97E-13
Fe			-100	Fe	7.13E-04	3.65E-04
Formaldehyde	3.66E-02	1.88E-02	-3	Formaldehyde	3.76E-02	1.93E-02
HCl	1.74E-03	8.92E-04	5	HCl	1.66E-03	8.51E-04
HF	2.41E-04	1.24E-04	5	HF	2.30E-04	1.18E-04
Hg	7.25E-07	3.72E-07	9	Hg	6.63E-07	3.40E-07
K			-100	K	1.26E-01	6.46E-02
Kerosene	9.81E-06	5.03E-06	4	Kerosene	9.44E-06	4.84E-06
Limonene	8.63E-03	4.42E-03	0	Limonene	8.63E-03	4.42E-03
Metals	1.93E-05	9.89E-06	89	Metals	1.02E-05	5.23E-06
Methane	4.84E-01	2.48E-01	190	Methane	1.67E-01	8.56E-02
Methanol	1.36E-01	6.97E-02	0	Methanol	1.36E-01	6.97E-02
Methyl ethyl ketone	6.81E-04	3.49E-04	0	Methyl ethyl ketone	6.81E-04	3.49E-04
Methyl i-butyl ketone	5.58E-04	2.86E-04	0	Methyl i-butyl ketone	5.58E-04	2.86E-04

Mn	2.71E-06	1.39E-06	-100	Mn	1.46E-03	7.48E-04
N-nitrodimethylamine	7.31E-08	3.75E-08	4	N-nitrodimethylamine	7.00E-08	3.59E-08
N_2O	1.96E-04	1.00E-04	5	N_2O	1.86E-04	9.53E-05
Na			-100	Na	2.91E-03	1.49E-03
Naphthalene	7.63E-08	3.91E-08	-100	Naphthalene	3.88E-04	1.99E-04
Ni	8.88E-06	4.55E-06	-91	Ni	9.63E-05	4.94E-05
Non methane VOC	8.13E-01	4.17E-01	123	Non methane VOC	3.64E-01	1.87E-01
NO_X	9.63E-01	4.94E-01	13	NO_X	8.50E-01	4.36E-01
Organic substances	1.48E-03	7.59E-04	-95	Organic substances	2.76E-02	1.41E-02
Particulates	3.65E-01	1.87E-01	-5	Particulates	3.85E-01	1.97E-01
Particulates (PM10)	2.26E-01	1.16E-01	0	Particulates (PM10)	2.26E-01	1.16E-01
Particulates (unspecified)	2.70E-02	1.38E-02	13	Particulates (unspecified)	2.39E-02	1.23E-02
Pb	1.43E-06	7.33E-07	-99	Pb	1.96E-04	1.00E-04
Phenol	2.49E-02	1.28E-02	-21	Phenol	3.14E-02	1.61E-02
Sb	3.14E-07	1.61E-07	31	Sb	2.41E-07	1.24E-07
Se	2.64E-06	1.35E-06	7	Se	2.46E-06	1.26E-06
SO_2	8.25E-04	4.23E-04	0	SO_2	8.25E-04	4.23E-04
SO_X	2.49E+00	1.28E+00	209	SO_X	8.06E-01	4.13E-01
Tetrachloroethene	3.31E-07	1.70E-07	5	Tetrachloroethene	3.14E-07	1.61E-07
Tetrachloromethane	5.54E-07	2.84E-07	20	Tetrachloromethane	4.63E-07	2.37E-07
THC as carbon	1.65E-01	8.46E-02	0	THC as carbon	1.65E-01	8.46E-02
Trichloroethene	3.28E-07	1.68E-07	5	Trichloroethene	3.13E-07	1.60E-07
VOC	6.69E-01	3.43E-01	0	VOC	6.69E-01	3.43E-01
Zn				Zn	7.13E-04	3.65E-04