CORRIM: Phase I Final Report

Module G

GLUED LAMINATED BEAMS – PACIFIC NORTHWEST AND SOUTHEAST

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Prepared by:

Maureen E. Puettmann
James B. Wilson[1]

[1] Puettmann is Research Associate, and Wilson is Principal Investigator and Professor, Department of Wood Science and Engineering, Oregon State University, Oregon, USA 97331-5751.

EXECUTIVE SUMMARY

The objective of this study was to develop a life cycle inventory (LCI) using CORRIM Research Guidelines (CORRIM 2001) for the production of softwood glued laminated (glulam) beams as manufactured in the Pacific Northwest (Oregon and Washington) and the southeast (Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, and Texas) Unites States. Glulam is an engineered, stress-rated wood product that consists of two or more layers of lumber that are glued together with the grain of all layers parallel to the length. The lumber is joined end-to-end, edge-to-edge, and face-to-face. The size of glulam is limited only by the capabilities of the manufacturing plant and the transportation system. Wood species used for lumber to make glulam in the Pacific Northwest (PNW) include Douglas-fir, western larch and Alaskan yellow cedar. Wood species used to make glulam in the southeast (SE) can be any combination of longleaf, shortleaf, loblolly, and slash pines (referred to as Southern Pine). Glulam plants were surveyed in these two regions to record all inputs and outputs associated with the production process. Input data consisted of lumber, resin, electricity, and fuel inputs to the glulam manufacturing plant. Output data consisted of emissions to air, water and land and products and co-products produced.

Glulam manufacturing plants in the PNW and in the SE were surveyed. The Year 2000 production for these plants represented 70% and 43%, respectively, of total production within each region. The surveyed plants produced 78 million board feet (MMBF) (2.13E+03 thousand cubic feet) in the PNW and 60 million board feet (MMBF) (1.60E+03 thousand cubic feet) in the SE. Plant operations included both radio frequency and cold cure processes, representing 81% and 19% for the PNW and 47% and 53 % for the SE, respectively in terms of regional production.

The process of producing glulam was modeled in SimaPro5.0 as a single box process. The glulam model imported the four-unit process for the production of PNW lumber and SE lumber (Milota 2003a; 2003b) and a single unit process for producing phenol-resorcinol-formaldehyde or melamine-urea-formaldehyde resins. The data is presented as average values derived by weighting production of each mill surveyed.

As expected the major portion of energy consumption (generated with fuel) was in manufacturing kiln-dried lumber and resin. PNW lumber production used 78% of the total heat energy for glulam manufacturing, of which 58% was provided by hogged fuel, and 42% by natural gas. The remaining 22% energy use occurred in glulam production. On-site energy consumption in glulam production was 1.58E+07 BTU/MCF for processing, of which 85% was from hogged fuel and the other 15% was from natural gas combustion. This energy was used either for re-drying of lumber or facility heating to maintain required conditions for glulam beam production.

On-site glulam production in the SE used 2.23E+07 BTU/MCF of heat, all from natural gas. This heat energy was used for facility heating and re-drying lumber of greater than 19% moisture content. Hogged fuel was used off-site as boiler inputs in SE lumber manufacturing and contributed 4.05E+07 BTU/MCF of heat energy to the glulam process. In contrast to the PNW, the SE glulam process total heat energy requirement was 6.26E+07 BTU/MCF of which 65% was consumed off-site in lumber production and 35% was consumed on-site in glulam production.

The on-site electricity requirement per MCF of glulam (with co-product) was 2,390 kWh for the PNW and 2,800 kWh for the SE. As such, assuming the weighted average annual production of 2.13E+03 MCF in the PNW and 1.60E+03 MCF in SE, the electricity bills for the plants surveyed are substantial; at $0.0425 and $0.047 per kWh, respectively, the annual bills for these hypothetical mills would be $216,355 for the PNW and $210,560 for the SE. With the projected cost increase of both natural gas and electricity, means to become more energy efficient will receive greater attention.

The PNW and SE had wood recoveries of 82% as determined by the output of wood in the form of glulam beams as a percentage of the wood input (lumber) to the plant. Wood inputs for production of 1000 ft^3 of glulam and co-products in the PNW were 27,300 lb (oven-dried basis) of planed-dried lumber, and 9,300 lb (oven-dried basis) of rough-green lumber. In the SE region, 41,770 lb (oven-dried basis) of planed dried lumber was required of which 15% needed to be re-dried on-site because the moisture content was greater than 17%.

Emissions and emissions mitigation are becoming increasingly important in terms of plant operations and manufacturing costs. Life-cycle inventory emissions are presented for four scenarios: 1) total emissions including those generated on-site for glulam, lumber, and resin, 2) scenario #1 excluding electricity, 3) scenario #1 excluding resin, and 4) production emissions generated on-site for glulam production (survey collected data). Allocations were made on a mass basis for products and co-products produced in the glulam manufacturing process. Therefore, inputs as collected by surveys and outputs (emissions) generated by the SimaPro model are allocated at 82% for PNW and SE glulam beam production. The remaining 18% of inputs and subsequent outputs are allocated to the co-products and are no longer a part of the glulam system.

Carbon dioxide (CO_2), a greenhouse gas of global concern, is generated by combustion of fuels. Lumber production burdens had a significant contribution to the glulam manufacturing process and a major portion of the heat generation for the production of lumber was based upon wood and bark hogged fuel. Emitted CO_2 from the combustion of wood and bark hogged fuel may not increase total atmospheric CO_2, because emissions are offset by the uptake of CO_2 by re-growing biomass. Emitted CO_2 from this source is generally not counted as greenhouse gas emissions because it is considered part of the life cycle (EPA 1999). Total CO_2 biomass (see Appendix 1) emissions from the combustion of hogged fuel were 68%, and 61% of the total CO_2 emissions for glulam production, for the PNW and SE, respectively. CO_2 biomass values were obtained from the "Wood into Industrial Boilers" process from the Franklin Associates database (FAL 2001).

The quality of the data was considered very good based on the production totals representing each region surveyed. Based on the amount of data for the participating manufacturers for each region, a comparison of values 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 the findings.

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1.0 PACIFIC NORTHWEST GLULAM BEAMS

1.1 INTRODUCTION

Structural glued laminated timber (glulam) is one of the oldest glued engineered wood products dating back to the late 1800s. Their uses are as structural concealed or exposed beams and columns in residential and commercial construction, warehouse roof beams and purlins, church arches, and girders and deck panels for timber bridges. Glulam beams come in a variety of sizes with production based on nominal[2] board feet[3], and sold by retailers on a linear-foot basis. Over one-half of US glulam goes to new residential and remodeling uses, representing 52% (APA 2001) of all glulam produced. The next largest segment is the nonresidential market representing 38%. The remainder goes into industrial (2%) and export (8%) markets. Glulam is made of various species in the Pacific Northwest (PNW) region with Douglas-fir dominating; western larch and Alaskan yellow cedar are also used. This report focuses on production practices in Oregon and Washington. The total annual glulam production for the region was 111 million board feet (MMBF) (APA 2001) in 2000, representing 31% of all US glulam production.

Primary data was collected through a survey of glulam manufacturers in the region. To conduct the survey, glulam plants in Oregon and Washington were preliminarily screened and identified based on their production capability and representativeness of the industry. Three plants agreed to participate in the survey. Manufacturing plants provided data in terms of glulam and co-product production, raw materials, electricity and fuel use, and emissions. The glulam producers surveyed represent 70% of the region's production. Total annual production from producers surveyed was 78 million board feet (MMBF) (nominal).

This report documents the life-cycle inventory (LCI) of glulam beam manufacture based on softwood resources from the PNW region. Primary data was collected through a survey of glulam manufacturers (Appendix 3), while secondary data was obtained from impacts associated with the manufacture and delivery of electricity and all fuels (FAL 2001; PRé Consultants 2001; EIA 2001), lumber production (Milota 2004a, 2004b) and with the manufacture and delivery of resin (Nilsson 2001).

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[2] Nominal size-The size designation for most lumber. In lumber, the nominal size usually is greater than the actual dimension; a kiln dried 2x4 (nominal) is surfaced to 1-1/2 x 3-1/2 inches (actual).
[3] Board foot (BF)-The basic unit of measurement for lumber in the US. One board foot is equal to a 1-inch board 12 inches in width and 1 foot in length.

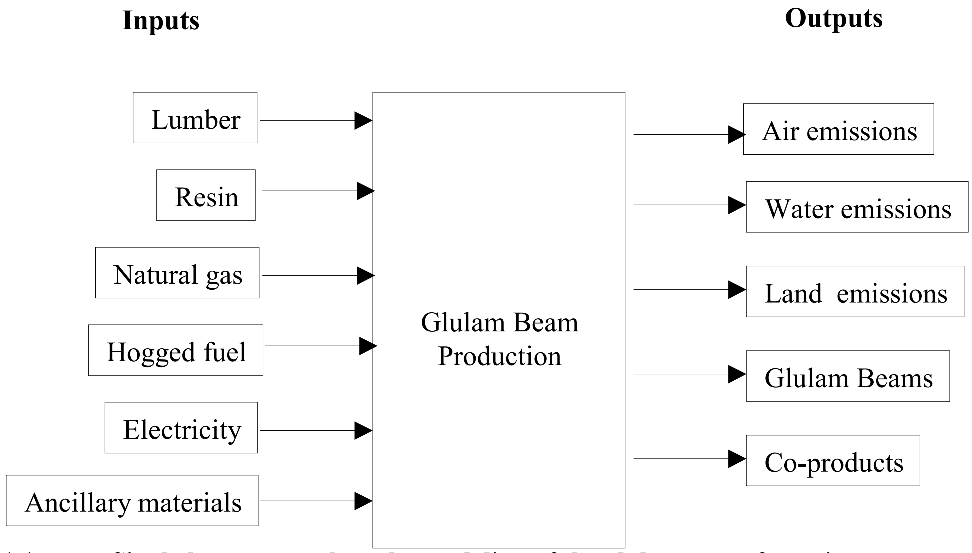

Figure 1.1. Single box approach to the modeling of the glulam manufacturing process.

A single unit process approach was taken in modeling the LCI of the glulam process (Figure 1.1). A typical manufacturing process consists of lumber drying (when purchasing green lumber), grading, trimming, finger jointing or end jointing, planing, face bonding, planing, and finishing and fabrication. Before shipping, each beam is typically individually wrapped for protection from weather.

The functional unit used throughout this report is 1000 cubic feet (MCF[4]), actual volume of glulam beams, which includes lumber and resin. The system boundary is gate to gate, i.e., from the point at which raw material enters the mill to the production of the product (glulam) and co-products[5] (shavings and trimmings). A mass-based allocation was used for products and co-products to assign environmental burdens.

The scope of this report encompasses an analysis of glulam beams from the PNW region (Oregon and Washington) excluding raw material transport[6] to the production facility and the production and delivery of logs. The full system boundaries are confined to the production of softwood lumber (Milota 2004a) and resin materials, (Nilsson 2001) production of electricity, natural gas, diesel, gasoline, ancillary materials, and glulam beams and its co-products (Figure 1.2a). The system boundaries for the on-site glulam LCI model are confined to those processes that take place at the glulam facility (Figure 1.2b). Burdens associated with resource extraction, lumber production, fuel and electricity production, resin production, and all transportation of raw materials and fuels have been omitted.

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[4] MCF=19.02 MBF (nominal), MBF=0.05 MCF

[5] Co-product is referred to as a material, other than the principal product, that is generated, retained, or sold for further commercial purposes because it has some economical value or function.

[6]Transportation distances are reported, but burdens associated with transportation are omitted from this report.

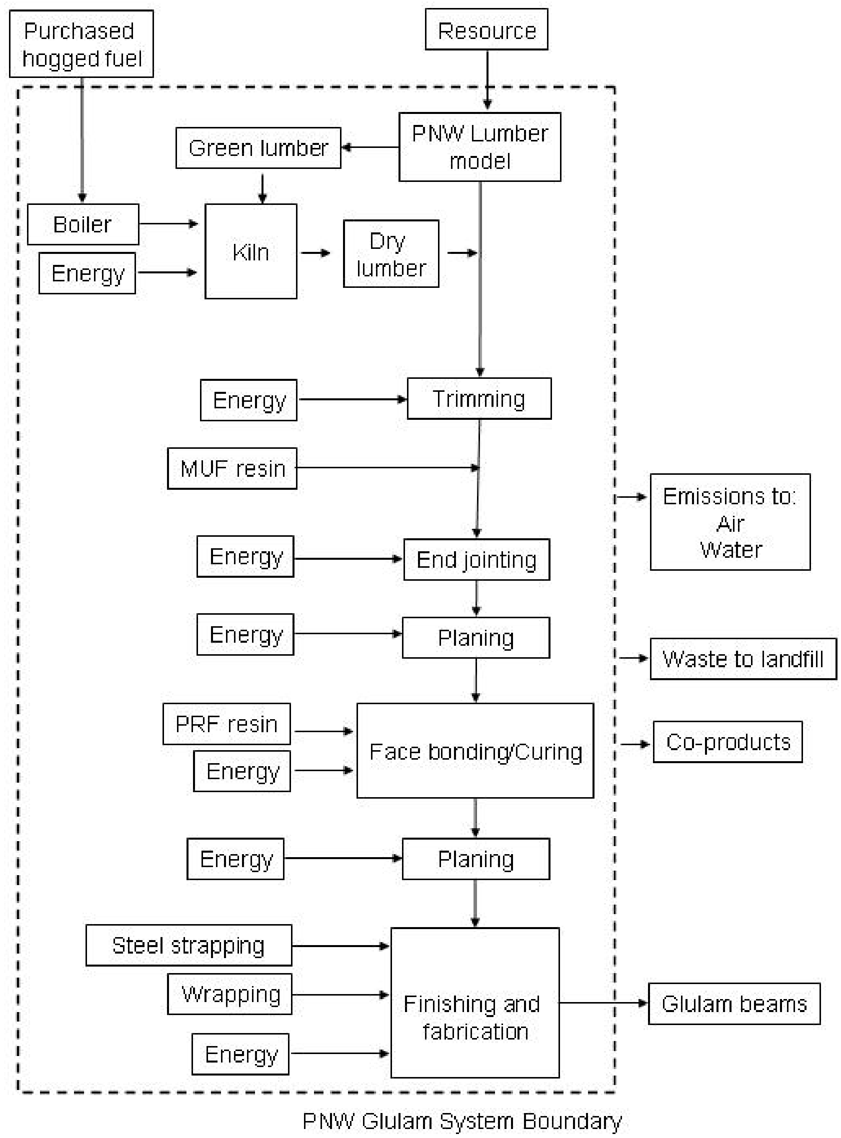

Figure 1.2a. **System boundary and PNW glulam production flow used to model the full glulam manufacturing process. Burdens associated with resource transportation to the sawmill, and resin, lumber and hogged fuel transportation to the glulam facility have been omitted.**

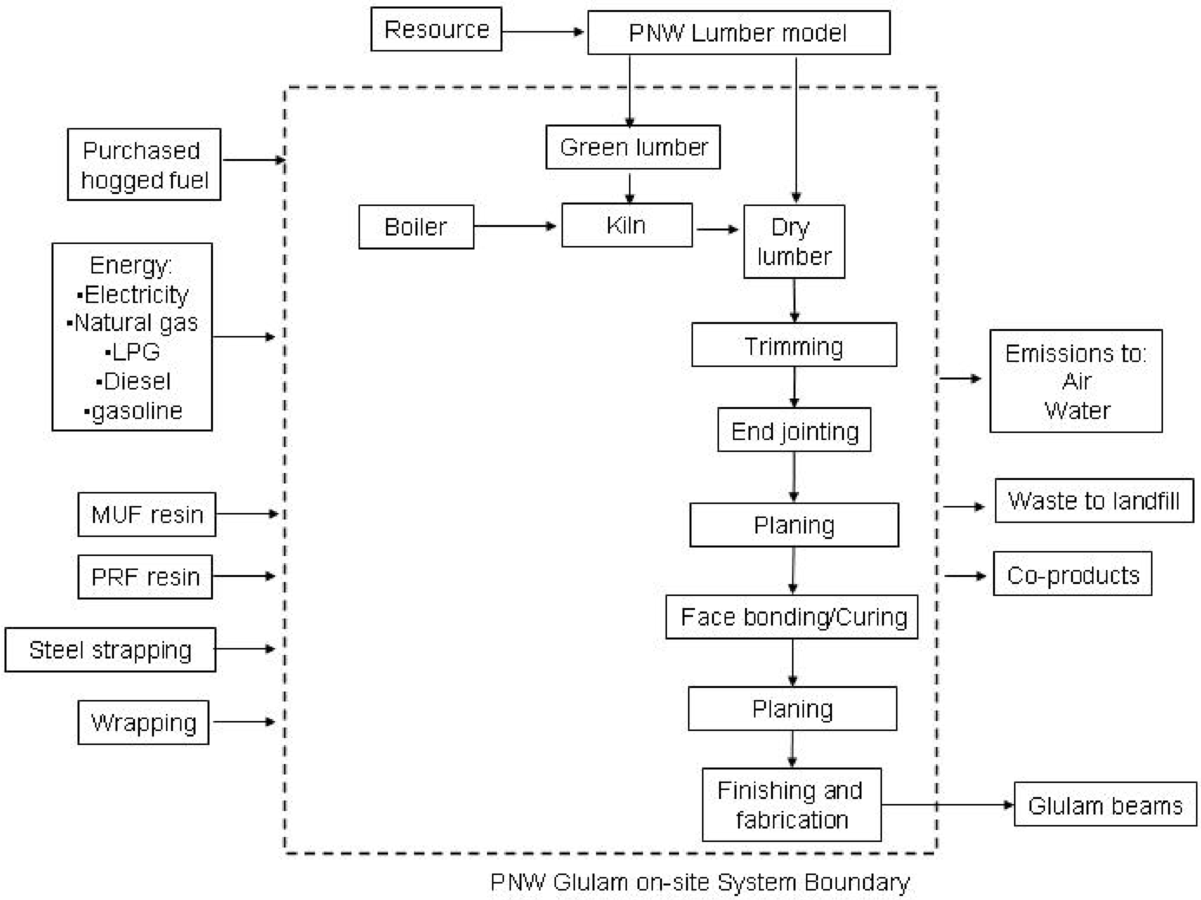

Figure 1.2b. **System boundary and PNW glulam production flow used to model the on-site glulam manufacturing process. Burdens associated with electricity and fuel production, resin manufacturing, lumber production, raw material production, and transportation are not included. Burdens associated with resource transportation to the sawmill, and resin, lumber and hogged fuel transportation to the glulam facility have been omitted.**

1.1.1 Glulam Manufacturing

The manufacturing process can be divided into four major parts: 1. drying and grading lumber, 2. end jointing the lumber into longer laminations, 3. face bonding the laminations, and 4. finishing and fabrication.

Lumber drying and grading

To minimize dimensional changes, the lumber must be kiln-dried to a maximum moisture content of 16%[7]. Lumber used may be purchased green and dried in on-site lumber kilns or purchased pre-dried from lumber suppliers. Lumber (laminations) with a moisture content greater than the threshold are removed from the process and re-dried. Re-drying is accomplished through either air or kiln drying. Two types of lumber grading systems used in glulam manufacturing are: visual grading (L-rating), and machine grading (E-rating). The rules for L-grading are based entirely upon apparent visual characteristics. E-rated lumber is graded by a combination of lumber stiffness and visual characteristics (AITC 1983; WWPA 1994).

End jointing

To manufacture glulam beams in lengths beyond those commonly available for lumber, laminations must be made by end jointing to the proper length. The most common end joint is a finger joint. Joints are cut on both ends of the lumber. A structural resin, such as radio frequency (RF) curing melamine-urea-formaldehyde is applied and cured under pressure and heat. Most manufacturers use a continuous RF curing system for this step.

Face bonding

The laminations are planed and adhesive is applied with a glue extruder. Phenol-resorcinol-formaldehyde is the most commonly used resin for face bonding. The laminations are then assembled into the required layup and pressure is applied. Two types of curing methods are cold set or cold cure (that uses only pressure and ambient heat for curing) and RF curing (that uses pressure and heat (200+ °F)).

Finishing and Fabrication

After proper pressing and curing time, beams are removed from the presses and then the wide faces are planed to remove adhesive that has squeezed out during pressing. The remaining two faces of the member may be lightly planed or sanded. For premium and architectural classifications, knots and planer skips are covered up. Depending upon use, final cuts are made, holes are drilled, connectors are added, and a finish may be applied. Each beam is individually wrapped for protection.

1.1.2 Material Flows

Those raw materials considered in the LCI analysis include those listed in Table 1.1a; the table does not include electricity and fuels. Input materials considered were dry lumber, green lumber, and phenol-resorcinol-formaldehyde (PRF) and melamine-urea-formaldehyde resins (MUF). Outputs were glulam beams and co-products consisting of trim, shavings, and wood waste. All flows of wood in the glulam process were determined on an oven-dried basis.

[7] The moisture content of laminations shall not exceed 16% at the time of gluing, except when it is known that the equilibrium moisture content of the laminated timber in use will be 16% or more, the moisture content of the laminations at the time of gluing shall not exceed 20% (AITC 1983).

Table 1.1a. Listing of Input Raw Materials, Co-products and Products for Producing PNW Glulam Beams.

Input Materials	Co-products Produced	Products
Lumber, >19%[1]	Trimmings	Glued laminated beams
Lumber, <19%	Shavings	
Phenol-resorcinol-formaldehyde resin (PRF)		
Melamine-urea-formaldehyde resin (MUF)		
Hogged fuel		
Steel strapping		
Wrapping material		

[1]Lumber >19% moisture content is referred to as "green" lumber (as reported in surveys), requiring additional drying by the glulam manufacturers.
Note: Listing does not include electricity and fuels

The weight of the input wood (lumber) was determined by converting board feet[8] (nominal) to cubic feet (actual). An actual to nominal ratio was calculated based on average percentages of each size beam produced (Appendix 2). Final conversions were made from cubic feet to mass (lb) by multiplying by the average weighted densities as determined by the species representation reported in the surveys (Table 1.1b). Densities of wood species were obtained from the Wood Handbook (FPL 1999).

Table 1.1b. Wood Densities of PNW Wood Species Used to Calculate Mass of Wood of Lumber Inputs

Wood Species	Represented in Surveys (%)		Specific Gravity		Density[1] lb/ft[3] (kg/m[3])	
	Green	<19%	Green	12%	Green[2]	12%[3]
Douglas-fir	26%	66%	0.45	0.48	28.1 (450)	30.0(480)
Western larch	3%	4%	0.48	0.52	30.0 (480)	32.5 (520)
Alaskan yellow cedar	0%	0.6%	0.42	0.44	26.3(420)	27.5 (440)
Glulam	-	-	-		-	30.2(483)

[1] Weighted average density used for PNW lumber inputs into the glulam process was 29.60 lb/ft^3 or 474 kg/m^3.
[2]Dry mass, volume at a moisture content greater than 30% oven-dry basis, commonly referred to as green
[3]Dry mass, volume at a moisture content of 12% oven-dry basis
Source: (FPL 1999).

[8] One board foot (BF) nominal=0.05 cubic feet (CF) actual; 1 CF (actual) =19.02 BF (nominal)

1.1.3 Transportation

Delivery of the input materials was by truck[9]. The one-way delivery distance for lumber, resin, strapping and wrapping paper are given in Table 1.1c.

Table 1.1c. Pacific Northwest Weighted Average Delivery Distance (One-Way) used for Glulam Production as Reported in Glulam Surveys. Burdens Associated with Transportation of the Materials are not Included in the SimaPro Glulam LCI Model.

	One-Way Delivery Distance	
Material	**miles**	**kilometers**
Lumber, green	28	52
Lumber, dry	75	139
Resin (PRF and MUF)	38	70
Steel strapping	438	811
Wrapping material	93	172

Note: Lumber production deliverables not included.

1.1.4 Assumptions

Procedures for data collection and analysis, and formulation of assumptions followed guidelines as defined in "Research Guidelines for Life Cycle Inventories (CORRIM 2001) dated April 8, 2001. Additional considerations include:

1. All data from the survey was weight averaged based on a particular mill's production in comparison to the total survey production for the year.

2. Missing data is defined as data not reported in surveys by the glulam facilities. Missing data were carefully noted so they were not averaged as zeros. When data was missing, for a variable, the weighted average for that variable reflected those facilities reporting the data in the surveys.

3. Density values for the wood species used to make the glulam were obtained from Wood Handbook—Wood as an Engineering Material (FPL 1999). A single density value was derived using FPL numbers and based on their weighted percentage of use of each species as reported by manufacturers. The PNW weighted average density was calculated to be 29.60 lb/ft^3 oven-dry weight, dry volume.

4. Lumber inputs were provided in board feet (BF) (Milota 2003a) and converted to actual volume using conversion factors developed in Appendix 2. PNW lumber was purchased as lamstock[10].

5. All conversion units for forestry and forest products were taken from Forest Products Measurements and Conversion Factors: With Special Emphasis on the US Pacific Northwest by Briggs (1994).

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[9] Transportation distances are reported, but burdens associated with transportation are omitted from this report. Lumber production deliverable are not included

[10] Lamstock is defined as a special grade of wood used in constructing laminated beams. In this study, lamstock was cut to 1.73" x 3.75", 1.73" x 5.875", 1.73" x 7.75", and 1.73" x 9.75".

6. The mass difference between reported input and output wood material flows was 9.3% (see Table 1.2 for material balance analysis). This difference is referred to herein as "unaccounted wood." In the SimaPro model for glulam, the "unaccounted wood" mass was added to the purchased kiln-dried lumber coming from the PNW softwood lumber model (Milota 2004a).

7. SimaPro version 5.0.009 (PRé 2001), a software package designed for analyzing the environmental impact of products during their whole life cycle, was used to do the life cycle inventory (LCI). Developed in The Netherlands by PRé Consultants B.V., SimaPro contains a US database for a number of materials, including paper products, fuels, and chemicals. The US database was obtained from Franklin Associates (FAL 2001) (http://www.fal.com).

1.2 PRODUCT YIELDS

The percentage of recovery of wood in terms of wood input as lumber and output as glulam beams is 82% - defined as the weight of wood in glulam beams divided by the total weight of input wood from the lumber times 100%. To yield 30,162 lb of glulam beam (1.0 MCF, actual volume), 36,929 lb of lumber was needed. A complete wood mass balance is given in Table 1.2. The difference between total wood input and output is 3,424 lb per MCF, which was labeled as the "unaccounted wood". The unaccounted wood amounted to 9.3% of the total wood input, which is reasonably close for a survey of this type. In the SimaPro model for glulam, the "unaccounted wood" mass was added to the purchased kiln-dried lumber coming from the PNW softwood lumber model (Milota 2004a).

The "unaccounted wood" may have come from lumber that was purchased the previous year and included in the inventory. The surveys were filled out in terms of one calendar year (2000). The glulam manufacturers were confident of how much lumber they purchased in the calendar year for which information was requested and of reported glulam beam production. The surveys did not ask for information from the previous year's inventory carry-overs. This issue might need to be addressed in subsequent surveys.

Table 1.2. Wood Mass Balance (Weighted Averages) for Glulam Production in the PNW Region Per 1,000 Cubic Feet (MCF) or Cubic Meters (m^3).

	lb/MCF, Based on Actual Volume	kg/m^3, Based on Actual Volume	Percent Allocation%
Inputs (w/co-product)			
Lumber	33,498	536	90.73
Unaccounted inputs (lumber)[1/]	3,424	55	9.27
Total	36,922	592	100.00
Outputs			
Glulam beams (wood only)[2/]	30,162	483	81.67
Shavings and trimmings	5,535	89	14.99
Wood waste	1,233	20	3.34
TOTAL	36,929	592	100

[1]Unaccounted for inputs of 9.27% is assumed to be lumber already on site prior to year of survey.
[2]2.13E+03 MCF/annual production, actual volume (2.56E+04 MBF, actual or 4.09E+04 MBF, nominal)
Note: All weights are on an oven-dry basis. Does not include lumber manufacturing mass wood balance.

1.3 MANUFACTURING ENERGY SUMMARY

1.3.1 Sources of Energy

Energy for the production of glulam beams comes from electricity, natural gas, purchased hogged fuel, gasoline, diesel, and liquid propane gas (LPG). A small amount of kerosene was reported for use in space heaters. The electricity is used to operate radio-frequency dryers, pneumatic and mechanical conveying equipment, fans, hydraulic pumps, and saws. Hogged fuel was used in a boiler for heat input for a green lumber dry kiln (one mill only) and for facility heating. Natural gas was also used for facility heating in other glulam facilities. On-site trucks and forklifts used diesel, gasoline, and LPG.

1.3.2 Electricity Use Summary

The source of fuel used to generate electricity has a major impact on the types of emissions resulting from energy production. Sources of fuels used in electricity generation are given in Table 1.3a. In 2000, the dominant source of electricity in the PNW was hydro, representing 74.3% of the total, followed by natural gas at 12.3% and coal sources at 8.1%. In the Franklin database (FAL 2001), no impacts are associated with hydro-generated electricity in the United States; however, combustion of coal can result in significant impacts. Considering the entire glulam production process glulam production required 52 percent of total electricity consumed, with lumber and resin production requiring 42 and 6 percent, respectively.

Table 1.3a. Electric Power Requirements Allocated to 1000 Cubic Feet (MCF) or 1000 Cubic Meters (10^3m^3) of the Glulam On-Site Process Including Lumber and Resin Production by Primary Energy Sources for the PNW Region[1/].

		Glulam Process Only "On-Site"		Glulam Process w/ PNW Lumber Production	
Fuel Source or Production Method	**Percent of Total Electricity Production 2000[2/]**	**kWh/MCF**	**MJ/10^3m^3**	**kWh/MCF**	**MJ/10^3m^3**
Coal	8.1	1.58E+02	2.01E+04	2.86E+02	3.63E+04
Petroleum	0.2	4.00E+00	5.08E+02	7.06E+00	8.97E+02
Natural gas	12.3	2.41E+02	3.06 E +04	4.34E+02	5.52E+04
Nuclear	4.0	7.80E+01	9.91E+03	1.41E+02	1.79E+04
Hydro	74.3	1.45E+03	1.84 E +05	2.62E+03	3.33E+05
Other	1.1	2.10E+01	2.67 E +03	3.88E+01	4.93E+03
SUBTOTAL	**100.0**	**1.96E+03**	**2.49E+05**	**3.53E+03**	**4.48E+05**
TOTAL w/ Resin		**2.21E+03**	**2.81 E +05**	**3.78E+03**	**4.80E+05**

[1]Average of Oregon and Washington
[2]*Source*: Energy Information Administration/State Electric Power Annual 2000 Volume I, Department of Energy (EIA 2001). http://www.eia.doe.gov/cneaf/electricity/epav1/epav1_sum.html.
Note: Co-products not included.

1.3.3 Thermal Energy Generation

Only one boiler was reported in the glulam surveys that used hogged fuel as its fuel source. The boiler was used to provide heat to a kiln to dry lamstock purchased at greater than 19% moisture content, and to heat the facilities. Inefficiencies in the boilers and the quantity of hogged fuel used were far higher than industry averages. Therefore wood drying energy requirements were taken from the PNW lumber model (Milota 2003a) and applied to the lamstock drying[11] making the heat energy requirement for the kilns at approximately 30% of the total heat energy requirement and approximately 70% for the facilities. The hogged fuel weight, following industry practice, was given as green weight and assumed to be 50% moisture content on a wet-weight basis. As such, the total hogged fuel burned was 2.25E+03 lb (oven-dry basis) per 1000 cubic feet of glulam production representing 1.35E+07 BTU per 1000 cubic feet glulam. See Table 1.3b and 1.3c for hogged fuel allocation.

Table 1.3b. On-Site Hogged Fuel[1/] Utilization and Natural Gas[2/] and Heat Energy Inputs Required for the Production of 1000 Cubic Feet (MCF) or 1000 Cubic Meters (10^3m^3) of Glulam Beam.

	Fuel Input[3/]		Heat Energy Input		Allocation
Fuel Type	**lb/MCF**	**kg/10^3m^3**	**BTU/MCF**	**MJ/10^3m^3**	**%**
Hogged fuel:	2.25E+03	3.61E+04	1.35E+07	5.03E+05	85%
Kiln	5.73E+02	9.17E+03	3.44E+06	1.28E+05	26%
Heating Required for Production	1.67E+03	2.68E+04	1.01E+07	3.75E+05	74%
	ft^3/MCF	**$m^3/10^3m^3$**	**BTU/MCF**	**MJ/10^3m^3**	
Natural gas	3.29E+03	3.29E+03	3.35E+06	8.68E+05	15%

[1]Weight of oven-dried hogged fuel multiplied by 6000 BTU/lb of oven-dried wood/bark, based on 67% boiler efficiency.
[2] Volume of natural gas multiplied by 1016 BTU/ft^3 at 80% efficiency.
[3] Data obtained from surveys (Appendix 3)
Note: Co-products not included.

[11]Used 1,966 BTU per pound of water removed.

Table 1.3c. Total Fuel Inputs[1/] into all Boilers Required for Heat Energy for the Production of Kiln-Dried Lumber Used for Glulam inputs and at the On-Site Glulam Facility for the Production of 1000 Cubic Feet (MCF) or 1000 Cubic Meters (10^3m^3) of PNW Glulam Beams.

			Heat Energy		
	Unit of Fuel Input	Fuel Input	BTU/MCF	MJ/10^3m^3	Heat Energy Allocation %
TOTAL			6.01E+07	2.24E+06	100%
Glulam Production			1.35E+07	5.04E+05	**22%**
Hogged fuel[2/] (100%)	lb/MCF ($kg/10^3m^3$)	2.25E+03 (3.60E+04)	1.35E+07	5.04E+05	
Lumber Production			4.66E+07	1.74E+06	**78%**
Hogged fuel (58%)	lb/MCF ($kg/10^3m^3$)	4.52E+03 (7.24E+04)	2.71E+07	1.01E+06	
Natural gas[3/] (42%)	ft^3/MCF ($m^3/10^3m^3$)	6.68E+03 (6.68E+03)	1.94E+07	7.25E+05	
Diesel[4/] (0.1%)	gal/MCF ($L/10^3m^3$)	3.34E-01 (4.47E+01)	4.64E+04	1.73E+03	

[1] Data obtained from surveys (Appendix 3, Milota 2004a)
[2] Weight of oven-dried hogged fuel multiplied by 6000 BTU/lb of oven-dried wood/bark, based on 67% boiler efficiency.
[3] Volume of natural gas multiplied by 1016 BTU/ft^3 at 80% efficiency.
[4] Volume of diesel fuel multiplied by 1.39E+05 BTU/gal
Note: Included are the fuel inputs and heat energy used on-site for the production of glulam and fuels and heat energy used in lumber production. Co-products not included.

For hogged fuel used in the glulam process, the "Wood into Industrial Boilers" module was used from the Franklin database (FAL 2001)(Table 1.3d). The emissions resulting from burning hogged fuel and fuel consumed in generating hogged fuel are included in the LCI analysis. Resource extraction and transportation of the hogged are not included in this data. Future work should develop more complete information on wood burning boilers using CORRIM data that takes into account the resource extraction, specific wood products industry, geographic location, wood species, transportation, and fuel source, i.e. bark, or wood. To date, CORRIM has collected boiler data from manufacturers of softwood plywood, softwood lumber, and oriented strand board (OSB) (CORRIM 2004).

Table 1.3d. Non Cumulative Franklin Data[1/] used in the SimaPro PNW Glulam Model. Data is for the Production of 3 Million BTU's of Heat Energy From the Combustion of 500 Lbs of Oven-Dried Wood.

Emissions to air	**lb/MCF**
Acetaldehyde	1.50E-03
As	4.40E-05
Ba	2.20E-03
Benzene	1.80E-03
Cl_2	3.90E-03
CO	6.80E+00
CO_2 (biomass)	1.05E+03
Cr	2.30E-05
Fe	2.20E-03
Formaldehyde	3.30E-03
K	3.90E-01
Mn	4.50E-03
Na	9.00E-03
Naphthalene	1.20E-03
Ni	2.80E-04
NOx	7.50E-01
Organic substances	8.30E-02
Particulates	8.50E-02
Pb	6.00E-04
Phenol	2.00E-02
SOx	3.80E-02
Zn	2.20E-03
Solid emissions	**lb/MCF**
Solid waste	1.04E+00
Products	**BTU/MCF**
Steam	3.00E+06

[1.]Reported here are only those inputs and outputs associated with combustion of hogged fuel in industrial boilers (PRé 2001; FAL 2001), raw material extraction and transportation are not included.
Note: Input is 500 lb of wood (hogged fuel) oven-dried basis; output is 3.00E+06 BTU.

1.4 ADHESIVE USE AND ENERGY/ELECTRICITY TO PRODUCE

Phenol-resorcinol-formaldehyde (PRF) and melamine-urea-formaldehyde (MUF) are the adhesives used in glulam production. The manufacture of these resins is energy intensive. The total energy requirement for the production of 312 lb of PRF resin for use in manufacturing 1.0 MCF of PNW glulam beams is 1.56E+07 BTU and 238 kWh of electricity. Energy requirements for production of 55 lb of MUF resin needed to manufacture 1.0 MCF of glulam beams was 1.96E+06 BTU, with 82% obtained from natural gas and 11 % from crude oil. Electricity for MUF production was 15 kWh/MCF. For both resins combined, electricity accounted for 7% of the total electricity requirement for glulam production (Table 1.3a). The PRF resin was composed of 85% resin and 15% hardener, while MUF was composed of 90% resin and 10% hardener. All resources, fuels, and emissions associated with producing PRF and MUF resins are listed in Tables 1.4a and 1.4b.

Output emissions listed in Tables 1.4a and 1.4b include all emissions resulting from the production of resin, fuel production and combustion, electricity generation, and material transportation. Due to the nature of the resin data, it was not possible to separate out emissions for each of the production processes, therefore, output emissions reflect total cradle-to-gate burdens for PRF and MUF resin manufacturing. Burdens associated with the transportation of the resins to the glulam facilities were not included in the SimaPro glulam production model.

Table 1.4a. Cumulated Input Data Exported from SimaPro for the Production of 1.0 Pound (lb) of Phenol-Resorcinol-Formaldehyde Resin (PRF) and Hardener.

	PRF	Harden		PRF	Hardener
Resources	**lb/lb**	**lb/lb**	**Emissions to air**	**lb/lb**	**lb/lb**
Air	1.54E-01	3.40E-	Aldehydes	2.00E-	0.00E+00
Nitrogen	8.99E-03	0.00E+	Aromatics	2.00E-	1.00E-05
Bauxite	4.70E-04	4.50E-	Benzene	0.00E+	1.00E-05
Bentonite	7.01E-05	0.00E+	CO	4.78E-	9.21E-04
Copper ore	1.10E-03	7.21E-	CO_2	2.23E+	1.75E+00
Iron ore	3.00E-04	2.00E-	Dust	2.14E-	8.31E-04
Limestone	1.20E-03	1.81E-	Ethene	2.00E-	2.80E-04
NaCl	2.11E-01	2.81E-	HCOOH	0.00E+	6.00E-05
Nitrogen	0.00E+00	5.24E-	HCL	7.01E-	0.00E+00
Phosphate	7.01E-05	1.20E-	Hydrocarbons	8.48E-	4.15E-03
Sand	1.50E-04	0.00E+	Methane	4.64E-	4.74E-03
Sulphur	8.13E-02	4.74E-	Methanol	3.00E-	6.71E-04
Uranium ore	6.41E-04	4.20E-	N_2O	3.00E-	3.00E-06
Energy Resources	**BTU/lb**	**BTU/lb**	NOx	1.38E-	7.70E-03
Coal	2.31E+03	5.15E+	Organics	1.10E-	1.80E-04
Crude oil	1.20E+04	9.43E+	PAH	0.00E+	2.00E-05
Hydro Energy	6.72E+02	6.39E+	Particles	0.00E+	1.30E-04
Lignite	2.47E+01	0.00E+	Phenol	2.00E-	3.00E-07
Natural gas	1.62E+04	1.73E+	Propylene	8.61E-	1.07E-02
Nuclear energy	1.49E+03	1.20E+	SO_2	4.09E-	2.20E-03
Recovered energy	-3.59E+02	-	SOx	7.84E-	3.26E-03
	lb/lb	**lb/lb**	Formaldehyde	0.00E+	2.00E-06
Wood	1.27E-02	0.00E+	Dimethylether	0.00E+	4.00E-06
Bio fuel	3.60E-04	0.00E+	VOC	1.37E-	2.00E-05
Biomass	1.50E-04	0.00E+	**Emission to**	**lb/lb**	**lb/lb**
Energy	**kWh/lb**	**kWh/lb**	Al3+	4.10E-	0.00E+00
Electricity	8.09E-01	4.95E-	BOD	1.89E-	4.00E-06
Raw materials	**lb/lb**	**lb/lb**	Cd	7.51E-	0.00E+00
Cellulose	0.00E+00	0.00E+	Cl-	3.05E-	4.00E-04
Silicic acid	7.41E-02	0.00E+	CO_3	4.55E-	0.00E+00
Residual product	6.61E-03	0.00E+	COD	1.21E-	5.43E-04
	BTU/lb	**BTU/lb**	Dissolved	1.79E-	1.30E-05
Heavy oil	2.47E+01	0.00E+	Dissolved solids	6.32E-	2.06E-04
Electricity	2.47E+01	0.00E+	Formaldehyde	0.00E+	7.01E-07
Other fuel	1.24E+03	0.00E+	H+	4.19E-	3.30E-05
Waste	**lb/lb**	**lb/lb**	Hg	5.10E-	3.00E-06
Building waste	2.10E-04	1.00E-	Hydrocarbons	9.39E-	0.00E+00
Hazardous waste	5.77E-03	5.24E-	Ionics	2.46E-	0.00E+00
Highly radioactive	2.00E-05	6.79E-	Metals	1.13E-	0.00E+00
Landfill	7.83E-03	1.77E-	N total	1.11E-	8.01E-06
Mineral waste	8.26E-03	9.16E-	Na+	4.92E-	3.30E-05
Mixed industrial waste	2.15E-03	5.90E-	NaCl	5.41E-	0.00E+00
Non hazardous waste	1.81E-01	3.64E-	Oil and fat	4.25E-	2.30E-05
Slags and ash	2.17E-03	2.18E-	Organic substance	3.57E-	0.00E+00
Sludge (dry matter)	1.65E-03	2.07E-	Organics	2.06E-	0.00E+00
Waste to incineration	3.02E-03	2.10E-	Phenol	4.70E-	3.00E-07
Waste to recycling	1.02E-03	3.60E-	P-tot	2.90E-	0.00E+00
			SO_4^2	9.71E-	1.47E-04
			Suspended solids	3.55E-	8.88E-04
			Total organic	2.34E-	2.18E-04

Source: Nilsson 2001

Table 1.4b. Cumulated Input Exported from SimaPro Input for the Production of 1.0 Pound (lb) of Melamine-Resorcinol-Formaldehyde Resin (MUF) and Hardener.

	MUF	Hardener		MUF	Hardener
Resources	**lb/lb**	**lb/lb**	**Emissions to air**	**lb/lb**	**lb/lb**
Air	4.83E-02	9.89E-01	Aromatics	0.00E+00	1.90E-05
Nitrogen	3.05E-03	8.41E-03	CO	7.21E-04	3.03E-03
Bauxite	4.40E-04	2.90E-04	CO_2	1.44E+00	1.35E+00
Cellulose	0.00E+00	1.12E-02	Dust	9.26E-04	1.42E-03
Copper ore	1.36E-04	1.57E-03	HCOOH	0.00E+00	4.44E-04
Iron ore	6.00E-05	2.10E-04	Hydrocarbons	2.13E-03	4.65E-03
Feldspar	2.30E-04	0.00E+00	Methane	6.89E-03	2.52E-03
Kaolin	0.00E+00	2.99E-01	NH_3	1.65E-04	0.00E+00
Limestone	4.30E-04	7.81E-04	N_2O	0.00E+00	2.30E-05
Methane	0.00E+00	2.20E-04	NO_x	5.27E-03	9.06E-03
NaCl	4.22E-03	2.30E-01	PAH	0.00E+00	1.60E-05
Nitrogen	0.00E+00	8.41E-03	Particles	0.00E+00	1.30E-05
Salt	1.48E-03	6.26E-03	SO_2	2.49E-03	3.29E-03
S	2.44E-03	9.01E-02	SO_x	4.65E-03	4.25E-03
Trona	0.00E+00	3.00E-04	Formaldehyde	2.00E-06	0.00E+00
Uranium ore	1.35E-04	1.27E-03	Dimethylether	2.00E-06	0.00E+00
Energy resources	**BTU/lb**	**BTU/lb**	Methanol	1.00E-04	2.40E-03
Bio fuel	0.00E+00	2.56E+02	VOC	0.00E+00	5.65E-04
Coal	7.44E+02	1.46E+03	**Emissions to**	**lb/lb**	**lb/lb**
Crude oil	1.76E+03	9.17E+03	Al3+	0.00E+00	5.00E-06
Heavy oil	0.00E+00	7.42E+01	AOX	0.00E+00	2.10E-05
Hydro energy	1.92E+02	1.15E+03	BOD	3.10E-05	1.80E-05
Hydrogen	1.24E+01	0.00E+00	Cd	0.00E+00	4.00E-06
Lignite	5.98E+01	0.00E+00	Cl-	0.00E+00	3.54E-03
Natural gas	1.49E+04	1.19E+04	COD	1.24E-03	1.73E-03
Nuclear energy	1.81E+02	1.60E+03	Dissolved organics	0.00E+00	1.00E-05
Recovered energy	-1.32E+02	-4.21E+02	Dissolved solids	1.91E-04	6.49E-03
Other fuel	0.00E+00	6.72E+02	Gypsum	0.00E+00	7.01E-05
Wood	6.19E+01	9.07E+01	H+	4.00E-05	2.60E-05
Energy	kWh/lb	kWh/lb	Hg	0.00E+00	5.00E-06
Electricity	2.46E-01	4.64E-01	Hydrocarbons	1.70E-05	5.80E-05
Raw materials	**lb/lb**	**lb/lb**	Limestone	1.00E-05	0.00E+00
Cellulose	2.40E-02	0.00E+00	Metals	5.70E-05	1.18E-04
Waste	**lb/lb**	**lb/lb**	N total	3.40E-04	9.01E-06
Building waste	7.01E-05	2.60E-04	Na+	5.09E-04	4.92E-04
Hazardous waste	1.09E-02	1.34E-02	NaCl	0.00E+00	5.58E-04
Highly radioactive waste	0.00E+00	3.00E-05	NH_4^+	6.56E-05	1.00E-06
Landfill	1.73E-02	3.36E-02	Oil and fat	4.40E-05	2.80E-05
Low radioactive waste	0.00E+00	0.00E+00	P-tot	0.00E+00	1.00E-06
Mineral waste	7.41E-03	2.66E-03	SiO_2	0.00E+00	1.20E-05
Mixed industrial waste	9.31E-04	9.21E-04	SO_4^{2}	0.00E+00	2.37E-03
Non hazardous waste	1.13E-02	1.46E-01	Sr_2^{+}	0.00E+00	8.01E-06
Slags and ash	1.80E-03	1.40E-03	Sulphates	9.29E-04	0.00E+00
Sludge	0.00E+00	3.10E-03	Suspended solids	4.89E-04	3.31E-03
Sludge (dry matter)	2.07E-03	1.52E-03	Total organic	2.28E-04	2.86E-04
Waste to incineration	1.94E-03	1.80E-04			
Waste to recycling	3.53E-03	3.92E-03			

Source: Nilsson 2001

1.5 STRUCTURE AND INPUT, SIMAPRO MODEL

A single unit process was defined for the PNW glulam process in SimaPro with the PNW lumber process, wood boiler process and resin processes as inputs into the glulam process (Figure 1.2). Other processes taken from the Franklin database (designated FAL) were also used for fuel, ancillary materials, and electricity inputs. Table 1.5 list the SimaPro 5 input table for the PNW glulam process. All data was obtained from the mill surveys collected for the production year 2000, weighted based on glulam production per 1000 cubic feet (MCF) actual volume. Production emissions for input into the glulam model were reported in surveys. They represent emissions associated with the pressing, sawing, trimming, planning and finishing. A boiler process was designed for the CORRIM products using Franklin emission data (Table 1.3d). Allocation was made on a mass basis allocating 81.68% (based on 3.02 E+04 lb/MCF of glulam) of the total output to glulam beams. Figure 1.5 shows an overview relationship among the input processes used in the glulam production model. Lines represent flows within the model. Not all material inputs are shown. A contribution cutoff of 1% was used in this example.

Table 1.5. Total Process Inputs Exported from SimaPro for the production of PNW Glulam per 1,000 Cubic Feet (MCF) (Not Allocated)

	Unit	Unit per MCF		Unit	Unit per MCF
Resources			**Emissions to air**[6]		
water (process)	lb	2.23E+06	VOC	lb	1.80E+01
			Methanol	lb	6.49E-01
Materials/fuels			Phenol	lb	6.55E-01
Steel cold rolled, BOF FAL	lb	1.77E+01	Formaldehyde	lb	2.15E-02
Natural gas equipment FAL[1]	BTU	1.11E+06	Particulates	lb	3.54E+01
Natural gas equipment FAL[2]	BTU	2.70E+00	Isopropanol	lb	1.31E+01
Gasoline equipment FAL	gal	6.86E-01	Ethanol	lb	3.13E-01
Diesel equipment FAL	gal	2.71E+00	Resorcinol	lb	6.25E-04
Lumber, green	lb	9.31E+03	Particulates (PM10)	lb	3.20E+00
Lumber, dry	lb	2.76E+04			
LDPE film recycled FAL	lb	8.85E+01	**Products**		
Kraft unbleached FAL	lb	9.62E+01	Glulam beams, PNW	lb	3.02E+04
Melamine-urea-formaldehyde (MUF)	lb	6.01E+01			
Phenol-resorcinol-formaldehyde (PRF)	lb	3.23E+02	**Co-Products**		
Hardener, MUF	lb	6.67E+00	Shavings, PNW	lb	5.44E+03
Hardener, PRF	lb	5.90E+01	Trimmings, PNW	lb	8.75E+01
			Landscaping, PNW	lb	1.23E+03
Electricity/heat					
Heat from nat. gas FAL	BTU	4.10E+06			
Electricity, PNW selector[3]	kWh	2.39E+03			
CORRIM glulam PNW wood boiler[4]	BTU	4.21E+06			
CORRIM glulam PNW wood boiler[5]	BTU	1.24E+07			

[1]Surrogate for LPG at 1.21E+01 gal/MCF
[2]Surrogate for kerosene at 1.23E-3 gal/MCF
[3]Table 1.3a shows the percent breakdown by fuel source for energy generation for the PNW
[4]Energy requirement for wood drying
[5]Energy requirement for production heating
[6] Input emissions for the glulam total process were obtained from the glulam surveys.. These are emissions associated with glulam on-site production, excluding emissions resulting from the combustion of fuels.
Notes: All inputs are from surveys and values are a weighted average based on the 2000 production year. Co-products included.

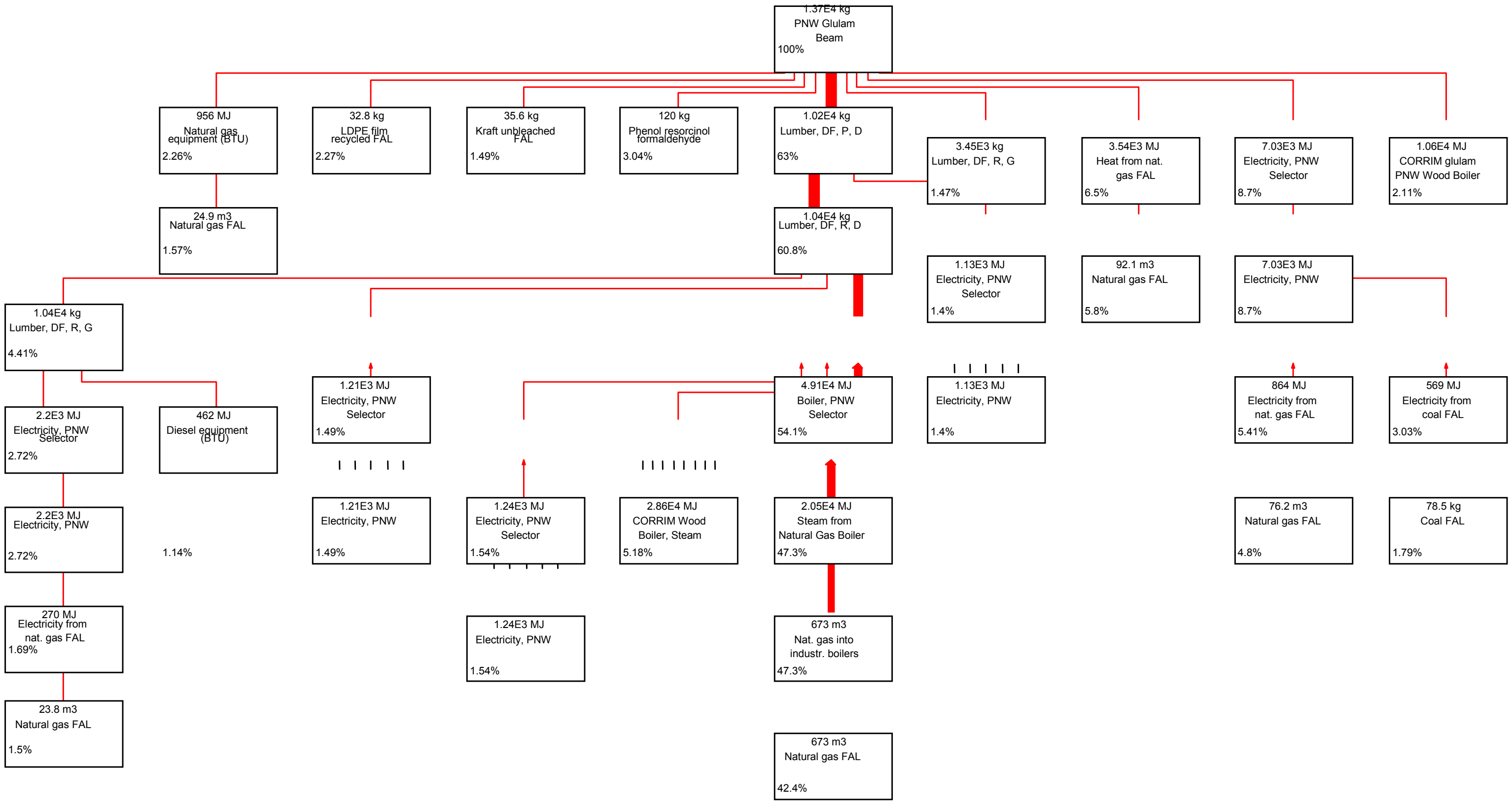

Figure 1.5. A process flow diagram on the relationship among input processes into the PNW Glulam Model in Simapro5.
Notes: Lines represent flows within the model. 1.37E+04 kg of product = 1000 cubic feet (MCF) of glulam or 3.02E+04 lb/MCF. Not all input materials (processes) are shown. A 1% cutoff is used for the figure example.

1.6 LIFE-CYCLE INVENTORY RESULTS

Life-cycle inventory results to produce 1000 cubic feet (MCF) of glulam beams in the PNW are presented in Tables 1.6a-e. Results include all processes within the system boundary defined in Figure 1.2a and 1.2b. were generated in SimaPro (PRé 2001). Burdens associated with transportation of the wood resource to the sawmills and of raw materials to the glulam facilities have been excluded from the glulam model as defined in Figures 1.2a and 1.2b. Four different inventory tables were generated to represent scenarios: Full LCI, no exclusions (Table 1.6a and 1.6b); LCI excluding electricity production and use (Table 1.6c); LCI excluding resin production (Table 1.6d) and; LCI for on-site glulam production (Table 1.6e). When primary data (survey data) was not available, the Franklin Database (FAL 2001) was used primarily for fuel manufacturing and use, ancillary material manufacturing (i.e. steel strapping and paper wrap), and electricity production. Life-cycle inventory data for the production of lumber from the PNW was taken from Milota (2004a) and production data for the resins was obtained from Nilsson (2001).

Table 1.6a. Cumulative LCI Raw Material Requirements from SimaPro for Production of 1000 Cubic Feet (MCF) or 1000 Cubic Meters ($10^3 m^3$) of PNW Glulam Beams. Results Include Inputs for the Production of PNW Lumber (Milota 2004a); Electricity, Fuels, Resins (Nilsson 2001) and Ancillary Materials. Co-Products Not Included

Substance	lb/MCF	kg/10^3m^3	Substance	lb/MCF	kg/10^3m^3
Air	6.43E+01	1.03E+03	Nitrogen	2.86E+00	4.59E+01
Bauxite	1.69E-01	2.70E+00	Oxygen	1.81E+00	2.89E+01
Bentonite	1.85E-02	2.96E-01	Pesticides	4.34E-04	6.96E-03
Cellulose	6.10E-02	9.77E-01	Phosphate (ore)	6.56E-02	1.05E+00
Coal	4.38E+02	7.02E+03	Rock salt	1.07E-01	1.71E+00
Copper (in ore)	3.40E-01	5.45E+00	Sand	3.96E-02	6.34E-01
Crude oil	1.69E+02	2.71E+03	S-containing raw material	6.11E-01	9.78E+00
Feldspar	1.13E-02	1.81E-01	Scrap, external	4.70E+01	7.53E+02
Iron (ore)	2.19E+01	3.49E+02	Seed corn	2.33E-03	3.73E-02
Kaolinite (chinaclay)	1.63E+00	2.61E+01	Silica	4.81E-03	7.71E-02
Limestone	1.91E+02	3.06E+03	Soda ash	7.19E-04	1.15E-02
	ft^3/MCF	**$m^3/10^3m^3$**	Sulphur	2.18E+01	3.48E+02
Logs, PNW	1.23E+03	1.23E+03	Sylvinite	2.03E-02	3.25E-01
	lb/MCF	**kg/10^3m^3**	Trona	1.64E-03	2.62E-02
Methane (kg)	1.20E-03	1.92E-02	Uranium FAL	2.05E-01	3.28E+00
Na_2SO_4	1.30E+00	2.08E+01	Water (process)	1.82E+06	2.92E+07
NaCl	2.66E+02	4.26E+03	Water (surface, for cooling)	1.22E+04	1.96E+05
Natural gas (feedstock)	2.96E+01	4.75E+02	Water (well, for cooling)	3.88E+03	6.21E+04
Natural gas FAL	1.97E+03	3.16E+04	Wood for fiber (feedstock)	3.54E+02	5.67E+03
				yd^3/MCF	**$m^3/10^3m^3$**
			Wood/wood wastes	2.42E+03	3.88E+04

Table 1.6b. Cumulative LCI Results from SimaPro for the Production of 1000 Cubic Feet (MCF) or 1000 Cubic Meters (10^3m^3) of Glulam in the PNW. Results Include Inputs for the Production of PNW Lumber (Milota 2004a), Electricity, Fuels, Resins (Nilsson 2001), and Ancillary Materials. Transportation of Resource to the Sawmill and Transportation of Raw Materials to the Glulam Facility Have Been Omitted. Co-Products Were Not Included.

Emissions to air	lb/MCF	kg/10^3m^3	Emissions to air	lb/MCF	kg/10^3m^3	Emissions to air	lb/MCF	kg/10^3m^3
Acetaldehyde	4.13E-02	6.62E-01	HCl	8.94E-02	1.43E+00	Resorcinol	5.11E-04	8.18E-03
Acrolein	2.38E-05	3.81E-04	HCOOH	5.31E-03	8.51E-02	Sb	1.23E-05	1.97E-04
Aldehydes	4.96E-02	7.95E-01	HF	9.88E-03	1.58E-01	Se	1.11E-04	1.78E-03
Ammonia	2.53E-02	4.05E-01	Hg	3.81E-05	6.10E-04	SO_2	1.33E+00	2.12E+01
Aromatics	5.86E-03	9.39E-02	Hydrocarbons	2.57E+00	4.12E+01	SOx	8.07E+01	1.29E+03
As	6.75E-04	1.08E-02	Isopropanol	1.07E+01	1.71E+02	Tetrachloroethene	1.36E-05	2.17E-04
Ba	3.01E-02	4.82E-01	K	5.33E+00	8.54E+01	Tetrachloromethane	2.49E-05	3.98E-04
Be	7.56E-06	1.21E-04	Kerosene	4.43E-04	7.10E-03	Total reduced sulfur	4.57E-03	7.32E-02
Benzene	2.52E-02	4.04E-01	Metals	5.61E-04	8.99E-03	Trichloroethene	1.34E-05	2.14E-04
Cd	3.35E-05	5.37E-04	Methane	1.70E+01	2.72E+02	VOC	1.93E+01	3.08E+02
Cl_2	5.34E-02	8.55E-01	Methanol	6.24E-01	9.99E+00	Zn	3.01E-02	4.82E-01
CO	1.12E+02	1.79E+03	Mn	6.18E-02	9.89E-01		**Bq/MCF**	**Bq/10^3m^3**
CO_2 (biomass)	1.42E+04	2.27E+05	N_2O	1.88E-02	3.00E-01	Radioactive substances	1.78E+07	6.29E+05
CO_2 (fossil)	6.59E+03	1.06E+05	Na	1.23E-01	1.97E+00			
CO_2 (non-fossil)	1.74E+02	2.79E+03	Naphthalene	1.64e-02	2.63E-01			
Cobalt	3.12E-05	5.00E-04	NH_3	8.13E-03	1.30E-01			
Cr	4.32E-04	6.92E-03	Ni	4.21E-03	6.74E-02			
Cu	2.73E-07	4.38E-06	N-nitrodimethylamine	2.99E-06	4.80E-05			
Dichloromethane	5.66E-05	9.06E-04	NMVOC	2.08E+01	3.33E+02			
Dimethyl ether	2.91E-04	4.67E-03	NOx	4.12E+01	6.60E+02			
Dioxin (TEQ)	7.56E-11	1.21E-09	Organic substances	1.56E+00	2.50E+01			
Dust	6.56E-01	1.05E+01	PAH's	1.05E-03	1.68E-02			
Dust (coarse)	5.17E+00	8.28E+01	Particulates	3.09E+01	4.95E+02			
Dust (PM10)	5.02E-01	8.04E+00	Particulates (PM10)	2.84E+00	4.55E+01			
Ethanol	2.56E-01	4.10E+00	Particulates (unspfd)	2.53E+00	4.05E+01			
Ethene	1.88E-02	3.00E-01	Pb	8.25E-03	1.32E-01			
Fe	3.01E-02	4.82E-01	Phenol	8.19E-01	1.31E+01			
Formaldehyde	1.35E-01	2.16E+00	propylene glycol	7.44E-01	1.19E+01			

Table continued (next page)

Table 1.6b cont. Cumulative LCI Results from SimaPro for the Production of 1000 Cubic Feet (MCF) or 1000 Cubic Meters ($10^3 m^3$) of Glulam in the PNW. Results Include Inputs for the Production of PNW Lumber (Milota 2004a), Electricity, Fuels, Resins (Nilsson 2001), and Ancillary Materials. Transportation of Resource to the Sawmill and Transportation of Raw Materials to the Glulam Facility Have Been Omitted. Co-Products Were Not Included.

Emissions to water	lb/MCF	kg/$10^3 m^3$	Emissions to water	lb/MCF	kg/$10^3 m^3$	Emissions to land	lb/MCF	kg/$10^3 m^3$
Acid as H+	1.61E-07	2.58E-06	Metallic ions	3.69E-03	5.91E-02	Building waste	6.50E-02	1.04E+00
Acids (unspcfd)	7.06E-03	1.13E-01	Metals	3.36E-02	5.38E-01	Hazardous waste	2.38E+00	3.81E+01
Al	8.69E-03	1.39E-01	Mn	3.43E-02	5.49E-01	Highly radioactive waste	3.33E-01	5.33E+00
Al_3	1.11E-03	1.77E-02	Na	1.60E-01	2.56E+00	Inorganic general	4.28E+01	6.85E+02
AOX	1.14E-04	1.83E-03	NaCl	1.46E-01	2.33E+00	Landfilled	3.95E+00	6.33E+01
B	4.08E-02	6.53E-01	NH_3	6.25E-03	1.00E-01	Mineral waste	3.00E+00	4.81E+01
BOD	2.25E-01	3.60E+00	NH_4+	3.23E-03	5.17E-02	Mixed industrial waste	6.44E-01	1.03E+01
Ca	1.84E-05	2.95E-04	Ni	9.50E-11	1.52E-09	Non hazardous waste	5.09E+01	8.15E+02
Calcium ions	3.63E-04	5.81E-03	Nitrate	3.56E-04	5.70E-03	Paper/board packaging	4.70E+00	7.53E+01
Cd	6.81E-03	1.09E-01	N-tot	2.37E-02	3.79E-01	Slags/ash	7.75E-01	1.24E+01
Chromate	1.89E-05	3.02E-04	Oil	1.88E+00	3.01E+01	Sludge	6.63E-01	1.06E+01
Cl-	4.88E+00	7.82E+01	Organic carbon	5.36E-03	8.58E-02	Solid waste	1.07E+03	1.71E+04
CO_3	1.20E+00	1.92E+01	Other organics	8.56E-01	1.37E+01	Waste in incineration	9.94E-01	1.59E+01
COD	2.93E+00	4.69E+01	P	7.69E-04	1.23E-02	Waste to recycling	4.81E-01	7.71E+00
Cr	4.83E-03	7.74E-02	Pb	3.55E-07	5.69E-06	Wood	4.34E-01	6.96E+00
Cyanide	3.46E-05	5.54E-04	Phenol	1.28E-03	2.05E-02			
Dissolved organics	5.41E-03	8.66E-02	Phosphate	1.33E-02	2.12E-01			
Dissolved solids	1.08E+02	1.73E+03	P-tot	5.12E-03	8.20E-02			
Fe	6.14E-02	9.84E-01	SiO_2	6.56E-05	1.05E-03			
Fluoride ions	1.76E-03	2.82E-02	SO_4^{2-}	2.76E-01	4.43E+00			
Formaldehyde	3.38E-05	5.42E-04	Sr^{4+}	4.36E-05	6.99E-04			
Gypson	3.82E-04	6.12E-03	Sulphate	4.06E+00	6.49E+01			
H+	1.48E-02	2.36E-01	Sulphide	2.34E-03	3.74E-02			
H_2SO_4	1.02E-02	1.63E-01	Suspended solids	3.68E+00	5.90E+01			
Hg	1.52E-03	2.43E-02	Total org. carbon	8.50E-02	1.36E+00			
Hydrocarbons	2.59E-02	4.16E-01	Water	1.28E+00	2.04E+01			
Ionics	6.50E-03	1.04E-01	Zn	1.71E-03	2.73E-02			
Limestone	4.91E-04	7.86E-03						

Table 1.6c. Reduced LCI Results Exported from SimaPro for the Production of 1,000 cubic feet (MCF) or 1,000 Cubic Meters (10^3m^3) of Glulam in the PNW. Results Include Inputs for the Production of PNW Lumber (Milota 2004a), Fuels, Resins (Nilsson 2001) and Ancillary Materials. PNW Electricity Generation[1/]; Transportation and Use Have Been Omitted. Co-Products Were Not Included.

Emissions to air	lb/MCF	kg/10^3m^3	Emissions to air	lb/MCF	kg/10^3m^3	Emissions to air	lb/MCF	kg/10^3m^3
Acetaldehyde	4.13E-02	6.62E-01	Fe	3.01E-02	4.82E-01	Propylene glycol	7.44E-01	1.19E+01
Acrolein	1.11E-05	1.78E-04	Formaldehyde	1.35E-01	2.16E+00	Particulates (PM10)	2.64E+00	4.24E+01
Aldehydes	4.60E-02	7.37E-01	HCl	2.59E-02	4.16E-01	Particulates (unspecified)	1.63E+00	2.60E+01
Ammonia	9.00E-03	1.44E-01	HCOOH	5.31E-03	8.51E-02	Pb	8.25E-03	1.32E-01
Aromatics	5.86E-03	9.39E-02	HF	1.01E-03	1.62E-02	Resorcinol	5.11E-04	8.18E-03
As	6.38E-04	1.02E-02	Hg	1.31E-05	2.09E-04	Sb	4.01E-06	6.42E-05
Ba	3.01E-02	4.82E-01	Hydrocarbons	2.57E+00	4.12E+01	Se	1.39E-05	2.23E-04
Be	4.15E-06	6.65E-05	Isopropanol	1.07E+01	1.71E+02	SO_2	1.33E+00	2.12E+01
Benzene	2.51E-02	4.03E-01	K	5.33E+00	8.54E+01	SOx	6.49E+01	1.04E+03
Cd	2.11E-05	3.38E-04	Kerosene	3.68E-05	5.90E-04	Tetrachloroethene	1.45E-06	2.32E-05
Cl_2	5.34E-02	8.55E-01	Metals	3.64E-04	5.83E-03	Tetrachloromethane	4.81E-06	7.70E-05
Co	1.10E+02	1.76E+03	Methane	1.33E+01	2.13E+02	Total reduced sulfur	4.57E-03	7.32E-02
CO_2 (biomass)	1.42E+04	2.27E+05	Methanol	6.24E-01	9.99E+00	Trichloroethene	1.38E-06	2.21E-05
CO_2 (fossil)	5.08E+03	8.15E+04	Mn	6.17E-02	9.88E-01	VOC	1.93E+01	3.08E+02
CO_2 (non-fossil)	1.74E+02	2.79E+03	N_2O	1.16E-02	1.85E-01	Zn	3.01E-02	4.82E-01
Cobalt	1.13E-05	1.81E-04	Na	1.23E-01	1.97E+00		**Bq/MCF**	**Bq/10^3m^3**
Cr	3.88E-04	6.21E-03	Naphthalene	1.64E-02	2.63E-01	Radioactive substance to air	9.66E+05	3.41E+06
Cu	2.73E-07	4.38E-06	NH_3	8.13E-03	1.30E-01			
Dichloromethane	6.44E-06	1.03E-04	Ni	4.03E-03	6.46E-02			
Dimethyl ether	2.91E-04	4.67E-03	N-nitrodimethylamine	3.11E-07	4.98E-06			
Dioxin (TEQ)	8.13E-12	1.30E-10	Non methane VOC	1.79E+01	2.86E+02			
Dust	6.56E-01	1.05E+01	NOx	3.55E+01	5.69E+02			
Dust (coarse)	5.17E+00	8.28E+01	Organic substances	1.55E+00	2.48E+01			
Dust (PM10)	5.02E-01	8.04E+00	PAH's	1.05E-03	1.68E-02			
Ethanol	2.56E-01	4.10E+00	Particulates	3.09E+01	4.95E+02			
Ethene	1.88E-02	3.00E-01	Phenol	8.19E-01	1.31E+01			

Table continued (next page)

Table 1.6c. Reduced LCI Results Exported from SimaPro for the Production of 1,000 cubic feet (MCF) or 1,000 Cubic Meters (10^3m^3) of Glulam in the PNW. Results Include Inputs for the Production of PNW Lumber (Milota 2004a), Fuels, Resins (Nilsson 2001) and Ancillary Materials. PNW Electricity Generation[1/]; Transportation and Use Have Been Omitted. Co-Products Were Not Included.

Emissions to land	lb/MCF	kg/10^3m^3	Emissions to water	lb/MCF	kg/10^3m^3	Emissions to water	lb/MCF	kg/10^3m^3
Building waste	6.50E-02	1.04E+00	Cd	6.08E-03	9.74E-02	NaCl	1.46E-01	2.33E+00
Hazardous waste	2.38E+00	3.81E+01	Chromate	9.69E-06	1.55E-04	NH_3	5.34E-03	8.55E-02
Highly radioactive waste	3.33E-01	5.33E+00	Cl-	4.13E+00	6.61E+01	NH_4^+	3.23E-03	5.17E-02
Inorganic general	4.28E+01	6.85E+02	CO_3	1.20E+00	1.92E+01	Ni	9.50E-11	1.52E-09
Landfilled	3.95E+00	6.33E+01	COD	2.69E+00	4.32E+01	Nitrate	2.03E-04	3.25E-03
Mineral waste	3.00E+00	4.81E+01	Cr	4.08E-03	6.53E-02	N-tot	2.37E-02	3.79E-01
Mixed industrial waste	6.44E-01	1.03E+01	Cyanide	3.34E-05	5.36E-04	Oil	1.59E+00	2.55E+01
Non hazardous waste	5.09E+01	8.15E+02	Dissolved organics	5.41E-03	8.66E-02	Organic carbon	5.36E-03	8.58E-02
Paper/board packaging	4.70E+00	7.53E+01	Dissolved solids	9.16E+01	1.47E+03	Other organics	8.06E-01	1.29E+01
Slags/ash	7.75E-01	1.24E+01	Fe	1.18E-02	1.89E-01	P	7.69E-04	1.23E-02
Sludge	6.63E-01	1.06E+01	Fluoride ions	1.47E-04	2.35E-03	Pb	3.33E-07	5.33E-06
Solid waste	8.82E+02	1.41E+04	Formaldehyde	3.38E-05	5.42E-04	Phenol	1.28E-03	2.05E-02
Waste in incineration	9.94E-01	1.59E+01	Gypson	3.82E-04	6.12E-03	Phosphate	9.19E-03	1.47E-01
Waste to recycling	4.81E-01	7.71E+00	H+	1.48E-02	2.36E-01	P-tot	5.12E-03	8.20E-02
Wood	4.34E-01	6.96E+00	H_2SO_4	2.03E-03	3.25E-02	SiO_2	6.56E-05	1.05E-03
Emissions to water	**lb/MCF**	**kg/10^3m^3**	Hg	1.52E-03	2.43E-02	SO_4^{2}-	2.76E-01	4.43E+00
Acid as H+	1.48E-07	2.37E-06	Hydrocarbons	2.59E-02	4.16E-01	Sr4+	4.36E-05	6.99E-04
Acids (unspecified)	7.06E-03	1.13E-01	Ionics	6.50E-03	1.04E-01	Sulphate	3.26E+00	5.22E+01
Al	8.69E-03	1.39E-01	Limestone	4.91E-04	7.86E-03	Sulphide	2.34E-03	3.74E-02
Al_3	1.11E-03	1.77E-02	Metallic ions	3.41E-03	5.47E-02	Suspended solids	2.85E+00	4.57E+01
AOX	1.14E-04	1.83E-03	Metals	3.36E-02	5.38E-01	Total organic carbon	8.50E-02	1.36E+00
B	8.13E-03	1.30E-01	Mn	6.50E-03	1.04E-01	Water	1.28E+00	2.04E+01
BOD	2.09E-01	3.34E+00	Na	1.59E-01	2.55E+00	Zn	1.44E-03	2.31E-02
Ca	1.84E-05	2.95E-04						
Calcium ions	1.32E-05	2.11E-04						

[1] Emissions from electricity production and use in the manufacturing of resins are included. These emissions cannot be separated from resin production emissions in the referenced database. (Nilsson 2001).

Table 1.6d. Reduced LCI Results Exported from SimaPro for the Production of 1,000 cubic feet (MCF) or 1,000 Cubic Meters (10^3m^3) of Glulam in the PNW. Included are PNW Lumber Production (Milota 2004a), Fuel, Ancillary Materials, and Electricity Production. Emissions from Resin Production Have Been Omitted. Co-Products Were Not Included

Emissions to air	lb/MCF	$kg/10^3m^3$	Emissions to air	lb/MCF	$kg/10^3m^3$	Emissions to air	lb/MCF	$kg/10^3m^3$
Acetaldehyde	4.13E-02	6.62E-01	Isopropanol	1.07E+01	1.71E+02	Trichloroethene	1.34E-05	2.14E-04
Acrolein	2.38E-05	3.81E-04	K	5.33E+00	8.54E+01	VOC	1.89E+01	3.02E+02
Aldehydes	3.89E-02	6.24E-01	Kerosene	4.43E-04	7.10E-03	Zn	3.01E-02	4.82E-01
Ammonia	2.53E-02	4.05E-01	Metals	5.61E-04	8.99E-03	Nonmaterial air emissions	**Bq/MCF**	**$Bq/10^3m^3$**
As	6.75E-04	1.08E-02	Methane	1.52E+01	2.43E+02	Radioactive substances to air	1.78E+07	6.29E+05
Ba	3.01E-02	4.82E-01	Methanol	5.66E-01	9.06E+00			
Be	7.56E-06	1.21E-04	Mn	6.18E-02	9.89E-01			
Benzene	2.46E-02	3.94E-01	N^2O	1.06E-02	1.69E-01			
Cd	3.35E-05	5.37E-04	Na	1.23E-01	1.97E+00			
Cl_2	5.34E-02	8.55E-01	Naphthalene	1.64E-02	2.63E-01			
CO	1.10E+02	1.76E+03	Ni	4.21E-03	6.74E-02			
CO_2 (biomass)	1.42E+04	2.27E+05	N-nitrodimethylamine	2.99E-06	4.80E-05			
CO_2 (fossil)	5.85E+03	9.37E+04	Non methane VOC	2.08E+01	3.33E+02			
CO_2 (non-fossil)	1.74E+02	2.79E+03	NOx	3.69E+01	5.91E+02			
cobalt	3.12E-05	5.00E-04	Organic substances	1.53E+00	2.44E+01			
Cr	4.32E-04	6.92E-03	Particulates	3.09E+01	4.95E+02			
Cu	2.73E-07	4.38E-06	Particulates (PM10)	2.84E+00	4.55E+01			
Dichloromethane	5.66E-05	9.06E-04	Particulates (unspecified)	2.53E+00	4.05E+01			
Dioxin (TEQ)	7.56E-11	1.21E-09	Pb	8.25E-03	1.32E-01			
Dust (coarse)	5.17E+00	8.28E+01	Phenol	8.13E-01	1.30E+01			
Dust (PM10)	5.02E-01	8.04E+00	Resorcinol	5.11E-04	8.18E-03			
Ethanol	2.56E-01	4.10E+00	Sb	1.23E-05	1.97E-04			
Fe	3.01E-02	4.82E-01	Se	1.11E-04	1.78E-03			
Formaldehyde	1.35E-01	2.16E+00	SOx	7.82E+01	1.25E+03			
HCl	7.13E-02	1.14E+00	Tetrachloroethene	1.36E-05	2.17E-04			
HF	9.88E-03	1.58E-01	Tetrachloromethane	2.49E-05	3.98E-04			
Hg	3.81E-05	6.10E-04	Total reduced sulfur	4.57E-03	7.32E-02			

Table continued (next page)

Table 1.6d Reduced LCI Results Exported from SimaPro for the Production of 1,000 cubic feet (MCF) or 1,000 Cubic Meters (10^3m^3) of Glulam in the PNW. Included are PNW Lumber Production (Milota 2004a), Fuel, Ancillary Materials, and Electricity Production. Emissions from Resin Production Have Been Omitted.

Emissions to land	lb/MCF	kg/10^3m^3	Emissions to water	lb/MCF	kg/10^3m^3
Solid waste	1.07E+03	1.71E+04	Hg	3.79E-07	6.08E-06
Inorganic general	4.28E+01	6.85E+02	Metallic ions	3.69E-03	5.91E-02
Paper/board packaging	4.70E+00	7.53E+01	Mn	3.43E-02	5.49E-01
Wood	4.34E-01	6.96E+00	N-tot	3.65E-03	5.85E-02
			Na	7.00E-04	1.12E-02
Emissions to water	**lb/MCF**	**kg/10^3m^3**	NH_3	6.25E-03	1.00E-01
Dissolved solids	1.07E+02	1.71E+03	Ni	9.50E-11	1.52E-09
Acid as H+	1.61E-07	2.58E-06	Nitrate	3.56E-04	5.70E-03
Acids (unspecified)	7.06E-03	1.13E-01	Oil	1.87E+00	2.99E+01
Al	8.69E-03	1.39E-01	Organic carbon	5.36E-03	8.58E-02
B	4.08E-02	6.53E-01	Other organics	3.06E-01	4.90E+00
BOD	2.18E-01	3.49E+00	P-tot	5.12E-03	8.20E-02
Ca	1.84E-05	2.95E-04	Pb	3.55E-07	5.69E-06
Calcium ions	3.63E-04	5.81E-03	Phenol	2.46E-05	3.94E-04
Cd	4.83E-03	7.74E-02	Phosphate	1.33E-02	2.12E-01
Chromate	1.89E-05	3.02E-04	Sulphate	4.01E+00	6.42E+01
Cl-	4.84E+00	7.75E+01	Sulphide	2.34E-03	3.74E-02
COD	2.51E+00	4.03E+01	Suspended solids	2.66E+00	4.27E+01
Cr	4.83E-03	7.74E-02	Water	1.28E+00	2.04E+01
Cyanide	3.46E-05	5.54E-04	Zn	1.71E-03	2.73E-02
Fe	6.14E-02	9.84E-01			
Fluoride ions	1.76E-03	2.82E-02			
H_2SO_4	1.02E-02	1.63E-01			

Table 1.6e. Cumulative On-site LCI Exported from SimaPro for the Production of 1,000 Cubic Feet (MCF) or 1,000 Cubic Meters (10^3m^3) of PNW Glulam Beams.

Emissions to air	lb/MCF	kg/10^3m^3
Acetaldehyde	6.75E-03	1.08E-01
As	1.98E-04	3.16E-03
Ba	9.88E-03	1.58E-01
Benzene	8.06E-03	1.29E-01
Cl_2	1.75E-02	2.80E-01
CO	3.08E+01	4.94E+02
CO_2 (biomass)	4.73E+03	7.57E+04
Cr	1.03E-04	1.65E-03
Ethanol	2.56E-01	4.10E+00
Fe	9.88E-03	1.58E-01
Formaldehyde	3.24E-02	5.19E-01
Isopropanol	1.07E+01	1.71E+02
K	1.75E+00	2.80E+01
Methanol	5.30E-01	8.49E+00
Mn	2.03E-02	3.24E-01
Na	4.04E-02	6.48E-01
Naphthalene	5.39E-03	8.64E-02
Ni	1.26E-03	2.01E-02
NOx	4.18E+00	6.70E+01
Organic substances	3.73E-01	5.98E+00
Particulates	2.93E+01	4.70E+02
Particulates (PM10)	2.61E+00	4.19E+01
Pb	2.69E-03	4.32E-02
Phenol	6.25E-01	1.00E+01
Resorcinol	5.11E-04	8.18E-03
SOx	1.98E-01	3.16E+00
VOC	1.47E+01	2.35E+02
Zn	9.88E-03	1.58E-01
Emissions to land		
Solid waste	2.06E+02	3.30E+03

Notes: Data is from On-Site Production of PNW Glulam Beams. Excludes Impacts Associated with Fuel, Electricity, Lumber, Resin and Ancillary Materials Production and Use. Included are Impacts Associated with Planing and Trimming, Face Bonding and Pressing, and Finishing of Glulam Beams and Boiler Emissions for Drying Lumber. Co-Products Were Not Included.

1.7 SENSITIVITY ANALYSIS

A sensitivity analysis was done on the radio-frequency cure process in comparison to the cold cure process. The radio frequency process represented the best opportunity for making variable changes because this process involved a boiler and made use of both purchased green and dry lumber. It was expected that the cold cure process would show a lesser energy requirement, and therefore a lower impact. This was not the case for any of the scenarios. The three scenarios were: 1) base case, no changes to either process, 2) substitution of facility heating with hogged fuel to facility heating with natural gas, using the natural gas weighted average requirement, and 3) substitution of purchased green lumber with dried lumber with no additional drying. The results of the analyses are shown in Table 1.7.

1.7.1 Base Case-No Change

In this analysis, a greater impact was indicated for the cold cure process based on emissions outputs (Table 1.7). The cold cure process used natural gas as its only heat source, 1.60E+07 BTU/MCF (w/co-product), while the radio frequency process used 2.39E+07 BTU/MCF all from hogged fuel. There is a much greater impact for the production and use of natural gas than there is from hogged fuel use. Carbon dioxide from fossil fuel combustion (CO_2, fossil) in the cold cure process was 48% higher than CO_2 (fossil) emissions from the radio frequency process due to the use of natural gas. As expected, electricity use was greater for the radio frequency process than the cold cure process with 1,959 kWh and 1,613 kWh/MCF, respectively but the impact of electricity generation in the PNW is not large because of the amount of hydropower generation (74%) that is used there.

1.7.2 Substitution of Hogged Fuel for Natural Gas

Based on survey data it appears that manufacturing employing the radio frequency process used an inefficient wood boiler to heat the glulam facility. In this case facility heating consumed a large amount of the energy (64%) required for glulam on-site production (Table 1.3b). This boiler was also used to heat kilns used for drying of green lumber. A model was run with removal of the hogged fuel burned for facility heating and replaced with the weighted average natural gas use reported from surveys that did not have a boiler or kiln. Differences were most noticeable in the release of CO_2 biomass and CO_2 fossil; the differences were 38% lower and 9% higher respectively. Overall, emissions associated with cold cure glulam manufacturing were still higher than those associated with radio frequency processing.

1.7.3 Substitution of Purchased Green Lumber with Kiln-Dried Lumber

This scenario examined the impacts on the RF glulam process of substituting kiln-dried lumber for green lumber. Based on survey data, approximately 25% of the total lumber purchased was purchased at a moisture content above 19% and thus required additional drying. All lumber drying was accomplished with 100 percent hogged fuel. This scenario removed the green lumber component and replaced it with kiln-dried lumber from the PNW lumber model (Milota 2003a). As in previous analyses, environmental impacts based on emission outputs from each glulam process were higher for the cold cure process than for the radio frequency process. After reviewing the surveys and follow-up with the glulam producers, it was confirmed that the differences between the two processes stemmed from resin use. The cold cure processes used more resin (461 lb/MCF for PRF and 86 lb/MCF for MUF, with co-product) than the radio frequency processes (279 lb/MCF for PRF and 55 lb/MCF for MUF, with co-product).

Table 1.7. Sensitivity Analysis Comparing the Cold Cure (CC) and Radio Frequency (RF) Glulam Processes.

Substance		CC Glulam	Scenario 1 RF Glulam, No Change	Scenario 2 RF Glulam, With Natural Gas Facility Heating	Scenario 3 RF Glulam, No Hogged Fuel
Emissions to air	**Unit**	**Unit/MCF**	**Unit/MCF**	**Unit/MCF**	**Unit/MCF**
CO	lb	1.01E+02	1.02E+02	6.95E+01	9.26E+01
CO_2 (biomass)	lb	1.22E+04	1.37E+04	8.56E+03	1.15E+04
CO_2 (fossil)	lb	9.14E+03	4.77E+03	5.22E+03	7.08E+03
Formaldehyde	lb	9.75E-02	8.94E-02	7.31E-02	9.31E-02
K	lb	4.57E+00	5.17E+00	3.26E+00	4.34E+00
Methane	lb	2.41E+01	1.23E+01	1.35E+01	1.86E+01
Na	lb	1.06E-01	1.19E-01	7.50E-02	1.00E-01
Non-methane VOC	lb	2.97E+01	1.39E+01	1.57E+01	2.28E+01
NOx	lb	4.59E+01	3.24E+01	2.93E+01	3.79E+01
Organic substances	lb	1.46E+00	1.45E+00	1.05E+00	1.41E+00
Particulates	lb	1.75E+00	1.67E+00	1.24E+00	1.68E+00
Particulates (unspecified)	lb	2.75E+00	2.07E+00	2.08E+00	2.84E+00
Phenol	lb	2.46E-01	2.73E-01	1.75E-01	2.31E-01
SOx	lb	1.15E+02	5.69E+01	6.34E+01	9.00E+01
VOC	lb	5.54E+00	3.53E+00	3.53E+00	4.99E+00
Raw materials					
Natural gas	ft^3	2.34E-01	1.78E-01	1.78E-01	2.19E-01
Natural gas FAL	lb	2.94E+03	1.31E+03	1.50E+03	1.11E+00
Wood/wood wastes FAL	lb	8.39E+01	3.50E+03	1.04E+03	1.93E+02
Solid waste	lb	1.02E+03	9.26E+02	7.20E+02	9.46E+02
Dissolved solids	lb	1.60E+02	7.32E+01	8.34E+01	1.22E+02
Iron (ore)	lb	5.78E+00	3.21E+00	3.21E+00	5.43E+00
Cl-	lb	7.19E+00	3.29E+00	3.76E+00	5.52E+00
Oil	lb	2.79E+00	1.28E+00	1.45E+00	2.13E+00
Sulphate	lb	5.81E+00	2.74E+00	3.11E+00	4.51E+00
Suspended solids	lb	5.09E+00	2.94E+00	3.12E+00	3.89E+00
Water (surface, for cooling)	lb	1.50E+04	9.18E+03	9.18E+03	1.41E+04

Notes: Three scenarios where modeled: 1) Base case, no changes to either process, 2) Substitute facility heating with hogged fuel for facility heating with natural gas, using the natural gas weighted average, and 3) Removal of purchased green lumber to purchasing all dried lumber with no additional drying.

1.8 CARBON BALANCE

A biomass carbon balance on the wood-based material into the glulam process model is shown in Figure 1.8. Inputs include only wood based materials (lumber and hogged fuel) into the glulam process (lumber manufacturing excluded). A PNW lumber carbon balance can be found in Softwood-Lumber-Pacific Northwest CORRIM Phase I Report (Milota 2003a). Outputs include products and co-products as reported in glulam surveys. Emissions related to wood combustion in boilers have been included (FAL 2001). Since there was very little co-product produced in the glulam process, the carbon balance was based on wood carbon only in and out of the glulam process. Table 1.8 shows wood-related carbon statistics for lumber and hogged fuel inputs and output air emissions and products and co-products for the production of 1000 cubic feet of glulam (MCF). The lumber input included a 9% unaccounted lumber inputs (Table 1.2) therefore making the carbon balance between inputs and outputs within 1.5%. The carbon ratios were obtained from Birdsey (1992) and Skog and Nicholson (1998). The sum of the carbon out of the glulam process (w/ boiler) was 19,881 lb/MCF. Of this, 76% was in product, with 17% in co-products. The other 7% was in the form of air emissions with CO_2 biomass contributing 97% of that. Carbon dioxide (biomass) emissions were a result of the combustion of wood in the hogged fuel boiler.

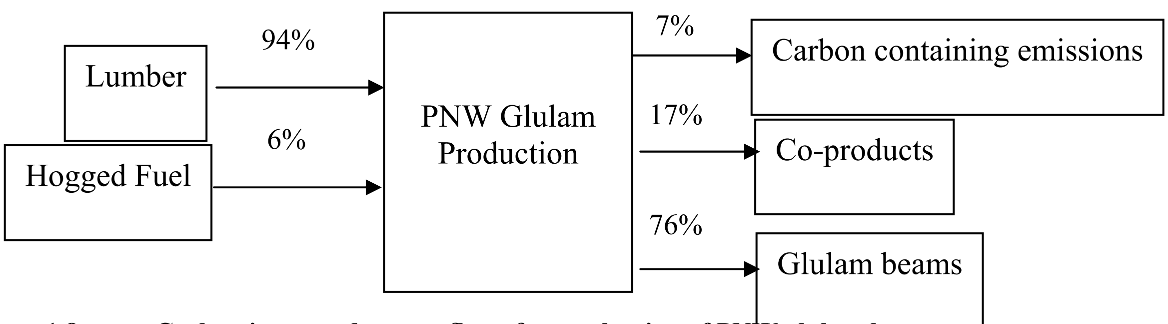

Figure 1.8. Carbon input and output flows for production of PNW glulam beams.
Note: Flows are for wood related carbon only.

Table 1.8. A Carbon Balance for PNW Glulam Production.

C-containing INPUTS	Substance	Glulam lb/MCF	Carbon lb/MCF	Carbon Ratio in Material
Green lumber	Raw	9.30E+03	4.68E+03	
Dry lumber	Raw	2.73E+04	1.38E+04	
Hogged fuel	Raw	2.25E+03	1.13E+03	
TOTAL INPUTS		**2.25E+03**	**1.96E+04**	

C-containing OUTPUTS	Substance	Glulam lb/MCF	Carbon lb/MCF	Carbon Ratio in Material
Acetaldehyde	Air	6.75E-03	3.65E-03	5.40E-01
Benzene	Air	8.06E-03	7.44E-03	9.23E-01
CO	Air	3.08E+01	1.32E+01	4.29E-01
CO_2 (biomass)	Air	4.73E+03	1.29E+03	2.73E-01
Ethanol	Air	2.56E-01	1.34E-01	5.22E-01
Formaldehyde	Air	3.24E-02	6.48E-03	4.00E-01
Isopropanol	Air	1.07E+01	6.43E+00	6.01E-01
Methanol	Air	5.30E-01	1.99E-01	3.75E-01
Naphthalene	Air	5.39E-03	5.05E-03	9.37E-01
Organic substances	Air	3.73E-01	1.87E-01	5.00E-01
Particulates	Air	2.93E+01	1.48E+01	5.04E-01
Particulates (PM10)	Air	2.61E+00	1.31E+00	5.04E-01
Phenol	Air	6.25E-01	2.39E-01	7.66E-01
Subtotal		**4.81E+03**	**1.33E+03**	
Glulam	Product	3.02E+04	1.52E+04	5.04E-01
Trimmings	Co-product	2.27E+02	1.14E+02	5.04E-01
Shavings	Co-product	5.18E+03	2.61E+03	5.04E-01
Wood waste	Co-product	1.23E+03	6.20E+02	5.04E-01
TOTAL OUTPUTS		**4.16E+04**	**1.99E+04**	

Notes: Included are wood related carbon containing inputs and outputs for the glulam process only. Carbon containing substances from fuels, electricity, resin, and PNW lumber production are not included.

1.9 COST ANALYSIS

A cost analysis was done of the glulam beam manufacturing process. The analysis was based on 2.13E+03 1,000 cubic feet (MCF, actual volume) of production per year representing a composite of the PNW glulam manufacturers surveyed. The assumptions for this analysis are shown in Table 1.9. Capital cost estimates were based on the construction of a new glulam facility and straight-line depreciation over 20 years and included value of land, buildings, and equipment. Energy costs were obtained from government sources. Lamstock prices were obtained from a manufacturer and reflect an average cost of random length lamstock for the year 2001. Insurance, maintenance, and labor costs were estimated based on discussions with industry personal. Results are shown as cost per year and as cost per 1,000 cubic foot (MCF) of glulam.

Table 1.9. PNW Glulam Production Cost Analysis for On-Site Production of 1,000 Cubic Feet (MCF) of Glulam Beams.

	Assumptions for Cost Analysis			Cost of Producing PNW Glulam Beams	
VARIABLE COST	**Units**	**Unit/MCF**	**$/Unit**	**$/Year**	**$/MCF**
Energy consumption:					
Electricity	kWh	2390.00	0.04	216,355	102
Hogged fuel (dry)	lbs	2768.00	0.01	29,479	14
Natural gas	MCF	4.03	5.64	48,413	23
Diesel	gallons	2.71	0.91	5,235	2
Gasoline	gallons	0.69	1.09	1,593	1
Liquid propane gas	gallons	12.10	1.07	27,680	13
Total energy cost				**328,756**	**154**
Materials:					
Green lumber, actual	MBF[1]	3.94	642.59	5,392,777	2,532
Dried lumber, actual	MBF	9.72	669.37	13,858,341	6,506
PRF resin	lbs	382.00	0.75	610,245	287
MUF resin	lbs	66.77	1.00	142,220	67
Total material cost				**20,003,583**	**9,391**
Total variable cost				**20,332,339**	**8,546**
FIXED COST					
Capital	$			1,000,000	463
Maintenance	$			1,000,000	463
Labor	$			4,140,000	1,917
Overhead	$			621,000	288
Interest	%		8.00%	1,600,000	741
Total fixed cost				**8,361,000**	**3,871**
Total Cost				**28,693,339**	**13,417**
Income:					
Co-products	lbs	6637.00	0.015	212,052	100
Selling price for glulam	$			28,926,439	13,580
Total income	**$**			**29,138,491**	**13,680**
Profit, sales, tax	**$**			**445,152**	**264**

[1] MBF=1,000 board feet

1.10 CONCLUSIONS

The data collected on PNW glulam production represents 70% of the regions glulam production for the production year 2000. Both cold cure and radio-frequency-cure processes were included in the survey. Total heat energy for glulam production was driven by the lumber drying process, which consumed 78% (without co-product) of the total heat energy (excluding resin) and 60% when resin was included. Hogged fuel contributed 65% of the total heat energy required (lumber and glulam processes only). Lumber manufacturing used 45% of the electrical energy required for glulam production. Resin manufacturing consumed 20% of the total energy primarily from natural gas and crude oil, and 7% of the total electricity.

Reported data on process air emissions differed between glulam manufacturers; differences were dependent upon government regulations that applied to each facility depending upon process type and whether they operated dry kilns and/or wood-fired boilers. Overall, emissions associated with the cold cure process were higher than those associated with the radio-frequency process.

Future work should emphasize regional boiler emissions for natural gas and hogged fuel types and resin production. Resin databases are based on European data, which may not represent regional energy production in the United States.

2.0 SOUTHEAST GLULAM BEAMS

2.1 INTRODUCTION

Structural glued laminated timber (glulam) is one of the oldest glued engineered wood products dating back to the late 1800s. Their uses are as structural concealed or exposed beams and columns in residential and commercial construction, warehouse roof beams and purlins, church arches, and girders and deck panels for timber bridges. Glulam beams come in a variety of sizes with production based on nominal[12] board feet[13], and sold by retailers on a linear-foot basis. Over one-half of US glulam goes to new residential and remodeling uses, representing 52% (APA 2001) of all glulam produced. The next largest segment is the nonresidential market representing 38%. The remainder goes to industrial (2%) and export (8%). Glulam in the Southeast (SE) is made primarily from southern pines[14]. This report focuses on production practices in Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, and Texas. The total annual glulam production for the region was 139 million board feet (MMBF) (APA 2000) in 2001, representing 39% of all US glulam production. This study collected data from representative plants that would be considered in the upper portion of this range

To conduct the survey, glulam plants in the SE region were preliminarily screened and identified based on their production capability and representativeness of the industry. Two plants agreed to participate in the survey. Manufacturing plants provided data in terms of glulam and co-product production, raw materials, electricity and fuel use, and emissions. The glulam producers surveyed represent 43% of the region's production. Total annual production from producers surveyed was 60 million board feet (MMBF) (nominal).

This report documents the life-cycle inventory (LCI) of glulam beam manufacture based on softwood resources of the SE region. Primary data was collected through a survey of glulam manufacturers, while secondary data was obtained from impacts associated with the manufacture and delivery of electricity and all fuels (FAL 2001; PRé Consultants 2001; EIA 2001), and with the manufacture and delivery of resin (Nilsson 2001).

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[12] Nominal size-The size designation for most lumber. In lumber, the nominal size usually is greater than the actual dimension; a kiln dried 2x4 (nominal) is surfaced to 1-1/2 x 3-1/2 inches (actual).
[13] Board foot (BF)-The basic unit of measurement for lumber. One board foot is equal to a 1-inch board 12 inches in width and 1 foot in length
[14] "Southern pine" or "southern yellow pine" are terms used to describe a collection of several pine species (Panshin and de Zeeuw, 1980), typically, longleaf pine (*Pinus palustris* Mill.), shortleaf pine (*P. echinata* Mill), and slash pine (*P. elliottii* Engelm.).

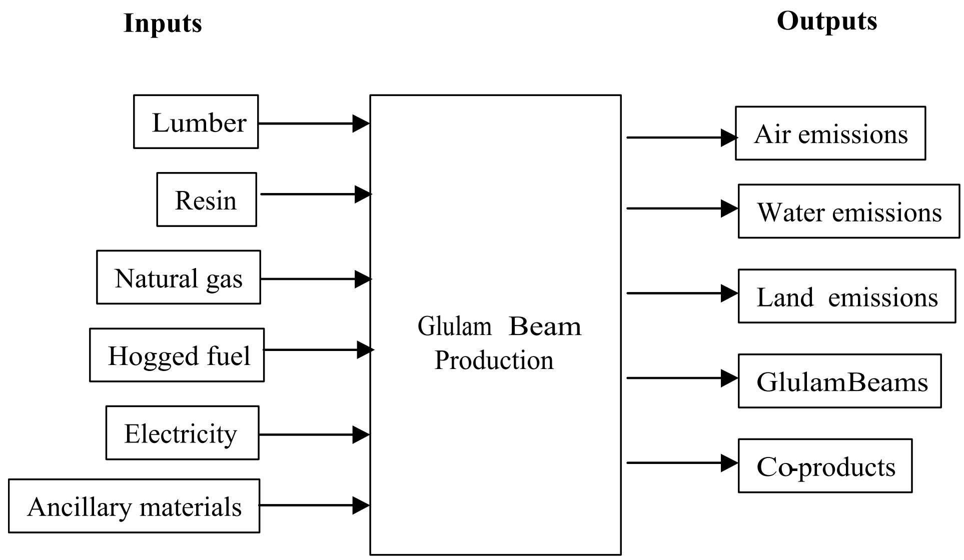

Figure 2.1. Single box approach to the modeling of the glulam manufacturing process.

A single unit process approach was taken in modeling the LCI of the glulam process (Figure 2.1). A typical manufacturing process consists of lumber drying (when purchasing green lumber), grading, trimming, finger jointing or end jointing, planing, face bonding, finishing and fabrication. Before shipping, each beam is typically individually wrapped for protection from weather.

The functional unit used throughout this report is 1000 cubic feet (MCF)[15], actual volume of glulam beams, which includes lumber and resin. The system boundary is gate to gate, i.e. from the point at which raw material enters the mill to production of the product (glulam) and co-products[16] (shavings and trimmings). A mass-based allocation was used for products and co-products.

The scope of this report encompasses an analysis of glulam beams from the SE region (AL, AR, FL, GA, LA, MS, and TX) excluding raw material transport[17] to the production facility. The full system boundaries are confined to the production of softwood lumber (Milota 2004b) and resin materials, (Nilsson 2001) production of electricity, natural gas, diesel, gasoline, ancillary materials, and glulam beams and its co-products (Figure 2.2a). The system boundaries for the on-site glulam LCI model are confined to those processes that take place at the glulam facility (Figure 2.2b). Burdens associated with resource extraction, lumber production, fuel and electricity production, resin production, and all transportation of raw materials and fuels have been omitted.

[15] MCF=19.02 MBF (nominal), MBF=0.05 MCF

[16] Co-product is referred to as a material, other than the principal product, that is generated, retained, or sold for further commercial purposes because it has some economical value or function.

[17]Transportation distances are reported, but burdens associated with transportation are omitted from this report.

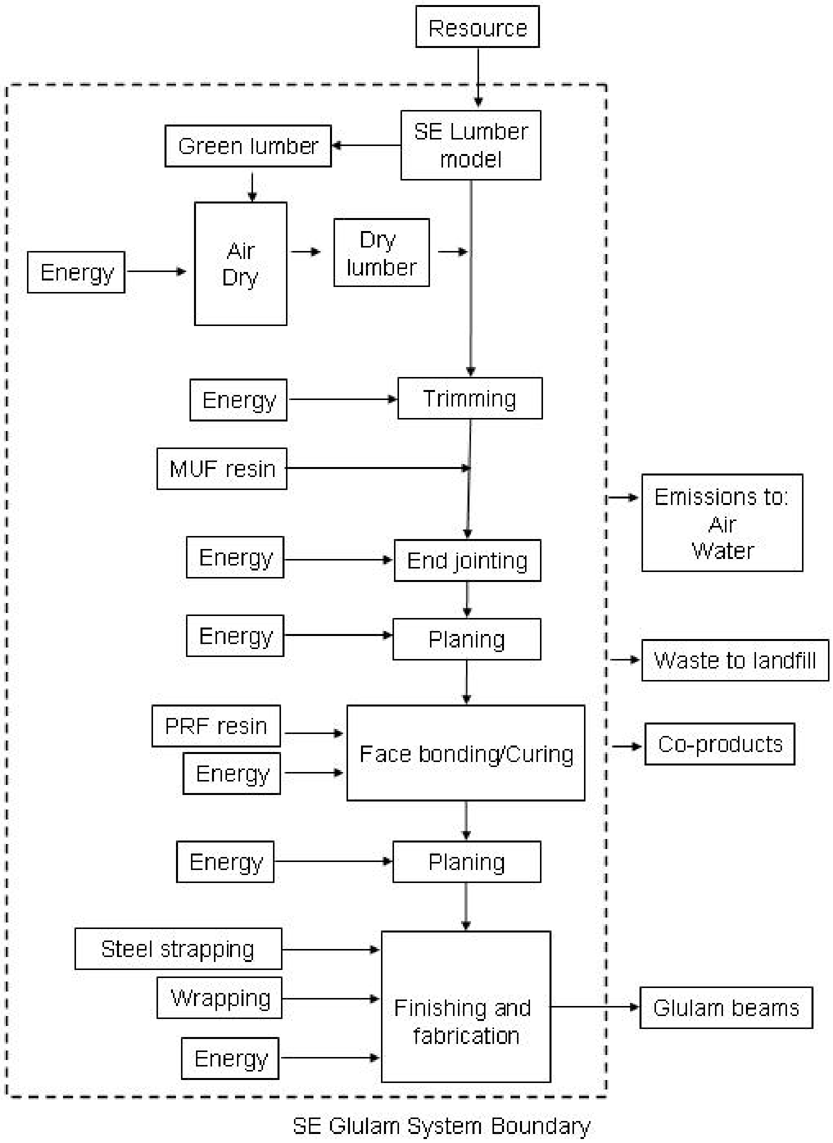

Figure 2.2a. **System boundary and SE glulam production flow used to model the full glulam manufacturing process. Burdens associated with resource transportation to the sawmill, and resin, lumber and hogged fuel transportation to the glulam facility have been omitted.**

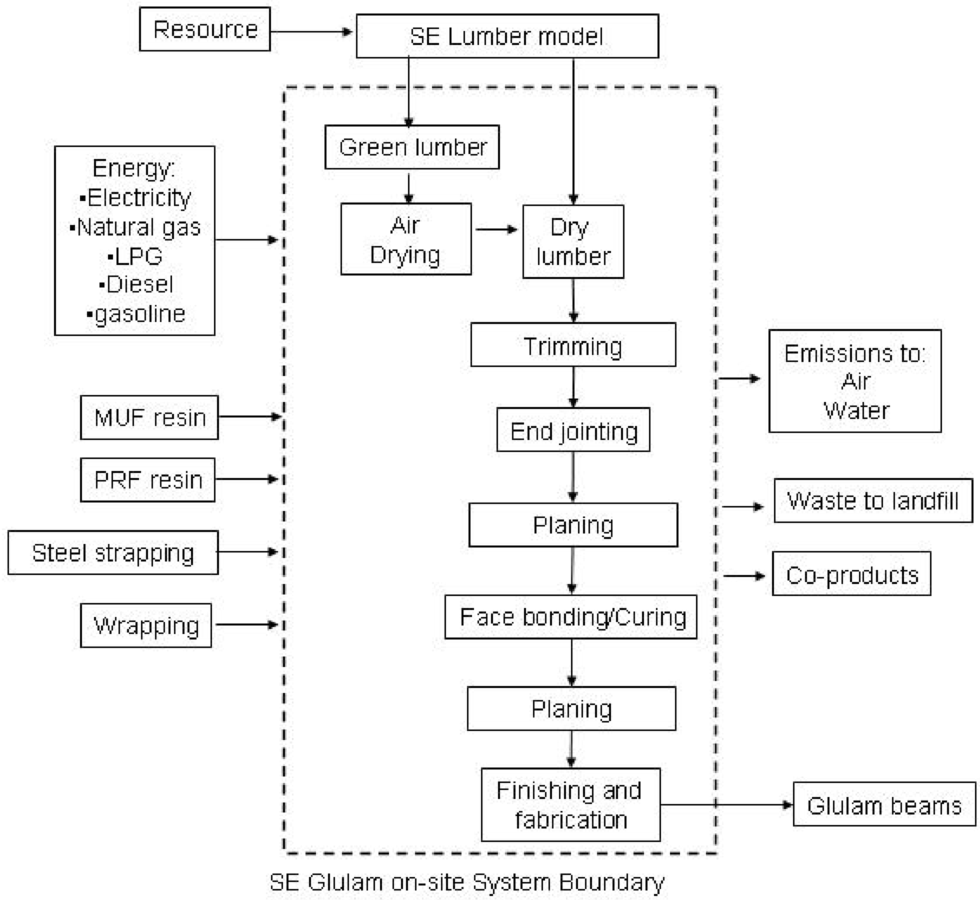

Figure 2.2b. System boundary and SE glulam production flow used to model the on-site glulam manufacturing process. Burdens associated with electricity and fuel production, resin manufacturing, lumber production, raw material production, and transportation are not included. Burdens associated with resource transportation to the sawmill, and resin, lumber and hogged fuel transportation to the glulam facility have been omitted.

2.1.1 Glulam Manufacturing

See Section 1.1.1

2.1.2 Material Flows

Those materials considered in the LCI analysis included those listed in Table 2.1a. Input materials considered were dry lumber, and phenol-resorcinol-formaldehyde (PRF) and melamine-urea-formaldehyde resins. Outputs were glulam beams and co-products consisting of trim, and shavings. All flows of wood in the glulam process were determined on an oven-dried weight basis. No hogged fuel was used in on-site production of glulam in the plants surveyed.

Table 2.1a. Listing of Input Materials, Co-products and Products for Producing Glulam Beams in the SE Region.

Input materials	Co-products Produced	Products
Lumber, >19%[1]	Trimmings	Glued laminated beams
Lumber, <19%	Shavings	
Phenol-resorcinol-formaldehyde resin (PRF)		
Melamine-urea-formaldehyde resin (MUF)		
Steel strapping		
Wrapping material		

[1]Lumber >19% moisture content is referred to as "green" (as reported in surveys), requiring additional drying by the glulam manufacturers.

The weight of the input wood (lumber) was determined by converting nominal board feet[18] to actual cubic feet. An actual to nominal ratio was calculated based on average percentages of each size beam produced (Appendix 2). Final conversions were made from cubic feet to mass (lb) by multiplying by the average weighted densities as determined by the species representation reported in the surveys (Table 2.1b). Densities of wood species were obtained from the Wood Handbook (FPL 1999). Lumber for glulam production in the SE was purchased as dimension lumber in the form of 2 x 8's (65%) and 2 x 6's (35%).

Table 2.1b. Average Density of Wood Species Used to Calculate Mass of Wood of Lumber Inputs and Glulam Beam Production.

Wood Species	Represented in Surveys %		Specific Gravity		Density[1] lb/ft^3 (kg/m^3)	
	Green	<19%	Green	12%	Green[2]	12%[3]
Loblolly pine	N/A	N/A	0.47	0.51	29.4 (471)	31.9 (511)
Slash pine	N/A	N/A	0.55	0.59	33.8 (542)	36.9 (591)
Average	0%	0.6%	0.51	0.55	31.6 (506)	34.3 (550)

[1]Wood density values are from the Wood Handbook: Wood as an Engineering Material (1999).
[2]Dry mass, volume at a moisture content greater than 30% oven-dry basis, commonly referred to as green
[3]Dry mass, volume at a moisture content of 12% oven-dry basis

[18] One board foot (BF) nominal = 0.05 cubic feet (CF) actual; 1 CF (actual) = 19.02 BF (nominal)

2.1.3 Transportation

Delivery of the input materials was by truck[19]. The one-way delivery distance for lumber, resin, strapping and wrapping paper are given in Table 2.1c.

Table 2.1c. Southeast Weighted Average Delivery Distance (One-Way) used for Glulam Production as Reported in Glulam Surveys. Burdens Associated with Transportation of the Materials are not Included in the SimaPro Glulam LCI Model.

	One-Way Delivery Distance	
Material	**Miles**	**Kilometers**
Lumber, green	N/A	N/A
Lumber, dry	234	433
Resin (PRF and MUF)	372	689
Steel strapping	658	1,219
Wrapping material	995	1,843

Note: Lumber production deliverables not included.

2.1.4 Assumptions

Procedures for data collection and analysis, and formulation of assumptions followed guidelines as defined in "Research Guidelines for Life Cycle Inventories (CORRIM 2001) dated April 8, 2001. Additional considerations include:

1. All data from the survey was weight averaged based on a particular mill's production in comparison to the total production for the year.

2. Missing data is defined as data not reported in surveys by the glulam facilities. Missing data were carefully noted so they were not averaged as zeros. When data was missing, for a variable, the weighted average for that variable reflected those facilities reporting the data in the surveys.

3. Density values for the wood species used to make the glulam were obtained from Wood Handbook—Wood as an Engineering Material (FPL 1999). A single density value was derived using the FPL numbers and the weighted percentage of use of each species as reported by manufacturers. The weighted average density for SE glulam was calculated to be 34.3 lb/ft^3 oven-dry weight, dry volume.

4. Lumber inputs were provided in board feet (BF) (Milota 2004b) and converted to actual volume using conversion factors developed in Appendix 2. SE lumber was purchased as dimension lumber.

5. The mass difference between reported input and output wood material flows was <1% (see Table 2.2 for material balance analysis).

6. SimaPro5 version 5.0.009 (PRé 2001), a software package designed for analyzing the environmental

[19] Transportation distances are reported, but burdens associated with transportation are omitted from this report. Lumber production deliverable are not included

impact of products during their whole life cycle, was used to do the life cycle analysis (LCI). Developed in The Netherlands by PRé Consultants, SimaPro5 contains a US database for a number of materials, including paper products, fuels, and chemicals. The US database is provided by Franklin Associates (FAL 2001) (http://www.fal.com).

2.2 PRODUCT YIELDS

To yield 34,400 lb of glulam beam (1.0 MCF, actual volume), 41,800 lb of lumber was required. A complete wood mass balance is given in Table 2.2. The difference between total wood input and output is 362 lb per 1,000 cubic feet. This unaccounted for wood amounted to <1% of the total wood input, which is considered very good for a survey of this type. The percentage of recovery of wood in terms of wood input as lumber and output as glulam beams is 82% - defined as the weight of wood in glulam beams divided by the total weight of input wood from the lumber time 100%.

Table 2.2. Wood Mass Balance (Weighted Averages) for Glulam Production From the SE Region Per 1,000 Cubic Feet (MCF) or Cubic Meter (m^3).

	lb/MCF Based on Actual Volume	kg/m^3 Based on Actual Volume	Allocation %
Inputs (*w/co-product)*			
Lumber	41,800	670	99.14
Unaccounted inputs (lumber)[1]	362	6	0.86
Total	42,162	676	100
Outputs			
Glulam beams (wood only)[2]	34,400	551	81.53
Shavings and trimmings	7,410	119	17.56
Wood waste	381	6	0.90
TOTAL	42,191	676	100

[1] Unaccounted for inputs of <1% is assumed to be lumber already on site prior to year of survey.
[2] 1.60E+03 MCF/annual production, actual volume, (1.92E+04 MBF, actual or 3.02E+04 MBF, nominal).
Notes: All weights are on an oven-dried basis. Does not include lumber manufacturing mass wood balance.)

2.3 MANUFACTURING ENERGY SUMMARY

2.3.1 Sources of Energy

Energy for the production of SE glulam beams comes from electricity, natural gas, gasoline, diesel, liquid propane gas (LPG) and hogged fuel used in lumber production. The electricity is used to operate the radio-frequency dryers, pneumatic and mechanical conveying equipment, kiln fans, hydraulic pumps, and saws. Hogged fuel was not used in SE glulam on-site manufacturing process. All hogged fuel use shown in this report is from the SE lumber model (Milota 2003b). Natural gas was used for additional drying of lumber in low heat kilns. On-site trucks and forklifts used diesel, gasoline, and LPG.

2.3.2 Electricity Use Summary

The source of fuel used to generate electricity has a major impact on the types of emissions resulting from energy production. In 2000 the dominant form of fuel source in the region was coal, representing 45.6% of the total, followed by natural gas at 23.0% and nuclear at 21.6% (see Table 2.3). In the Franklin database, no impacts are associated with hydro-generated electricity in the United States; however, combusting of coal can contribute significant impact values. Glulam production required 52% percent of total electricity with lumber and resin requiring 34 and 14 percent, respectively.

Table 2.3.a. Electric Power Requirements Allocated to 1,000 Cubic Feet (MCF) or 1,000 Cubic Meters (10^3m^3) of the Glulam On-Site Process Including Lumber and Resin Production by Primary Energy Sources for the SE region[1/].

		Glulam Process Only "On-Site"		Glulam Process with SE Lumber Production	
Fuel Source	**Percent of Total Electricity Production 2000[2]**	**kWh/MCF**	**MJ/10^3m^3**	**kWh/MCF**	**MJ/10^3m^3**
Coal	45.6	1.04E+03	1.32E+05	1.72E+03	2.18E+05
Petroleum	4.5	1.03E+02	1.30E+04	1.70E+02	2.15E+04
Natural Gas	23.0	5.25E+02	6.67E+04	8.67E+02	1.10E+05
Nuclear	21.6	4.93E+02	6.26E+04	8.14E+02	1.03E+05
Hydro	1.8	4.11E+01	5.22E+03	6.79E+01	8.62E+03
Other	3.5	7.99E+01	1.01E+04	1.32E+02	1.68E+04
SUB TOTAL	**100.0**	**2.28E+03**	**2.90E+05**	**3.77E+03**	**4.79E+05**
TOTAL w/ resin		**2.88E+03**	**1.06E+06**	**4.37E+03**	**9.44E+05**

[1] Average of Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, and Texas
[2] Source: Energy Information Administration/State Electric Power Annual 2000 Volume I, Department of Energy (EIA 2001). http://www.eia.doe.gov/cneaf/electricity/epav1/epav1_sum.html
Note: Co-products not included.

2.3.3 Thermal Energy Generation

No boilers were reported in the SE glulam production surveys. Boilers were reported for wood drying energy requirements in the SE lumber model (Milota 2004b) and are reported in Table 2.3b allocated to the energy required for lumber inputs used in the production of 1000 cubic feet of glulam beams.

Table 2.3b. Total Fuel Inputs1/ into all Boilers Required for Heat Energy for the Production of Kiln-Dried Lumber Used for Glulam inputs and at the On-Site Glulam Facility for the Production of 1000 Cubic Feet (MCF) or 1000 Cubic Meters (103m3) of SE Glulam Beams.

			Heat Energy		
	Unit of Fuel Input	**Fuel Input**	**BTU/MCF**	**MJ/10^3m^3**	**Heat Energy Allocation %**
TOTAL	-	-	4.79E+07	1.78E+06	100
Glulam Production	0.00	0.00	0.00	0.00	0
Hogged fuel[1/] (0%)	lb/MCF (kg/10^3m^3)	0.00	0.00	0.00	
Lumber Production	-	-	4.79E+07	1.78E+06	100
Hogged fuel (100%)	lb/MCF (kg/10^3m^3)	7.95E+03 (1.27E+05)	4.78E+07	1.78E+06	
Diesel (0.2%)	gal/MCF (L/10^3m^3)	7.42^E-01 (9.88^E+01)	1.03E+05	3.80E+03	

For hogged fuel used in the glulam process, the "Wood into Industrial Boilers" module was used from the Franklin database (FAL 2001) (Table 2.3c). The emissions resulting from burning hogged fuel and fuel consumed in generating hogged fuel are included in the LCI analysis. Resource extraction and transportation of the hogged are not included in this data. Future work should develop more complete information on wood burning boilers using CORRIM data that takes into account the resource extraction, specific wood products industry, geographic location, wood species, transportation, and fuel source, i.e. bark, or wood. To date, CORRIM has collected boiler data from manufacturers of softwood plywood, softwood lumber, and oriented strand board (OSB) (CORRIM 2004).

Table 2.3c. Non Cumulative Franklin Data[1/] used in the SimaPro SE Glulam Model. Data is for the Production of 3 Million BTU's of Heat Energy From the Combustion of 500 Lbs of Oven-Dried Wood.

Emissions to air	**lb/MCF**
Acetaldehyde	1.50E-03
As	4.40E-05
Ba	2.20E-03
Benzene	1.80E-03
Cl_2	3.90E-03
CO	6.80E+00
CO_2 (biomass)	1.05E+03
Cr	2.30E-05
Fe	2.20E-03
Formaldehyde	3.30E-03
K	3.90E-01
Mn	4.50E-03
Na	9.00E-03
Naphthalene	1.20E-03
Ni	2.80E-04
NOx	7.50E-01
Organic substances	8.30E-02
Particulates	8.50E-02
Pb	6.00E-04
Phenol	2.00E-02
SOx	3.80E-02
Zn	2.20E-03
Solid emissions	**lb/MCF**
Solid waste	1.04E+00
Products	**BTU/MCF**
Steam	3.00E+06

[1.] Reported here are only those inputs and outputs associated with combustion of hogged fuel in industrial boilers (PRé 2001; FAL 2001), raw material extraction and transportation are not included.
Note: Input is 500 lb of wood (hogged fuel) oven-dried basis; output is 3.00E+06 BTU.

2.4 ADHESIVE USE AND ENERGY/ELECTRICITY TO PRODUCE

Phenol-resorcinol-formaldehyde (PRF) and melamine-urea-formaldehyde (MUF) are the adhesives used in glulam production. The manufacture of these resins is energy intensive. The total PRF resin and hardener requirement for use in manufacturing 1000 cubic feet (MCF) of SE glulam production is 406 lb and 56 lb, respectively (w/out co-product). The MUF requirement was 39 lb and 4 lb for resin and hardener respectively. The total energy requirement for the PRF resin process was 1.47E+07 BTU/MCF glulam beams of energy resources and 602 kWh/MCF of electricity. Production of MUF resin is less energy intensive requiring energy resources totaling 7.97E+05 BTU/MCF for 43 lb of resin, with 82% from natural gas and 11 % from crude oil. Electricity for MUF production per MCF was 11 kWh. For both resins combined, electricity provided 17% of the total energy requirement for glulam production (includes lumber production) (Table 2.3). The PRF resin was composed of 85% resin and 15% hardener, while MUF was composed of 90% and 10% hardener. All resources, fuels and emissions to produce PRF and MUF resins are listed in Tables 1.4a-b.

Output emissions listed in Tables 1.4a and 1.4b include all emissions resulting from the production of resin, fuel production and combustion, electricity generation, and material transportation. Due to the nature of the resin data, it was not possible to separate out emissions for each of the production processes; therefore, output emissions reflect total cradle-to-gate burdens for PRF and MUF resin manufacturing. Burdens associated with the transportation of the resins to the glulam facilites were not included in the SimaPro glulam production model.

2.5 STRUCTURE AND INPUT, SIMAPRO MODEL

A single unit process was defined for the SE glulam process in SimaPro with the SE Lumber process, wood boiler process and resin processes as inputs into the glulam process (Figure 2.2). Other processes taken from the Franklin database (designated FAL) were also used for fuel, ancillary materials, and electricity inputs. Table 2.5 lists the SimaPro input table for the SE glulam process. All data were obtained from the mill surveys collected for the production year 2000, and weighted based on glulam production per 1000 cubic feet (MCF) actual volume Production emissions for input into the glulam model were reported in surveys. They represent emissions associated with the pressing, sawing, trimming, planing and finishing. Allocation was made on a mass basis allocating 82% (based on 3.44E+04 lb/MCF of glulam) of the total output to glulam beams. Figure 2.5 shows an overview of the relationship among the processes used as inputs into the glulam production process. Lines represent flows within the model. Not all material inputs are shown, a percentage contribution cutoff of 1.3% was used in this figure example.

Table 2.5. Total Process Inputs Exported from SimaPro for the production of SEGlulam per 1,000 Cubic Feet (MCF) (Not Allocated).

Resource	Unit	Unit/MCF	Emissions to air[3]		Unit/MCF
Water (process)	lb	8.77E+04	VOC	lb	5.18E+01
			Particulates	lb	5.60E+01
Materials/fuels			Particulates (PM10)	lb	5.60E+01
Steel cold rolled, BOF FAL	lb	2.36E+01	HAPS, total	lb	2.62E+01
Natural gas equipment FAL[1]	BTU	2.81E+05			
Gasoline equipment FAL	gal	2.89E+00	**Solid emissions**		
Kraft unbleached FAL	lb	1.39E+02	Particulates from pollution abatement equip.	lb	1.04E+02
Diesel equipment FAL	gal	4.95E+00			
LDPE film recycled FAL	lb	1.28E+02	**Products**		
Phenol-resorcinol-formaldehyde	lb	4.97E+02	SE, Glulam beams	lb	3.44E+04
Melamine-urea-formaldehyde	lb	4.80E+01			
Hardener, PRF	lb	6.89E+01	**Co-Products**		
			Shavings, SE	lb	3.97E+03
Hardener, MUF	lb	4.59E+00	Trim, SE	lb	3.43E+03
Lumber, dry	lb	3.54E+04	Wood waste, SE	lb	3.33E+02
Lumber, green	lb	6.37E+03			
Electricity/heat					
Heat from nat. gas FAL	BTU	2.72E+07			
Electricity, SE selector[2]	kWh	2.80E+03			

[1]Surrogate for LPG at 3.07E+00 gal/MCF

[2]Table 2.3 shows the percent breakdown by fuel source for energy generation for the SE.

[3] Input emissions for the glulam total process were obtained from the glulam surveys.. These are emissions associated with glulam on-site production, excluding emissions resulting from the combustion of fuels

Notes: All values are a weighted average based on the production year for 2000. Co-products included.

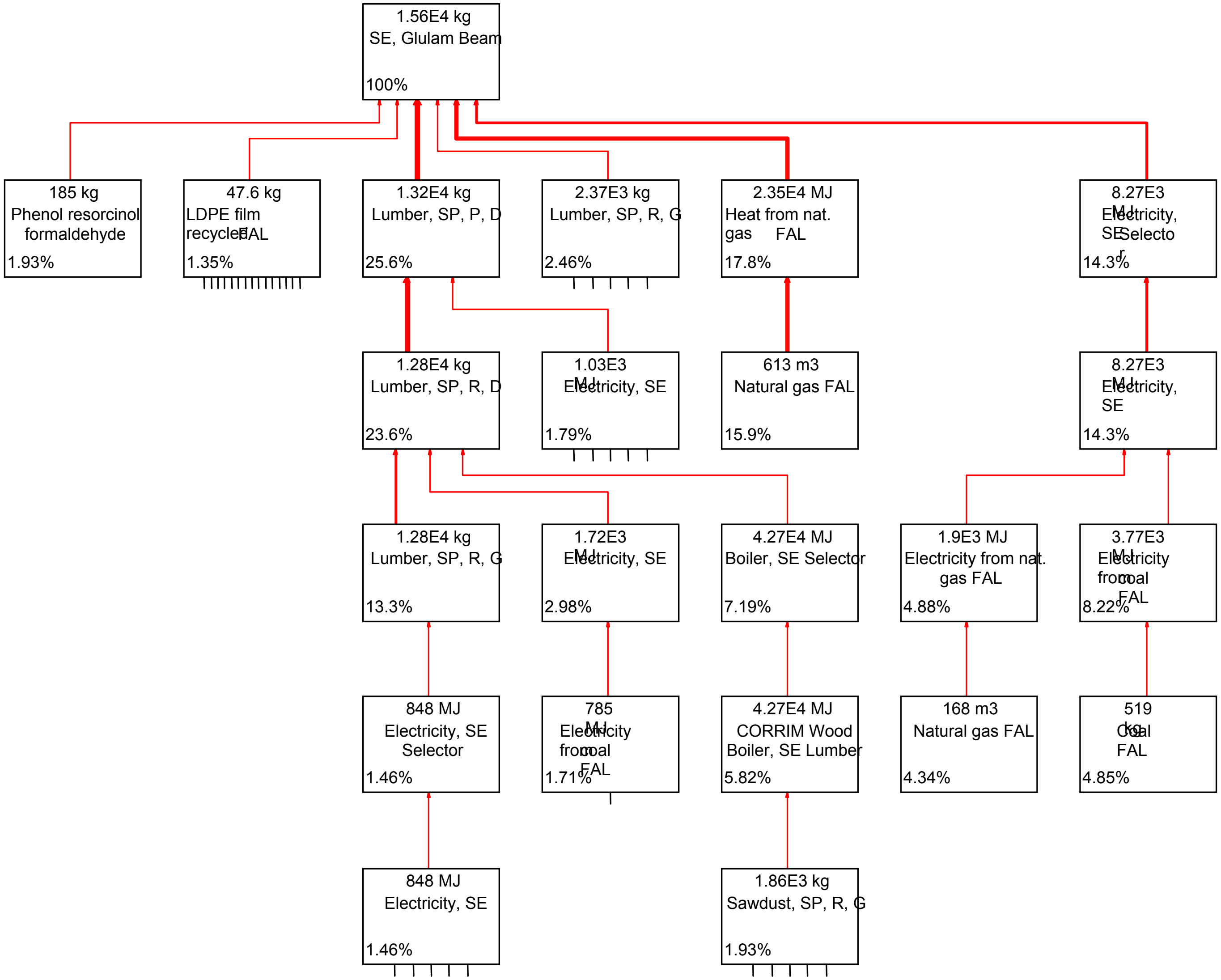

Figure 2.5. **A process flow diagram on the relationship among input processes into the SE Glulam Model in Simapro5.**
Notes: Lines represent flows within the model. 1.56E+04 kg of product = 1,000 cubic feet (MCF) of glulam or 3.44E+04 lb/MCF. Not all input materials (processes) are shown. A 1.3% cut-off is used for the figure example.

2.6 LIFE-CYCLE INVENTORY RESULTS

Life-cycle inventory results to produce 1000 cubic feet (MCF) of glulam beams in the SE are presented in Tables 1.6a-e. Results include all processes within the system boundary defined in Figure 2.2a and 2.2b and were generated in SimaPro (PRé 2001). Burdens associated with transportation of the wood resource to the sawmills and of raw materials to the glulam facilities have been excluded from the glulam model as defined in Figures 2.2a and 2.2b. Four different inventory tables were generated to represent scenarios: Full LCI, no exclusions (Table 2.6a and 2.6b); LCI excluding electricity production and use (Table 2.6c); LCI excluding resin production (Table 2.6d) and; LCI for on-site glulam production (Table 2.6e). When primary data (survey data) was not available, the Franklin Database (FAL 2001) was used primarily for fuel manufacturing and use, ancillary material manufacturing (i.e. steel strapping and paper wrap), and electricity production. Life-cycle inventory data for the production of lumber from the PNW was taken from Milota (2004b) and production data for the resins was obtained from Nilsson (2001).

Table 2.6a. Cumulative LCI Raw Material Requirements from SimaPro for Production of 1000 Cubic Feet (MCF) or 1000 Cubic Meters (103m^3) of SE Glulam Beams. Results Include Inputs for the Production of PNW Lumber (Milota 2004b); Electricity, Fuels, Resins (Nilsson 2001) and Ancillary Materials. Co-Products Were Not Included.

Substance	lb/MCF	kg/10^{3}m^3	Substance	lb/MCF	kg/10^{3}m^3
Air	8.73E+01	1.40E+03	S-containing raw material	4.35E-01	6.97E+00
Bauxite	2.36E-01	3.77E+00	Scrap, external	6.53E+01	1.05E+03
Bentonite	2.86E-02	4.58E-01	Seed corn	3.37E-03	5.40E-02
Cellulose	4.21E-02	6.75E-01	Silica	6.94E-03	1.11E-01
Coal FAL	1.94E+03	3.11E+04	Sulphur	3.35E+01	5.37E+02
Copper (in ore)	5.00E-01	8.01E+00	Sylvinite	2.94E-02	4.72E-01
Crude oil (feedstock) FAL	1.33E+01	2.12E+02	Trona	1.13E-03	1.81E-02
Crude oil FAL	2.69E+02	4.31E+03	Uranium FAL	2.95E-01	4.88E+00
Feldspar	9.06E-03	1.45E-01	Water (process)	1.59E+05	2.54E+06
Iron (ore)	2.31E+01	3.73E+02	Water (well, for cooling)	1.17E+04	1.87E+05
Kaolinite (chinaclay)	1.13E+00	1.80E+01	Wood for fiber (feedstock) FAL	5.13E+02	8.22E+03
Limestone	1.48E+02	2.37E+03	Wood/wood wastes FAL	2.41E+02	3.86E+03
	ft^3/MCF	**m^3/10^{3}m^3**			
Logs, SE	1.23E+03	1.23E+03			
	lb/MCF	**kg/10^{3}m^3**			
Methane (kg)	8.25E-04	1.32E-02			
Na_2SO_4	1.88E+00	3.01E+01			
NaCl	2.55E+02	4.09E+03			
Natural gas (feedstock) FAL	4.06E+01	6.51E+02			
Natural gas FAL	1.87E+03	3.00E+04			
Nitrogen	4.14E+00	6.64E+01			
Oxygen	1.92E+00	3.07E+01			
Pesticides	6.31E-04	1.01E-02			
Phosphate (ore)	5.98E-02	1.52E+00			
Rock salt	8.19E-02	1.31E+00			
Sand	6.11E-02	9.79E-01			

Table 2.6b. Cumulative LCI Results from SimaPro for the Production of 1000 Cubic Feet (MCF) or 1000 Cubic Meters (10^3m^3) of Glulam in the SE. Results Include Inputs for the Production of SE Lumber (Milota 2004b), Electricity, Fuels, Resins (Nilsson 2001), and Ancillary Materials. Transportation of Resource to the Sawmill and Transportation of Raw Materials to the Glulam Facility Have Been Omitted. Co-Products Were Not Included.

Emissions to air	lb/MCF	kg/10^3m^3	Emissions to air	lb/MCF	kg/10^3m^3	Emissions to air	lb/MCF	kg/10^3m^3
Acetaldehyde	2.06E-02	3.30E-01	HAPS, total	2.15E+01	3.44E+02	Phenol	2.83E-01	4.54E+00
Acrolein	6.75E-05	1.08E-03	HCl	3.76E-01	6.02E+00	Propylene glycol	9.56E-01	1.53E+01
Aldehydes	5.78E-02	9.25E-01	HCOOH	5.06E-03	8.11E-02	Sb	3.26E-05	5.22E-04
Ammonia	6.18E-02	9.90E-01	HF	4.74E-02	7.60E-01	Se	4.91E-04	7.86E-03
Aromatics	8.81E-03	1.41E-01	Hg	1.41E-04	2.25E-03	SO_2	1.90E+00	3.04E+01
As	8.06E-04	1.29E-02	Hydrocarbons	3.79E+00	6.08E+01	SOx	1.02E+02	1.63E+03
Ba	3.02E-02	4.84E-01	K	5.36E+00	8.58E+01	Tetrachloroethene	6.50E-05	1.04E-03
Be	2.29E-05	3.66E-04	Kerosene	2.09E-03	3.35E-02	Tetrachloromethane	1.51E-04	2.41E-03
Benzene	2.54E-02	4.07E-01	Metals	1.14E-03	1.82E-02	Total reduced sulfur	6.63E-03	1.06E-01
Cd	4.43E-05	7.09E-04	Methane	2.41E+01	3.86E+02	Trichloroethene	6.38E-05	1.02E-03
Cl_2	5.36E-02	8.59E-01	Methanol	6.31E-02	1.01E+00	VOC	7.10E+01	1.14E+03
CO	1.20E+02	1.92E+03	Mn	6.24E-02	1.00E+00	Zn	3.02E-02	4.84E-01
CO_2 (biomass)	1.42E+04	2.27E+05	N_2O	5.34E-02	8.56E-01		**Bq/MCF**	**Bq/10^3m^3**
CO_2 (fossil)	1.02E+04	1.64E+05	Na	1.24E-01	1.98E+00	Radioactive substances	7.52E+07	2.13E+06
CO_2 (non-fossil)	2.53E+02	4.05E+03	Naphthalene	1.65E-02	2.64E-01			
Cobalt	1.28E-04	2.04E-03	NH_3	6.50E-03	1.04E-01			
Cr	6.09E-04	9.76E-03	Ni	5.44E-03	8.71E-02			
Cu	2.90E-07	4.65E-06	N-nitrodimethylamine	1.43E-05	2.29E-04			
Dichloromethane	3.21E-04	5.15E-03	Non methane VOC	2.06E+01	3.30E+02			
Dimethyl ether	3.05E-04	4.89E-03	NOx	5.43E+01	8.69E+02			
Dioxin (TEQ)	3.89E-10	6.23E-09	Organic substances	1.39E+00	2.23E+01			
Dust	9.63E-01	1.54E+01	PAH's	1.19E-03	1.90E-02			
Dust (PM10)	3.36E+01	5.39E+02	Particulates	4.77E+01	7.64E+02			
Ethene	2.40E-02	3.84E-01	Particulates (PM10)	4.71E+01	7.55E+02			
Fe	3.02E-02	4.84E-01	Particulates (unspecified)	5.21E+00	8.34E+01			
Formaldehyde	1.33E-01	2.12E+00	Pb	8.50E-03	1.36E-01			

Table continued on next page

Table 2.6b. Cumulative LCI Results from SimaPro for the Production of 1000 Cubic Feet (MCF) or 1000 Cubic Meters (10^3m^3) of Glulam in the SE. Results Include Inputs for the Production of SE Lumber (Milota 2004b), Electricity, Fuels, Resins (Nilsson 2001), and Ancillary Materials. Transportation of Resource to the Sawmill and Transportation of Raw Materials to the Glulam Facility Have Been Omitted. Co-Products Were Not Included.

Emissions to water	lb/MCF	kg/10^3m^3
Acid as H+	2.80E-07	4.49E-06
Acids (unspecified)	9.88E-03	1.58E-01
Al	1.26E-02	2.01E-01
Al_3	1.69E-03	2.70E-02
AOX	7.88E-05	1.26E-03
B	1.87E-01	2.99E+00
BOD	2.74E-01	4.39E+00
Ca	2.52E-05	4.04E-04
Calcium ions	1.78E-03	2.84E-02
Cd	7.69E-03	1.23E-01
Chromate	1.03E-04	1.65E-03
Cl-	4.70E+00	7.53E+01
CO_3	1.86E+00	2.97E+01
COD	3.51E+00	5.63E+01
Cr	4.63E-03	7.42E-02
Cyanide	3.60E-05	5.77E-04
Dissolved organics	8.06E-03	1.29E-01
Dissolved solids	1.05E+02	1.68E+03
Fe	2.71E-01	4.35E+00
Fluoride ions	8.38E-03	1.34E-01
Formaldehyde	3.96E-05	6.35E-04
Gypson	2.64E-04	4.23E-03
H+	2.06E-02	3.30E-01
H_2SO_4	4.68E-02	7.49E-01
Hg	2.27E-03	3.63E-02
Hydrocarbons	3.91E-02	6.27E-01
Ionics	1.00E-02	1.60E-01
Limestone	3.94E-04	6.31E-03

Emissions to water	lb/MCF	kg/10^3m^3
Metallic ions	6.25E-03	1.00E-01
Metals	4.90E-02	7.85E-01
Mn	1.53E-01	2.44E+00
Na	2.28E-01	3.64E+00
NaCl	2.23E-01	3.56E+00
NH_3	1.04E-02	1.66E-01
NH_4+	2.59E-03	4.15E-02
Ni	1.37E-10	2.19E-09
Nitrate	1.06E-03	1.70E-02
N-tot	2.37E-02	3.79E-01
Oil	1.82E+00	2.91E+01
Organic carbon	7.38E-03	1.18E-01
Other organics	1.18E+00	1.88E+01
P	1.19E-03	1.90E-02
Pb	5.75E-07	9.21E-06
Phenol	1.97E-03	3.15E-02
Phosphate	3.52E-02	5.64E-01
P-tot	7.44E-03	1.19E-01
SiO_2	4.52E-05	7.24E-04
SO_4^{2-}	4.13E-01	6.62E+00
Sr_4+	3.01E-05	4.83E-04
Sulphate	4.71E+00	7.54E+01
Sulphide	3.15E-03	5.05E-02
Suspended solids	6.56E+00	1.05E+02
Total organic carbon	1.18E-01	1.88E+00
Zn	1.65E-03	2.64E-02

Emissions to land	lb/MCF	kg/10^3m^3
Building waste	9.50E-02	1.52E+00
Hazardous waste	3.13E+00	5.01E+01
Highly radioactive waste	3.92E-01	6.28E+00
Landfilled	5.00E+00	8.01E+01
Mineral waste	4.19E+00	6.71E+01
Mixed industrial waste	9.50E-01	1.52E+01
Non hazardous waste	7.68E+01	1.23E+03
Paper/board packaging	2.18E+01	3.48E+02
Particulates from pollution abatement equip.	3.95E+01	6.33E+02
Slags/ash	1.09E+00	1.74E+01
Sludge	8.88E-01	1.42E+01
Solid waste	1.23E+03	1.97E+04
Waste in incineration	1.43E+00	2.28E+01
Waste to recycling	5.90E-01	9.45E+00
Wood	1.48E+01	2.36E+02

Table 2.6c. Reduced LCI Results Exported from SimaPro for the Production of 1,000 cubic feet (MCF) or 1,000 Cubic Meters (10^3m^3) of Glulam in the SE. Results Include Inputs for the Production of SE Lumber (Milota 2004b), Fuels, Resins (Nilsson 2001) and Ancillary Materials. Electricity Generations[1/] Transportation and Use Have Been Omitted. Co-Products Were Not Included.

Emissions to air	lb/MCF	kg/10^3m^3	Emissions to air	lb/MCF	kg/10^3m^3	Emissions to air	lb/MCF	kg/10^3m^3
Acetaldehyde	2.06E-02	3.30E-01	Formaldehyde	1.32E-01	2.11E+00	Pb	8.25E-03	1.32E-01
Acrolein	1.66E-06	2.66E-05	HAPS, total	2.15E+01	3.44E+02	Phenol	2.83E-01	4.54E+00
Aldehydes	4.17E-02	6.68E-01	HCl	3.71E-02	5.94E-01	Propylene glycol	9.56E-01	1.53E+01
Ammonia	1.24E-02	1.98E-01	HCOOH	5.06E-03	8.11E-02	Sb	3.90E-06	6.25E-05
Aromatics	8.81E-03	1.41E-01	HF	1.16E-03	1.85E-02	Se	1.52E-05	2.43E-04
As	6.56E-04	1.05E-02	Hg	1.71E-05	2.74E-04	SO_2	1.90E+00	3.04E+01
Ba	3.02E-02	4.84E-01	Hydrocarbons	3.79E+00	6.08E+01	SOx	5.53E+01	8.86E+02
Be	5.53E-06	8.85E-05	K	5.36E+00	8.58E+01	Tetrachloroethene	1.63E-06	2.61E-05
Benzene	2.53E-02	4.06E-01	Kerosene	4.20E-05	6.73E-04	Tetrachloromethane	4.69E-06	7.52E-05
Cd	2.42E-05	3.87E-04	Metals	3.09E-04	4.95E-03	Total reduced sulfur	6.63E-03	1.06E-01
Cl2	5.36E-02	8.59E-01	Methane	1.19E+01	1.91E+02	Trichloroethene	1.57E-06	2.51E-05
CO	1.16E+02	1.86E+03	Methanol	6.31E-02	1.01E+00	VOC	7.10E+01	1.14E+03
CO_2 (biomass)	1.42E+04	2.27E+05	Mn	6.19E-02	9.92E-01	Zn	3.02E-02	4.84E-01
CO_2 (fossil)	4.66E+03	7.46E+04	N_2O	1.53E-02	2.45E-01	Radioactive substances	1.09E+06	3.85E+07
CO_2 (non-fossil)	2.51E+02	4.02E+03	Na	1.24E-01	1.98E+00			
Cobalt	1.11E-05	1.77E-04	Naphthalene	1.65E-02	2.64E-01			
Cr	4.13E-04	6.62E-03	Nh3	6.50E-03	1.04E-01			
Cu	2.90E-07	4.65E-06	Ni	4.05E-03	6.49E-02			
Dichloromethane	7.25E-06	1.16E-04	N-nitrodimethylamine	3.53E-07	5.66E-06			
Dimethyl ether	3.05E-04	4.89E-03	Non methane VOC	1.48E+01	2.36E+02			
Dioxin (TEQ)	9.19E-12	1.47E-10	NOx	3.39E+01	5.43E+02			
Dust	9.63E-01	1.54E+01	Organic substances	1.37E+00	2.19E+01			
Dust (PM10)	3.36E+01	5.39E+02	PAH's	1.19E-03	1.90E-02			
Ethene	2.40E-02	3.84E-01	Particulates	4.77E+01	7.64E+02			
Fe	3.02E-02	4.84E-01	Particulates (PM10)	4.61E+01	7.39E+02			
			Particulates (unspfd)	5.55E-01	8.89E+00			

Table continued on next page

Table 2.6c. Reduced LCI Results Exported from SimaPro for the Production of 1,000 cubic feet (MCF) or 1,000 Cubic Meters (10^3m^3) of Glulam in the SE. Results Include Inputs for the Production of SE Lumber (Milota 2004b), Fuels, Resins (Nilsson 2001) and Ancillary Materials. Electricity Generations[1/] Transportation and Use Have Been Omitted. Co-Products Were Not Included.

Emissions to land	lb/MCF	$kg/10^3m^3$	Emissions to water	lb/MCF	$kg/10^3m^3$	Emissions to water	lb/MCF	$kg/10^3m^3$
Building waste	9.50E-02	1.52E+00	Cd	6.38E-03	1.02E-01	NH_4^+	2.59E-03	4.15E-02
Hazardous waste	3.13E+00	5.01E+01	Chromate	9.38E-06	1.50E-04	Ni	1.37E-10	2.19E-09
Highly radioactive waste	3.92E-01	6.28E+00	Cl-	3.34E+00	5.36E+01	Nitrate	2.89E-04	4.64E-03
Landfilled	5.00E+00	8.01E+01	CO_3	1.86E+00	2.97E+01	N-tot	2.37E-02	3.79E-01
Mineral waste	4.19E+00	6.71E+01	COD	3.09E+00	4.96E+01	Oil	1.30E+00	2.08E+01
Mixed industrial waste	9.50E-01	1.52E+01	Cr	3.29E-03	5.28E-02	Organic carbon	7.38E-03	1.18E-01
Non hazardous waste	7.68E+01	1.23E+03	Cyanide	3.40E-05	5.45E-04	Other organics	1.06E+00	1.69E+01
Paper/board packaging	2.18E+01	3.48E+02	Dissolved organics	8.06E-03	1.29E-01	P	1.19E-03	1.90E-02
Poll. abatement equip.	3.95E+01	6.33E+02	Dissolved solids	7.53E+01	1.21E+03	Pb	3.64E-07	5.83E-06
Slags/ash	1.09E+00	1.74E+01	Fe	1.44E-02	2.30E-01	Phenol	1.96E-03	3.13E-02
Sludge	8.88E-01	1.42E+01	Fluoride ions	1.68E-04	2.68E-03	Phosphate	1.30E-02	2.08E-01
Solid waste	3.49E+02	5.59E+03	Formaldehyde	3.96E-05	6.35E-04	P-tot	7.44E-03	1.19E-01
Waste in incineration	1.43E+00	2.28E+01	Gypson	2.64E-04	4.23E-03	SiO_2	4.52E-05	7.24E-04
Waste to recycling	5.90E-01	9.45E+00	H+	2.06E-02	3.30E-01	SO_4^{2-}	4.13E-01	6.62E+00
Wood	1.48E+01	2.36E+02	H_2SO_4	2.45E-03	3.92E-02	Sr_4^+	3.01E-05	4.83E-04
Emissions to water	**lb/MCF**	**$kg/10^3m^3$**	Hg	2.27E-03	3.63E-02	Sulphate	2.63E+00	4.23E+01
Acid as H+	1.60E-07	2.56E-06	Hydrocarbons	3.91E-02	6.27E-01	Sulphide	3.15E-03	5.05E-02
Acids (unspecified)	9.88E-03	1.58E-01	Ionics	1.00E-02	1.60E-01	Suspended solids	3.18E+00	5.10E+01
Al	1.26E-02	2.01E-01	Limestone	3.94E-04	6.31E-03	Total organic carbon	1.18E-01	1.88E+00
Al_3	1.69E-03	2.70E-02	Metallic ions	3.74E-03	5.99E-02	Zn	1.19E-03	1.91E-02
AOX	7.88E-05	1.26E-03	Metals	4.90E-02	7.85E-01			
B	9.81E-03	1.57E-01	Mn	8.06E-03	1.29E-01			
BOD	2.44E-01	3.90E+00	Na	2.24E-01	3.59E+00			
Ca	2.52E-05	4.04E-04	NaCl	2.23E-01	3.56E+00			
Calcium ions	1.09E-05	1.75E-04	NH_3	6.56E-03	1.05E-01			

[1] Emissions from electricity production and use in the manufacturing of resins is included. These emissions cannot be separated from resin production emissions in the referenced database. (Nilsson 2002)

Table 2.6d. Reduced LCI Results Exported from SimaPro for the Production of 1,000 cubic feet (MCF) or 1,000 Cubic Meters (10^3m^3) of Glulam in the SE. Included are SE Lumber Production (Milota 2004b), Fuel, Ancillary Materials, and Electricity Production. Emissions from Resin Production Have Been Omitted. Co-Products Were Not Included.

Emissions to air	lb/MCF	kg/10^3m^3	Emissions to air	lb/MCF	kg/10^3m^3	Emissions to air	lb/MCF	kg/10^3m^3
Acetaldehyde	2.06E-02	3.30E-01	K	5.36E+00	8.58E+01	Zn	3.02E-02	4.84E-01
Acrolein	6.75E-05	1.08E-03	Kerosene	2.09E-03	3.35E-02		**Bq/MCF**	**Bq/10^3m^3**
Aldehydes	4.13E-02	6.61E-01	Metals	1.14E-03	1.82E-02	Radioactive substances	7.52E+07	2.66E+09
Ammonia	6.18E-02	9.90E-01	Methane	2.17E+01	3.47E+02			
As	8.06E-04	1.29E-02	Mn	6.24E-02	1.00E+00	**Emissions to land**	**lb/MCF**	**kg/10^3m^3**
Ba	3.02E-02	4.84E-01	N_2O	4.09E-02	6.56E-01	Paper/board packaging	2.18E+01	3.48E+02
Be	2.29E-05	3.66E-04	Na	1.24E-01	1.98E+00	Part. From poll. abatement equip.	3.95E+01	6.33E+02
Benzene	2.48E-02	3.97E-01	Naphthalene	1.65E-02	2.64E-01	Solid waste	1.23E+03	1.97E+04
Cd	4.43E-05	7.09E-04	Ni	5.44E-03	8.71E-02	Wood	1.48E+01	2.36E+02
Cl_2	5.36E-02	8.59E-01	N-nitrodimethylamine	1.43E-05	2.29E-04			
CO	1.18E+02	1.89E+03	Non methane VOC	2.06E+01	3.30E+02			
CO_2 (biomass)	1.42E+04	2.27E+05	NOx	4.80E+01	7.69E+02			
CO_2 (fossil)	9.14E+03	1.46E+05	Organic substances	1.34E+00	2.14E+01			
CO_2 (non-fossil)	2.53E+02	4.05E+03	Particulates	4.77E+01	7.64E+02			
Cobalt	1.28E-04	2.04E-03	Particulates (PM10)	4.71E+01	7.55E+02			
Cr	6.09E-04	9.76E-03	Particulates (unspecified)	5.21E+00	8.34E+01			
Cu	2.90E-07	4.65E-06	Pb	8.50E-03	1.36E-01			
Dichloromethane	3.21E-04	5.15E-03	Phenol	2.75E-01	4.41E+00			
Dioxin (TEQ)	3.89E-10	6.23E-09	Sb	3.26E-05	5.22E-04			
Dust (PM10)	3.36E+01	5.39E+02	Se	4.91E-04	7.86E-03			
Fe	3.02E-02	4.84E-01	SOx	9.86E+01	1.58E+03			
Formaldehyde	1.33E-01	2.12E+00	Tetrachloroethene	6.50E-05	1.04E-03			
HAPS, total	2.15E+01	3.44E+02	Tetrachloromethane	1.51E-04	2.41E-03			
HCl	3.47E-01	5.56E+00	Total reduced sulfur	6.63E-03	1.06E-01			
HF	4.74E-02	7.60E-01	Trichloroethene	6.38E-05	1.02E-03			
Hg	1.41E-04	2.25E-03	VOC	7.04E+01	1.13E+03			

Table continued on next page

Table 2.6d. Reduced LCI Results Exported from SimaPro for the Production of 1,000 cubic feet (MCF) or 1,000 Cubic Meters (10^3m^3) of Glulam in the SE. Included are SE Lumber Production (Milota 2004b), Fuel, Ancillary Materials, and Electricity Production. Emissions from Resin Production Have Been Omitted. Co-Products Were Not Included.

Emissions to water	lb/MCF	kg/10^3m^3	Emissions to water	lb/MCF	kg/10^3m^3
Acid as H+	2.80E-07	4.49E-06	H_2SO_4	4.68E-02	7.49E-01
Acids (unspecified)	9.88E-03	1.58E-01	Hg	3.64E-07	5.83E-06
Al	1.26E-02	2.01E-01	Metallic ions	6.25E-03	1.00E-01
B	1.87E-01	2.99E+00	Mn	1.53E-01	2.44E+00
BOD	2.64E-01	4.24E+00	Na	3.31E-03	5.31E-02
Ca	2.52E-05	4.04E-04	NH_3	1.04E-02	1.66E-01
Calcium ions	1.78E-03	2.84E-02	Ni	1.37E-10	2.19E-09
Cd	4.63E-03	7.42E-02	Nitrate	1.06E-03	1.70E-02
Chromate	1.03E-04	1.65E-03	N-tot	5.27E-03	8.44E-02
Cl-	4.65E+00	7.45E+01	Oil	1.79E+00	2.87E+01
COD	2.94E+00	4.71E+01	Organic carbon	7.38E-03	1.18E-01
Cr	4.63E-03	7.42E-02	Other organics	3.19E-01	5.12E+00
Cyanide	3.60E-05	5.77E-04	Pb	5.75E-07	9.21E-06
Dissolved solids	1.02E+02	1.63E+03	Phenol	3.33E-05	5.34E-04
Fe	2.71E-01	4.35E+00	Phosphate	3.52E-02	5.64E-01
Fluoride ions	8.38E-03	1.34E-01	P-tot	7.44E-03	1.19E-01
			Sulphate	4.67E+00	7.48E+01
			Sulphide	3.15E-03	5.05E-02
			Suspended solids	5.00E+00	8.01E+01
			Zn	1.65E-03	2.64E-02

Table 2.6e. Cumulative On-site LCI Exported from SimaPro for the Production of 1,000 Cubic Feet (MCF) or 1,000 Cubic Meters (10^3m^3) of SE Glulam Beams.

Substance	lb/MCF	kg/10^3m^3
Emissions to air		
HAPS, total	2.15E+01	3.44E+02
VOC	4.25E+01	6.81E+02
Particulates	4.59E+01	7.35E+02
Particulates (PM10)	4.59E+01	7.35E+02
Emissions to land		
Particulates from pollution abatement equip.	8.53E+01	1.37E+03

Notes: Data is from On-Site Production of SE Glulam Beams. Excludes Impacts Associated with Fuel, Electricity, Lumber, Resin and Ancillary Materials Production and Use. Included are Impacts Associated with Planing and Trimming, Face Bonding and Pressing, and Finishing of Glulam Beams and Boiler Emissions for Drying Lumber. Co-Products Were Not Included

2.7 SENSITIVITY ANALYSIS

A sensitivity analysis was done on the radio frequency process in comparison to the cold cure process. It was expected that the cold cure process would show a lower energy requirement, resulting in lower impacts. This was not the case for the scenario. The results of the analysis are listed in Table 2.7.

2.7.1 Cold Cure Process Compared to Radio Frequency

In this analysis, a greater impact was indicated for the cold cure (CC) process based on emissions outputs (Table 2.7). This difference occurred in the natural gas consumption and resin use. The cold cure used a significantly greater quantity of natural gas 5.09E+07 BTU/MCF than the radio frequency process 2.63E+04 BTU/MCF. In addition, similar to the PNW processes, the cold cure process required a larger quantity of resin, particularly PRF (62% of the total PRF resin).

Table 2.7. Sensitivity Analysis on SE Glulam Beam Production Comparing the Cold Cure (CC) and Radio-Frequency (RF) Glulam Processes.

Substance	Cold Cure lb/MCF	RF Cure lb/MCF	Substance	Cold Cure lb/MCF	RF Cure lb/MCF
Raw material inputs			**Emissions to water**		
Crude oil (feedstock) FAL	1.34E+01	0.00E+00	Acids (unspecified)	1.00E-02	4.33E-06
Iron (ore)	2.04E+02	2.59E+01	Al	1.27E-02	0.00E+00
Limestone	2.11E+02	9.86E+01	BOD	3.46E-01	3.26E-02
Na_2SO_4	1.90E+00	0.00E+00	Cd	1.16E-02	3.30E-03
Natural gas (feedstock) FAL	4.11E+01	0.00E+00	Cl-	7.88E+00	1.13E+00
Natural gas FAL	3.19E+03	4.44E+02	COD	4.64E+00	7.63E-01
Oxygen	1.69E+01	2.14E+00	Cr	7.81E-03	1.08E-03
Pesticides	6.38E-04	0.00E+00	Cyanide	2.68E-04	3.41E-05
Phosphate (ore)	6.04E-02	0.00E+00	Dissolved solids	1.76E+02	2.57E+01
Scrap, external	1.25E+02	8.52E+00	NH_3	1.32E-02	3.30E-03
Seed corn	3.41E-03	0.00E+00	Ni	1.38E-10	0.00E+00
Silica	7.06E-03	0.00E+00	Nitrate	1.30E-03	6.00E-04
Sylvinite	2.98E-02	0.00E+00	N-tot	2.83E-02	1.31E-02
Wood for fiber (feedstock) FAL	5.18E+02	0.00E+00	Oil	3.05E+00	4.38E-01
Wood/wood wastes FAL	2.45E+02	1.29E+00	Organic carbon	7.44E-03	0.00E+00
			Other organics	1.59E+00	7.13E-01
Emissions to air			Phosphate	4.23E-02	1.73E-02
Aldehydes	7.63E-02	3.41E-02	P-tot	7.50E-03	0.00E+00
Ammonia	8.19E-02	3.99E-02	Sulphate	7.50E+00	1.64E+00
CO_2 (fossil)	1.51E+04	5.53E+03	Sulphide	3.18E-03	0.00E+00
CO_2 (non-fossil)	2.56E+02	1.72E+00	Suspended solids	9.13E+00	3.75E+00
Metals	1.62E-03	6.94E-04	Water	3.21E+02	0.00E+00
Methane	3.68E+01	1.14E+01	Zn	2.75E-03	3.75E-04
Non-methane VOC	3.32E+01	6.81E+00			
SOx	1.58E+02	4.07E+01			
Total reduced sulfur	6.69E-03	0.00E+00			
Emissions to land					
Solid waste	2.10E+03	8.61E+02			

2.8 CARBON BALANCE

A biomass carbon balance on the wood-based material into the glulam process model is shown in Figure 1.8. Inputs include only wood based materials (lumber) into the glulam process (lumber manufacturing carbon balance excluded). Southeast lumber carbon balance can be found in Softwood Lumber-Southeast Region CORRIM Phase I Report (Milota 2003b). Carbon containing outputs include products, co-products and emission as reported in glulam surveys.

Since there was very little co-product produced in the glulam process, the carbon balance was based on wood carbon only in and out of the glulam process. Table 2.8 shows wood-related carbon statistics for products, co-products, and emissions associated with the production of 1000 cubic feet of glulam (MCF). The lumber input included <1% unaccounted lumber inputs (Table 2.2) making the carbon balance between inputs and outputs within 1.4%. The carbon ratios were obtained from Birdsey (1992) and Skogs and Nicholson (1998). The sum of the carbon out of the glulam process is 20,754 lb/MCF. Of this, 81% was in product, 18% was in co-products and less than 1% was in air emissions and wood wastes.

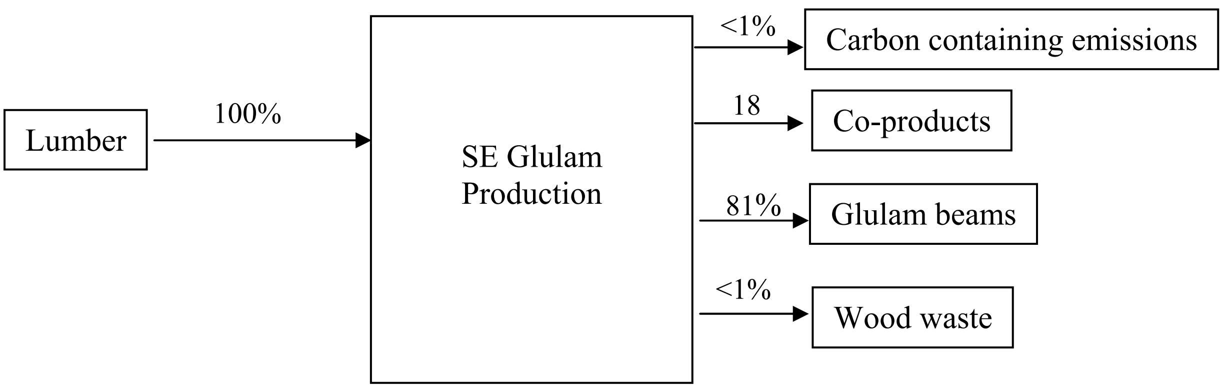

Figure 2.8. Carbon input and output flows for production of SE glulam beams.
Note: Flows are for wood related carbon only.

Table 2.8. Carbon Balance for SE Glulam Production.

C-Containing INPUTS	Substance	Glulam lb/MCF	Carbon lb/MCF	Carbon Ratio in Material
Green lumber	Raw	6.37E+03	3.21E+03	
Dry lumber	Raw	3.54E+04	1.78E+04	
Hogged fuel	Raw	0.00E+00	0.00E+00	
TOTAL INPUTS		**4.18E+04**	**2.10E+04**	
C-Containing OUTPUTS	**Substance**	**Glulam lb/MCF**	**Carbon lb/MCF**	**Carbon Ratio in Material**
Acetaldehyde	Air	0.00E+00	0.00E+00	5.40E-01
Benzene	Air	8.06E-03	7.44E-03	9.23E-01
CO	Air	0.00E+00	0.00E+00	4.29E-01
CO_2 (biomass)	Air	0.00E+00	0.00E+00	2.73E-01
Ethanol	Air	0.00E+00	0.00E+00	5.22E-01
Formaldehyde	Air	3.24E-02	6.48E-03	4.00E-01
Isopropanol	Air	0.00E+00	0.00E+00	6.01E-01
Methanol	Air	0.00E+00	0.00E+00	3.75E-01
Naphthalene	Air	5.39E-03	5.05E-03	9.37E-01
Organic substances	Air	0.00E+00	0.00E+00	5.00E-01
Particulates	Air	5.60E+01	2.75E+01	4.91E-01
Particulates (PM10)	Air	5.60E+01	2.75E+01	4.91E-01
Phenol	Air	0.00E+00	0.00E+00	7.66E-01
Subtotal		**1.12E+02**	**5.50E+01**	
Glulam	Product	3.44E+04	1.69E+04	4.91E-01
Trimmings	Co-product	3.97E+03	1.95E+03	4.91E-01
Shavings	Co-product	3.43E+03	1.69E+03	4.91E-01
Wood waste	Co-product	3.33E+02	1.64E+02	4.91E-01
TOTAL OUTPUTS		**4.22E+04**	**2.08E+04**	

Notes: Included are wood related carbon containing inputs and outputs for the glulam process only. Carbon (C) containing substances from fuels, electricity, resin, and SE lumber production are not included.

2.9 COST ANALYSIS

A cost analysis was done of the glulam manufacturing process. The analysis was based on 1.60E+06 cubic feet (actual volume) per year, representing a composite of the SE glulam manufacturers surveyed. The assumptions for this analysis are shown in Table 2.9. Capital cost estimates was based on the construction of a new glulam facility and straight-line depreciation over 20 years and included value of land, buildings, and equipment. Energy costs were obtained from government sources. Lamstock prices reflect an average cost of random length lamstock for the year 2001. Insurance, maintenance, and labor costs were estimated based on discussions with industry personal. The cost analysis shown in Table 2.9 is based on the assumptions above. Results are shown as cost per production year and as cost per actual cubic foot of glulam.

Table 2.9. SE Glulam Production Cost Analysis for On-Site Production of 1000 Cubic Feet (MCF) of Glulam Beams.

	Assumptions for Cost Analysis			Cost Analysis for 1000 Cubic Feet of SE Glulam Beams	
VARIABLE COSTS	**Unit**	**Unit/MCF**	**$/Unit**	**$/Year**	**$/MCF**
Energy consumption:					
Electricity	kWh	2,800.00	0.05	210,560	132
Hogged fuel (dry)	lb	0.00	0.01	0	0
Natural gas	MCF	33.40	3.73	199,064	124
Diesel	gallons	4.95	1.40	11,088	7
Gasoline	gallons	2.89	1.51	6,982	4
Liquid propane gas	gallons	3.07	1.07	5,275	3
Total energy cost				**432,970**	**271**
Materials:					
Dried lumber, actual	MBF	13.50	644.61	13,923,625	8,702
PRF resin	lb	565.00	0.97	878,688	549
MUF resin	lb	52.59	0.96	80,778	50
Total material cost				**14,883,091**	**9,302**
Total variable cost				**15,316,061**	**9,573**
FIXED COSTS					
Capital cost	$			650,000	406
Maintenance	$			1,000,000	625
Labor	$			3,690,000	2,306
Overhead	$			621,000	388
Interest	%		8.00%	1,040,000	650
Total fixed cost				**7,001,000**	4,376
Total cost				**22,317,061**	**13,948**
Income					
Co-products	lbs	7,733.00	0.015	247,069	116
Glulam	$			22,706,766	14,192
Total income	$			**22,953,836**	**14,308**
Profit, sales, tax	$			**636,775**	**360**

2.10 CONCLUSIONS

The data collected on SE glulam production represents 43% of the regions glulam production for the production year 2000. Total heat energy for glulam production was driven by the lumber drying process which consumed 15% of the natural gas consumption 100% of the hogged fuel with a total heat energy requirement of 5.32E+07 BTU/MCF (w/out co-product) compared to on-site glulam usage which required 2.23E+07 BTU/MCF. Lumber manufacturing used 34% of the electrical energy required for glulam production and resin manufacturing used 14%.

The level of detail in energy and raw material use and product and co-product produced are what can be expected for this industry. Survey reported data on process air emissions differ between glulam manufactures, differences are dependent upon government regulations that would apply to each facility depending upon process type and if they operate kiln and/or boilers.

Future work should emphasize on regional boiler emissions for natural gas and hogged fuel types and resin production. Resin databases are based on European data, which may not represent regional energy production in the United States.

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APPENDIX 1: LIST OF TERMS

Table A1.1. List of Terms

Board foot	One board foot is equal to a 1-inch thick board, 12 inches in width, and 1 foot in length (1” x 12” x 1 ft).
BTU	British thermal unit
CO	Carbon monoxide
CO_2	Carbon dioxide
CO_2 (biomass)	Carbon dioxide emitted from the combustion wood or biomass
CO_2 (fossil)	Carbon dioxide emitted from the combustion on fossil fuels
CO_2 (non-fossil)	Carbon dioxide emitted from the combustion of non-fossil fuels and may include wood or biomass
CORRIM	The Consortium for Research on Renewable Industrial Materials
cuft	Cubic feet
cuin	Cubic inches
DOE	Department of Energy
EPA	Environmental Protection Agency
gal	US gallon
Hogged fuel	Wood waste (shavings, trimmings, bark, planer shavings etc.) used to fire boiler or furnaces, often at the mill or plant at which the fuel was processed.
kg	Kilogram
in^2	Inches squared
kg/m^3	Kilogram per cubic meter
kWh	Kilowatt hour
L	Liter
lb	US pound
lb/ft^3	Pound per cubic foot (density), US
LCA	Life-cycle assessment
LCI	Life-cycle inventory
LCIA	Life-cycle impact assessment
M	1,000
m^3	Cubic meters
MBF	1000 board feet
MCF	1000 cubic feet
MJ	Mega joules
mm	Millimeters
mm^2	Millimeters squared
10^3m^3	1000 cubic meters
MMBF	Million board feet
NMVOC	Non methane volatile organic substances
NO	Nitrogen oxide
NO_2	Nitrogen dioxide
NOx	Nitrogen oxide and nitrogen dioxide
Particulate matter	A general term used for a mixture of solid particles and liquid droplets found in the air.
PM10	Particulate matter less than 10 microns in diameter
PNW	Pacific Northwest region (boundaries defined in report)
SE	Southeast United States region (boundaries defined in report)
SO_2	Sulfur dioxide
VOC	Volatile organic compounds

APPENDIX 2: UNIT CONVERSIONS

Table A2.1. Unit Conversion Factors

BTU =	1.054 E-03 MJ
BTU =	1,054.3 J
BTU/MCF =	0.0373 MJ/1000 m^3
cubic foot =	7.482 gal
cubic inch =	0.0043 gal
cubic unit =	200 ft^3
cubic yard =	27 ft^3
ft^3 =	2.832 E-02 m^3
ft^3 =	28,316.85 cm^3
gal	231in^3
gal (US) =	3.785 liters
gal =	3,785.4 cm^3
gal/MCF =	133.67 L/1000 m^3
J =	10^6 MJ
kWh/ft^3 =	127 MJ/m^3
kWh=	3,414.4 BTUs
lb =	0.454 kg
lb/ft^3 =	16.02 kg/m^3
liter =	0.02642 gal (US)
long ton =	2240 lb
m^3 =	35.32 ft^3
miles =	1.852 kilometers
pound =	16 oz
short ton =	2,000 lb

Table A2.2. Energy Content Conversions

	BTU	per	MJ	per
Natural gas[1]	1,015.68	ft^3	37.82	m^3
Motor gasoline	124,447.14	gal	34.66	L
Kerosene	135,290.48	gal	37.68	L
Propane	91,665.76	gal	25.53	L
Diesel oil	138,880.99	gal	38.68	L
Light oil	138,880.99	gal	38.68	L
Heavy oil	149,832.05	gal	41.73	L
Hogged fuel[2]	3,000	lb	6.96	kg
Hogged fuel[3]	6,000	lb	13.93	kg

[1]80% efficiency was used for natural gas
[2] green weight
[3] oven-dried weight

Table A2.3. Fuel Density Conversions

	Typical Unit	Density kg/m^3	Wt of Unit kg/unit	Energy MJ/unit	Energy MJ/kg
Coal	kg	N/A	1	26.07	26.07
Coke	kg	N/A	1	28.83	28.83
Diesel	L	880	0.88	38.68	43.95455
Fuel oil	L	880	0.88	41.84	47.54545
LPG	L	510	0.51	26.64	52.23529
Natural gas	m^3	0.7	0.7	38.03	54.32857
Gasoline	L	720	0.72	34.87	48.43056
Uranium	kg	N/A	1	2293635	2293635
Wood	kg	450	1	10.47	10.47

Source: Careron Hydraulic Data, Ingersoll-Rand, 1979; Marks' Handbook for Mechanical Engineers – 8th Edition, McGraw Hill, 1978.

Table A2.4. Carbon Conversion Factors For Western Species.

Wood Species	Conversion factor [1,2]
Douglas -fir	15.11
Spruce	9.8
Hemlock	12.17
Larch	14.26

[1]Birdsey R.A. 1992. Carbon storage and accumulation in US forest ecosystems. General Technical Report WO-59. Washington, D.C. USDA Forest Service.
[2]Skog, K.E. and G.A. Nicholson. 1998. Carbon cycling through wood products: the role of wood and paper products in carbon sequestration. For. Prod. J. 48(7/8):75-83.

Table A2.5. Carbon Conversion Factors For Various US Regions.

Region	Softwood Factors (lb/ft^3)[1]
PNW-west	15.11
PNW-east	13.39
S Central	16.9
SE	16.9

[1] Skog, K.E. and G.A. Nicholson. 1998. Carbon cycling through wood products: the role of wood and paper products in carbon sequestration. For. Prod. J. 48(7/8):75-83.

Table A2.6. Factors Used To Convert Nominal Board Feet To Actual Volume[1/]. Pacific Northwest Region Conversions.

			Green lumber			Dry lumber			Glulam beams		
Lumber (Dim.)	Dim. mix %	Nominal (Dim.) in² (mm²)	Actual (Dim.) in² (mm²)	Ratio actual: nominal	Weighted Average	Actual (Dim.) in² (mm²)	Ratio actual: nominal	Weighted Average	Actual (Dim.) in² (mm²)	Ratio actual: nominal	Weighted Average
2x4	25	8.00 (5,161)	6.49 (4,86)	0.81	0.20	5.25 (3,387)	0.66	0.16	4.69 (3,024)	0.59	0.15
2x6	55	12.00 (7,742)	10.16 (6,557)	0.85	0.47	8.25 (5,323)	0.69	0.38	7.69 (4,960)	0.64	0.35
2x8	15	16.00 (10,323)	13.41 (8,650)	0.84	0.13	10.88 (7,016)	0.68	0.10	10.13 (6,532)	0.63	0.09
2x10	5	20.00 (12,903)	16.87 (10,882)	0.84	0.04	13.88 (8,952)	0.69	0.03	13.13 (8,468)	0.66	0.03
Total					**0.84**			**0.68**			**0.63**

[1] Conversion example: (1 BF, nominal of green lumber x 0.84)/12 = 1 cubic foot of actual volume of lumber.

Table A2.7. Factors Used To Convert Nominal Board Feet To Actual Volume[1/]. Southeast Region Conversion.

			Green lumber			Dry lumber			Glulam beams		
Lumber (Dim.)	Dim. mix (%)	Nominal (Dim.) in² (mm²)	Actual (Dim.) in² (mm²)	Ratio actual: nominal	Weighted Average	Actual (Dim.) in² (mm²)	Ratio actual: nominal	Weighted Average	Actual (Dim.) in² (mm²)	Ratio actual: nominal	Weighted Average
2x6	35%	12.00 (7,742)	10.16 (6,557)	0.85	0.30	8.25 (5,323)	0.69	0.22	7.69 (4,960)	0.64	0.22
2x8	65%	16.00 (10,323)	13.41 (8,650)	0.84	0.54	10.88 (7,016)	0.68	0.44	10.13 (6,532)	0.63	0.41
Total					**0.84**			**0.68**			**0.64**

[1] Conversion example: (1 BF, nominal of green lumber x 0.84)/12 = 1 cubic foot of actual volume of lumber.

APPENDIX 3: CORRIM GLULAM SURVEY

The Consortium for Research on Renewable Industrial Materials (CORRIM II)
Glulam Beam Manufacturers
February 15, 2001

The information from the attached survey will be used in a project by CORRIM II, a consortium comprised of universities, industry, and government groups to conduct an environmental assessment of forest products. CORRIM's life-cycle assessment will describe environmental influences of the manufacturing of building materials with an initial focus on structural building materials. A number of forest products manufacturers, as well as their association representatives, such as AF&PA and APA, support our effort. The assessment will cover all activities from planting a seedling, to the manufacturing of the products, all the way through the use and disposal or recycling of these products.

The attached survey that we would like you to complete is part of the overall study and will be used to compile a database of information based on energy and environmental performances. The database will be used in a life-cycle computer modeling program to determine the performance. The outcome of our study will be used by managers to help them in their decision making as they guide our industry in the coming years. The database will also be used to compare the environmental performance of wood to alternative materials such as concrete, steel, and plastic, and could be used to competitively position wood in the marketplace.

CORRIM's objective is to acquire a database and produce life-cycle models of environmental performances 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 cycle. 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.

We need quality data and we need your cooperation to make this study a success. We recognize the sensitivity of the data your company will be providing, therefore we intend to keep your company name and specific data strictly confidential and to assure you that data will be used in a conglomeration with other mill data to mask specific mill information.

This CORRIM survey is designed specifically for glulam manufacturers. Questions will be concentrated on annual production, electricity production and usage, fuel use, material flows, and environmental emissions. If you operate a cold cure and a radio frequency line, we would appreciated you to fill a separate survey for each. Two surveys have been enclosed for your convenience. 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.

If you have questions about the survey, contact:

Maureen Puettmann
Research Associate
Oregon State University
Department of Forest Products
138 Richardson Hall
Corvallis, OR 97331-5751
541-737-8506
maureen.puettmann@orst.edu

Company: ______________________________

Facility Site (city, state): ______________________________

Company's Plant Name: ______________________________

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

Name:	**Title:**
Telephone:	**E-mail:**

Annual Production Period:	**1999 or 2000 (please circle one)**
Annual Production:	
Type of Facility:	**Cold Cure or Radio Frequency (please circle one)**

Information on Raw Material as Received

Inputs	Quantity	Units	Moisture Content
Raw Materials			
Total Lumber		MBF	
Lumber By Wood Species:			
1.		MBF	
2.		MBF	
3.		MBF	
4.		MBF	

Inputs	Quantity	Units	Type or Source
Raw Materials			
Water			
Strapping			
Wrapping Material			

Resin Use Information

Please check all resins that apply and then continue with the following table

GPhenol Resorcinol Formaldehyde = **PRF**

GMelamine = **M**

GMelamine Urea Formaldehyde = **MUF**

GMelamine Formaldehyde = **MF**

GResorcinol =**R**

Inputs	Quantity (lbs, dry solid basis)					Range % of Solids When Used
Raw Materials	**PRF**	**M**	**MUF**	**MF**	**R**	
Resin						
Catalyst/fillers/extenders						
Other						

Transportation of Input Materials to Plant Information
(Please include truck dimension (i.e., 20 ton, 40 ton), rail, or other transport type)

Inputs	Transport Type	Average Distance of Delivery
Raw Materials		
Lumber		
green		
dry		
Resin		
Miscellaneous Inputs		
Strapping		
Wrapping Material		
Other		

On-site Transportation Information
(Please include all on-site transportation, e.g. forklifts):

Transport Type	Dimension	Hours of Operation

Energy Consumption Information

Inputs	Quantity	Units
Energy Consumption		
Purchased Electricity		
Purchased Steam		
Coal		
Natural Gas		
Liquid Propane Gas[1/]		
Kerosene		
Diesel Fuel[1/]		
Gasoline[1/]		
Hog Fuel		
Self Generated		
Purchased		
Wood Waste		
Residual Fuel Oil		
Distillate Fuel Oil		

1/ All on-site transportation should be included in this total

Boiler Information

G**Do not have a boiler**

If you have a boiler, what is its heat source? Check appropriate box
GHogged fuel
GOil
GNatural Gas
GOther ______________________________

Kiln Information

G**Do not operate a kiln**

If you have a kiln, please answer the following questions:

What species do you dry?

Wood Species	Quantity thousand board feet	% of total
________________	________________	________________
________________	________________	________________
________________	________________	________________
________________	________________	________________
Total	________________	**100%**

What is the average moisture content of the wood before drying? ____________________
What is the average moisture content of the wood after drying? ____________________

Fuel Source (check appropriate box)
GSteam
GNatural Gas
GHogged Fuel
GOil
GOther ____

Annual Production Information

Outputs	Quantity	Units
Products		
Glulam Production		

Outputs	Quantity	Units
Co-products[1/]		
1. Shavings		
2. Trimmings		
3.		
4.		
5.		

1/ Co-products are products produced (sawdust, trimmings, etc.) in addition to the main product (i.e. glulam beams) that are not landfilled. These products are sold to other manufacturers or used internally back into the production sequence.

Annual Emission Control Devices and Environmental Emission Information

The following is a chart of emission control devices and 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 for 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.

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

	ECD 1	**ECD 2**	**ECD 3**	**ECD 4**	**ECD 5**
Equipment controlled (i.e., boiler, press, etc.)					
Model/ Type					
Year Installed					
Electricity used ; either KWH or % of total plant use					
Natural Gas Used; either $ft.^3$ or % of total plant use					

Annual Emission to Air
(Please provide units of measurement if different)

Output	Emission Control Device				
Air Emission	**ECD 1**	**ECD 2**	**ECD 3**	**ECD 4**	**ECD 5**
Equipment controlled (i.e., boiler, press, etc.)					
Units	Tons/year	Tons/year	Tons/year	Tons/year	Tons/year
CO_2					
CO					
NO_X					
SO_2					
VOC					
acrolein*					
Methanol*					
Phenol*					
Acetaldehyde*					
Formaldehyde*					
Propionaldehyde*					
Water Vapor					
Particulate					
PM10					
* HAPS; you may want to provide total HAPS rather than specific chemicals					
Other (Please specify)					

Annual Emission to Land
(please provide units of measurement if different)

Output		
Emissions to Land and water	**Quantity (i.e. tons, lbs.)**	**Method of disposal or end use (i.e. land fill, landscaping)**
Wood waste		
Boiler ash and fly ash		
Recovered particulates from pollution abatement equipment		
Water		
Other (Please specify)		

General Information on the Glulam Production Process

A. Type resin used for Finger Jointing (check appropriate box)

G Phenol Resorcinol Formaldehyde
G Melamine
G Melamine Urea Formaldehyde
G Melamine Formaldehyde
G Resorcinol
G Other ____________________

B. Type of curing method for Finger Jointing (check appropriate box)

	Energy Consumption	Units
G Radio frequency		
G Cold cure		
G None		

C. Type resin used for Face Bonding (check appropriate box)

G Phenol Resorcinol Formaldehyde
G Melamine
G Melamine Urea Formaldehyde
G Melamine Formaldehyde
G Resorcinol
G Other ____________________

D. Type of curing method for Face Bonding (check appropriate box)

	Energy Consumption	Units
G Radio frequency		
G Cold cure		
G None		