GATE-TO-GATE LIFE-CYCLE INVENTORY OF ORIENTED STRANDBOARD PRODUCTION

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ABSTRACT

A life-cycle Inventory (LCI) for Southeast oriented strandboard (OSB) manufacturing was conducted by surveying four OSB manufacturing plants in the Southeast. The survey responses were returned for 1999 production data and represented approximately 18% of OSB production in the survey region. All LCI data presented herein were based on a standard production unit of 0.88 m³ OSB panel product (1000 ft², 3/8-inch basis).

Southeastern OSB requires 771.6 kg (1701 lb, oven-dry basis) of roundwood raw material input. 545.7 kg (1203 lb) of this input ends in final OSB product, giving a total wood recovery of 71%. The remaining wood input ends as wood residue for fuel, wood residues sold as co-products, and wood waste sent to the landfill.

On-site energy requirements for southeastern OSB are 5261 MJ (4.99 million BTU). Heat energy is the largest energy need, 89.6% of which is generated from combustion of wood residues. 182 kWh (655 MJ heat equivalent) of electricity is required for processing OSB. The highest use of fossil fuel (natural gas) is used to reduce VOC emissions in the emission control process at 465 MJ (4.4 million BTU).

Considering the carbon cycle for on-site OSB production for a unit of product, OSB requires 396 kg (873 lb) of carbon from wood raw material. Other carbon input is utilized in the form of resins/wax (11.4 kg/25 lb) and fuels (12.3kg/27 lb). OSB holds 290 kg (640 lb or 69% of total carbon input) carbon. A small percentage of carbon (4%) is held in the form of co-products (e.g. mulch and wood residues). The remainder of carbon is released back to nature in the form of non-fossil CO_2 (24%), fossil CO_2 (3%), VOCs and other emissions (0.4%).

Keywords: Life-cycle inventory, carbon balance, oriented strandboard.

INTRODUCTION

Oriented strandboard (OSB) evolved from waferboard in the late 1970s. OSB is manufactured by processing a log into strands of predetermined length, width, and uniform thickness. These strands are oriented, not randomly placed, to create a final panel product that can be used for structural applications. These applications include wall sheathing, roof sheathing, subfloors, underlayment, structural insulated panels, I-joists, and rim boards. Today, all building codes in the U.S. and Canada recognize OSB panels for the same uses as plywood on a thickness-by-thickness basis. Although OSB comes in a variety of grade and thickness, its commercial production is based on a thousand square feet (MSF) of 3/8-inch thickness equivalence (0.88 m³). In 2000, the reported total annual OSB production for the U.S. was 11.9 million MSF 3/8-inch (APA 2001).

The goal of this study was to document the life-cycle inventory (LCI) of manufacturing OSB based on resources from the Southeast OSB manufacturing region. This study is part of the Consortium for Research on Renewable Industrial Materials (CORRIM) Phase I project to study the life-cycle impact of renewable building materials (Lippke et al 2004). The output of this study is intended for use by researchers and practitioners as an input to the life-cycle analysis (LCA) of structural building materials in an overall cradle-to-grave analysis. This study considers those impacts associated primarily with the on-site manufacture of OSB (gate-to-gate), documenting all inputs and outputs. Primary data were collected by direct survey of OSB

manufacturers. Supplemental secondary data were obtained for impacts associated with the manufacture, delivery, and consumption of electricity and all fuels, resins, and wax additives (Kline 2004).

Scope of study

This study focuses on OSB production practices in the Southeast region of the U.S., which includes Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee, Texas, and Virginia (Fig. 1). Almost two-thirds of total OSB production (7.9 million MSF) was reported in the south region (APA 2001). To conduct the survey of OSB manufacturers in this region, all OSB manufacturing plants (22 plants for the Southeast region) were sent a LCI survey in October 2000. Of these, four plants (18%) responded with complete data in terms of OSB and by-products production, raw materials, electricity and fuel use, and emissions. Surveyed LCI data represent 1999 production data.

OSB process description

The overall OSB manufacturing system consists of 10 primary processes: Log Handling, Flaking, Drying, Screening, Blending, Mat Formation, Pressing, Finishing, Heat Generation, and Air Emission Control. The inputs into this system are roundwood (a log with bark), energy (electricity, fuels, gas), and water. Outputs include primary products (OSB), secondary products (bark mulch, fines, dust), air emissions, and other solid waste that is disposed of (e.g. to landfill). The interrelationships between these inputs, outputs, and processes are shown in Fig. 2.

Unit processes and system boundary

The 10 primary OSB processes described in Fig. 2 were organized into six functional sub-unit processes. These sub-unit processes are shown in Fig. 3 and serve as the basic models within the system boundary considered for LCI analysis of OSB processing. Unit processes were based on a standard production unit of 0.88 m^3
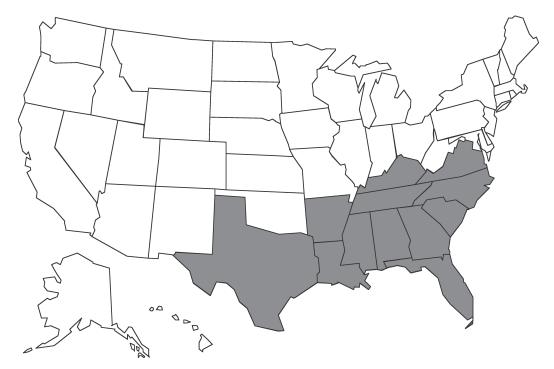

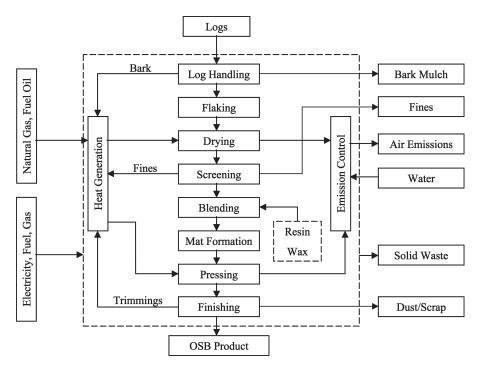FIG. 1. Survey region for OSB production practices in the Southeast.

FIG. 2.   Description of the OSB manufacturing processes. System boundary for on-site OSB processes is represented by dashed line.
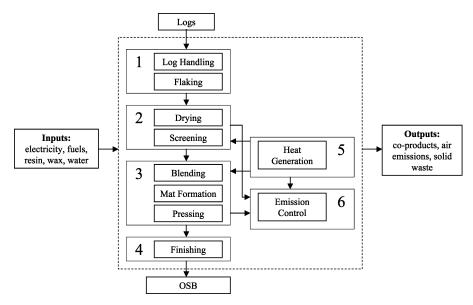
FIG. 3.   Sub-unit processes used to model the OSB manufacturing process.

OSB panel product (1000 ft², 3/8-inch basis). While part of the rationale for these six basic sub-unit processes was due to limited allocation data of the various fuel and electricity inputs to all of the processes, the most important processes are represented in terms of both process-

ing function importance and environmental impact. The following describes each of the sub-unit processes and rationale for their use in terms of analyzing ways to improve efficiency and reduce environmental impacts.

1. *Log Handling/Flaking*. Includes log handling operations, debarking, bucking, and flaking of logs. This sub-unit demands over 25% of the electrical needs of OSB processing and significant fossil fuels for log handling operations. The primary co-product produced is bark mulch. This process can be used to study the impact of different input log species, quality, and size as well as different technologies comparing tree-length versus log bolt processing.

2. *Drying and Screening*. Includes drying of green flakes (50% wet basis) and screening operations to separate materials that are too small for OSB manufacturing. This sub-unit requires a large electrical input and demands up to 80% of the heat requirements of OSB processing. Due to high temperature drying, this sub-unit is the primary source of volatile organic compounds (VOC). Sometimes screening fines are sold as a co-product or disposed of to landfills. This process can be used to study the impact of different drying technologies (e.g. low-temperature drying) and screening methods (e.g. green flake screening to reduce drying load).

3. *Blending and Pressing*. Includes addition of resin, wax, etc. to wood strands, mat formation, and hot-pressing operations. This sub-unit demands the remainder of the heat needs to produce OSB panels. This operation also requires resin to bond OSB flakes. Resins used contain hazardous air pollutants such as formaldehyde that can be released during pressing as VOC compounds. This process can be used to study the impact of employing different press emission collection systems.

4. *Finishing*. Includes all final operations (e.g., sawing to size, sanding, packaging, etc.) to complete panels before their distribution to market. This sub-unit demands the least amount of energy resources but produces a stream of OSB board scrap and sander/machining dust. This scrap and dust are sometimes sold as a co-product or disposed of in landfills.

5. *Heat Generation*. Includes combustion of all fuel sources to provide the heating requirements for OSB processing. Because this sub-unit uses wood residue as a primary fuel source, significant amounts of particulates and VOC gases can be generated due to incomplete/inefficient combustion. Also, wood ash is generated that must be disposed of to landfills. All wood residues generated in sub-units 1 through 4 above can be used as fuel for heat generation. Also, fossil fuels can be used as a fuel source. When residues are used for fuel, they are considered to remain within the system boundary for the LCI analysis. This process can be used to study the impact of employing different drying technologies as well as different fuel mixes.

6. *Emission Control*. Includes all technologies used to collect significant process emissions and treat them for reduced environmental impact before releasing them to the atmosphere. In treating various process emissions, this sub-unit can consume substantial resources such as fossil fuel, electricity, and water. With recent Maximum Achievable Control Technology (MACT) standards required by the 1990 Clean Air Act Amendments, this process can be used to study the life-cycle impact of employing different emission control technologies.

Assumptions

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

- All data from the survey were weight-averaged for the four plants based on their production in comparison to the total production for the year. Where appropriate, missing

data from various plants were not included in weight averages.

- OSB oven-dry board density, which can vary somewhat depending on species used and products produced, was assumed to be 0.649 g/cm^3 (40.5 lb/ft^3).
- 100% of the diesel fuel reported was allocated for mobile equipment in the Log Handling/ Flaking sub-unit process
- 100% of the liquid petroleum gas (LPG) and gasoline reported was allocated to the Finishing sub-unit process.
- The heat value of wood is assumed to occur at 67% combustion efficiency or 3000 BTU/lb wood at 50% MC (wet-basis). Since wood residue used for heating is exclusively generated within the OSB system boundary, there is no burden assigned due to transportation. Heat values, burdens, and emissions for the combustion of other fuels are provided by Franklin Associates (Kline 2004).
- Electricity consumption reported for OSB mills was not clearly separated between processes and administration. To be conservative, all reported electricity consumption was allocated to process-related data.
- Transportation of logs, resin, wax, and other ancillary materials related to OSB processing is excluded from the life-cycle inventory in this study. However, a table is provided of the one-way transportation mileage of these materials to the OSB mill.
- Air emission data related to the effectiveness of various emission control technologies were taken from the National Council for Air and Stream Improvement Technical Bulletin No. 772 (NCASI 1999).
- CO_2 emissions originating from fossil fuel sources and non-fossil fuel sources (e.g. combustion of wood residues) are reported separately in this study. This separate reporting is done because the Environmental Protection Agency (EPA) recognizes that CO_2 from biofuel has a neutral impact on global warming.
- SimaPro5, a software package designed for analyzing the environmental impact of products during their whole life cycle, was used to input the OSB life-cycle inventory (LCI). De-veloped in The Netherlands by PRé Consultants (2001) B.V., SimaPro5 contains a U.S. database for a number of materials, including paper products, fuels, and chemicals. The U.S. database is provided by Franklin Associates (Kline 2004).

Data quality and standard compliance

The survey responses represented 1999 production data and these plants represented approximately 18% in terms of total production for the survey region. Reported results were cross-referenced with secondary data to ensure data integrity. Reported material inputs and outputs were cross-referenced with published secondary data and were found to align closely with results reported in the literature for OSB (e.g. Lees 1993; NCASI 1999). The study procedures and report are in conformity with the applicable standards included in ISO 14,040 (ISO 1997) and ISO 14,041 (IS0 1998). Burdens, a method of assigning allocations of emissions to products, were assigned to OSB products and by-products on a mass basis. Details of this study and the overall CORRIM project can be found in Kline (2004) and Bowyer et al. (2004).

This report was independently reviewed by external reviewer Frank Werner from Environment and Development in Zurich, Switzerland. The external review was to assure that the study procedures are scientifically and methodologically sound and that the report is representative, transparent, and complete for life-cycle inventory data for the OSB production processes.

MATERIAL FLOWS

Process input

Table 1 lists reported inputs associated with one standard production unit of OSB. The input to produce a standard unit of OSB consists of 1.4 m^3 (49.5 ft^3) of roundwood (logs with bark). From this roundwood input, 710 kg (1566lb) of wood and 61 kg (135 lb) of bark were produced during processing operations. 19 kg (42.4 lb) of PF resin, 3.7 kg (8.16 lb) MDI resin, and 8.8 kg

TABLE 1. *Overall gate-to-gate LCI inputs for a standard production unit of OSB (0.88 m³/1000 ft², 3/8-inch basis) in the Southeast. Results do not include inputs for the production and delivery of wood, fuel, electricity, resins, or wax.*

INPUTS		
Materials[1]	Units	
Roundwood	m³ (ft³)	1.4 (49.5)
Wood	kg (lb)	710.3 (1566)
Bark	kg (lb)	61.2 (135)
Phenol-formaldehyde	kg (lb)	19.2 (42.4)
MDI resin	kg (lb)	3.7 (8.16)
Wax	kg (lb)	8.8 (19.3)
Water input		
Ground water	l (gal)	32.1 (8.48)
Electricity input		
Electricity	kWh	182
Fuel input		
Wood fuel (produced)[1,2]	kg (lb)	176.5 (389)
Natural gas	m³ (ft³)	21.2 (747)
Liquid propane gas	l (gal)	2.68 (0.708)
Diesel	l (gal)	0.07 (0.019)
Fuel oil	l (gal)	0.70 (0.186)
Gasoline	l (gal)	0.03 (0.0077)

[1] All materials and wood fuel are given as oven-dry or solids weights.
[2] Wood fuel includes bark, screening fines, and OSB trimmings that are produced within the OSB system boundary.

(19.3 lb) wax were added to wood flakes to produce OSB (density assumed to be 0.649 g/cm³). Table 1 also lists reported electricity and fuel inputs required for each standard production unit OSB.

Process output

Table 2 lists reported outputs associated with one standard production unit of OSB. One standard production unit of OSB results in 574 kg (1266 lb) of primary OSB product and small amounts of secondary co-products including bark mulch, fines, and dust. Materials reported that are disposed (i.e. landfills) include wood waste and wood boiler ash. Air emissions are a significant concern in LCI studies. Survey emissions reported in this study are from OSB emission control systems which collect and process emissions from burners, dryers, and presses. However, CO_2 emissions were not available from survey data and therefore were calculated

TABLE 2. *Overall gate-to-gate LCI inputs for a standard production unit of OSB (0.88 m³/1000 ft², 3/8-inch basis) in the Southeast.*

OUTPUTS		
Product	Units	
OSB	kg (lb)	574.2 (1266)
Co-products		
Bark mulch	kg (lb)	20.3 (44.7)
Fines	kg (lb)	8.3 (18.2)
Dust/scrap	kg (lb)	4.3 (9.53)
Material		
Wood waste	kg (lb)	0.05 (0.11)
Wood ash	kg (lb)	1.91 (4.22)
Air emission		
CO_2 (non fossil)[1,2]	kg (lb)	3.81E + 02 (8.41E + 02)
CO_2 (fossil)[1]	kg (lb)	4.63E + 01 (1.02E + 02)
CO	kg (lb)	1.13E + 00 (2.49E + 00)
SO_2	kg (lb)	2.67E − 02 (5.89E − 02)
NO_x	kg (lb)	3.16E − 01 (6.97E − 01)
Particulates (PM10)	kg (lb)	2.79E − 01 (6.15E − 01)
VOC[3]	kg (lb)	9.89E − 01 (2.18E + 00)
Methanol[4]	kg (lb)	1.80E − 01 (3.97E − 01)
Formaldehyde[4]	kg (lb)	5.08E − 02 (1.12E − 01)
Acetaldehyde[4]	kg (lb)	5.94E − 02 (1.31E − 01)
Acrolein[4]	kg (lb)	2.14E − 02 (4.71E − 02)
Phenol[3]	kg (lb)	1.10E − 02 (2.42E − 02)
MDI[3]	kg (lb)	7.26E − 05 (1.60E − 04)

[1] Not from survey data; calculated from FAL Database. 1998.
[2] Includes 24 lb CO_2 (non-fossil) from combustion of VOCs assuming a 64% average VOC removal efficiency.
[3] VOCs weight average as reported by survey mills.
[4] VOCs only reported for one mill.

based on CO_2 emissions data from various fuel sources (Kline 2004). As shown in Table 2, 381 kg (841 lb) or 89% of total CO_2 emissions come from biomass (i.e. self-generated wood residues). No output emissions to water were reported in this survey.

Wood mass balance

An overall wood mass balance is given in Table 3. The difference in "unaccounted wood" between the total wood input and output is 16.3 kg (37 lb) (more input than output). The unaccounted wood is 2.2% of the total wood input. While this small amount of unaccounted wood is relatively small, it is important to note that it is based on several assumptions noted earlier. Any

TABLE 3. *Wood mass balance for OSB production from the Southeast region for a standard production unit of OSB (0.88 m³/1000 ft², 3/8-inch basis). All weights are reported on an oven-dry basis.*

Input	kg (lb)
Roundwood (logs)[1]	771.6 (1701)
Output	
OSB (wood only)[2]	545.7 (1203)
Wood fuel (produced)	176.4 (389)
Bark mulch sold	20.4 (45)
Fines sold	8.2 (18)
Dust/scrap sold	4.5 (10)
Wood waste landfilled[3]	—
Total output:	755.2 (1665)
Unaccounted wood[4]	16.4 (37)

[1] Includes weight of both bark and solid wood from Table 1.
[2] OSB is 95.1% wood fiber and 4.9% resin/wax based on survey data.
[3] Less than 1 lb per production unit reported.
[4] 2.2% less output than reported wood input.

relatively small change in these assumptions could yield more or less unaccounted wood. Nevertheless, this mass balance appears to verify that the material information provided from the survey information is reasonable.

Material transportation

Delivery of the input materials was by truck. The one-way delivery distances for logs, resin, and wax are given in Table 4. These distances are weighted averages of the survey data. Delivery distances for fuel inputs were not included in the survey.

MANUFACTURING ENERGY

Energy for the production of OSB comes from electricity, diesel, and liquid propane gas (LPG), natural gas, and wood fuel from bark, fines, and other wood residue (Table 1). The electricity is

TABLE 4. *Southeast delivery distance (one-way) for OSB production.*

Material	Delivery distance km (miles)
Logs with bark (roundwood)	143 (89)
PF resin	932 (579)
MDI resin	1328 (825)
Wax	1149 (714)

used to operate all the systems described in Figs. 2 and 3. Diesel fuel use is assumed to be used by log loaders in the "log handling" process. Forklift trucks used small amounts of LPG primarily in the "finishing" process.

Electricity usage

The overall electrical usage reported per standard OSB production unit is 182 kWh. The source of fuel used to generate the electricity used in the manufacturing process is very important in determining the type and amount of impact in the LCI analysis. The breakdown of electricity use in the Southeast by fuel source is given in Table 5 (USDOE 2000). In 1998, the dominant form of fuel source in the region was coal, representing 49.2% of the total, followed by nuclear at 25.6%, natural gas at 9.6%, petroleum at 3.7%, and hydroelectric at 3.4%.

Energy requirements

Energy demand (both on-site and cumulative) for southeastern OSB is listed in Table 6. The total cumulative energy demand for one standard production unit of southeastern OSB is 9660 MJ (9.16 million BTU). Cumulative energy demand includes both on-site energy required to produce OSB plus off-site energy embodied in the feedstock, manufacturing, and delivery of required electricity, fuels, and resin. On-site energy added during OSB processing is 5261 MJ (4.99 million BTU) or 54.5% of total cumulative energy. Wood fuel generated on site is utilized as the largest energy input of 3693 MJ (3.5 million BTU). Wood fuel provides for 89.6% of on-site heat energy requirement. The remainder of heat energy requirement is supplemented with natural gas, LPG, and DFO. Resin, which includes MDI, phenol-formaldehyde, and slack wax, requires a significant 2985 MJ (2.8 million BTU) of off-site energy input (i.e. heat value of feed stocks and energy required for manufacturing). 182 kWh (655 MJ equivalent) of electricity is required for processing OSB. Total cumulative energy required to generate the required electricity demand is 1784 MJ (1.7 million BTU).

TABLE 5. *Electric power industry generation of electricity by primary energy sources and state for the Southeast region as defined by the U.S. Department of Energy (2000).*

	Percentage share, 1998[1]												
Fuel source	AL[2]	AR	FL	GA	KY	LA	MS	NC	SC	TN	TX	VA	Avg
Coal	59.5	50.7	34.6	60.6	95.7	23.2	34.1	56.9	37.1	56.4	37.4	43.6	49.2
Petroleum	0.2	0.3	21.6	0.6	0.1	0.7	15.7	0.2	0.4	0.7	0.0	3.7	3.7
Gas	2.0	8.1	16.7	1.5	0.6	31.6	16.4	0.8	0.5	0.6	33.9	3.0	9.6
Nuclear	23.9	28.7	16.4	27.2	0.0	18.3	26.7	31.9	55.9	29.0	10.9	37.7	25.6
Hydro	8.8	6.8	0.1	4.4	3.6	0.0	0.0	3.4	2.9	9.6	0.4	0.4	3.4
Non utility	5.5	5.4	10.6	5.7	0.0	26.2	7.1	6.8	3.3	3.7	17.4	11.6	8.5

[1] Source: Energy Information Administration/State Electric Profiles 2000, Department of Energy. http://www.eia.doe.gov/cneaf/electricity/st_profiles/toc.html.
[2] Abbreviations of Southeastern states.

TABLE 6. *Southeast on-site (gate-to-gate) and cumulative (on- and off-site) energy input requirements for a standard production unit of OSB (0.88 m^3/1000 ft^2, 3/8-inch basis).*

Energy input	Onsite[1] MJ (1000 BTU)	Cumulative[2] MJ (1000 BTU)
Electricity	655 (621)	1784 (1691)
Wood fuel[3]	3693 (3501)	3693 (3501)
Natural gas	811 (769)	1085 (1029)
Propane (LPG)	71.3 (67.6)	76.3 (72.4)
Fuel oil (DFO)	30.0 (28.5)	35.4 (33.5)
Gasoline	1.11 (1.05)	1.12 (1.06)
Resin[4]	—	2985 (2830)
Total	5261 (4988)	9660 (9158)

[1] Heating equivalent assumptions: for electricity 3.6 MJ/kWh; for wood 20.9 MJ/kg oven-dry; for natural gas 54.4 MJ/kg; for LPG 54.0 MJ/kg; for DFO 45.5 MJ/kg; for gasoline 45.0 MJ/kg.
[2] Cumulative energy includes heating value of feed stocks and offsite energy required for manufacturing. Transportation energy for delivery of materials is not included.
[3] Wood fuel generated on site.
[4] Resin includes MDI, phenol-formaldehyde, and wax.

FIG. 4. Comparison of on-site energy requirements to produce a standard OSB production unit (0.88 m^3/1000 ft^2, 3/8-inch basis) for each unit-process stages.

Figure 4 shows the relative onsite energy requirements from different sources (e.g. electricity, non-fossil, fossil) for each OSB sub-unit process. The largest consumption of energy occurs during the drying and screening sub-unit process, 83.1% of which is provided by on-site generated wood fuel (non-fossil). The highest use of fossil fuel (natural gas) is required to reduce VOC emissions in the emission control process at 465 MJ (4.4 million BTU). Very small amounts of fossil fuels are used (less than 20 MJ) to support processing activities such as log handling and forklifts.

LIFE-CYCLE INVENTORY

Two life-cycle inventory (LCI) scenarios are used to study emissions generated to air, water and land for Southeast OSB. The first scenario considers a LCI which includes both on-site impacts and all off-site impacts including the production and delivery of resin, wax, electricity, fuel, etc. The second scenario considers a gate-to-gate LCI, which includes only on-site impacts for OSB production. A complete listing of emissions to air, water, and land is itemized in Tables 7, 8, and 9 for both of these LCI scenarios. Compared to water and land emissions reported, air emissions influenced by OSB manufacturing contribute much larger impacts and are further discussed in the following paragraphs.

TABLE 7. *Emissions to air for cumulative on-site and off-site impact and gate-to-gate (on-site impact) for a standard production unit of OSB (0.88 m^3/1000 ft^2, 3/8-inch basis). Burden is the allocation of emissions to primary OSB product.*

Substance	Cumulative			On-site		
	kg	lb	Burden	kg	lb	Burden
CO_2 (fossil)	2.37E + 02	5.22E + 02	98.2%	4.58E + 01	1.01E + 02	98.2%
CO_2 (biomass)	3.75E + 02	8.26E + 02	98.2%	3.75E + 02	8.26E + 02	98.2%
CO	1.44E + 00	3.18E + 00	98.3%	1.13E + 00	2.49E + 00	98.1%
Acetaldehyde	5.85E − 02	1.29E − 01	98.1%	5.85E − 02	1.29E − 01	98.1%
Acrolein	2.10E − 02	4.64E − 02	98.1%	2.10E − 02	4.64E − 02	98.1%
Formaldehyde	7.58E − 02	1.67E − 01	98.5%	5.03E − 02	1.11E − 01	98.1%
Methanol	1.77E − 01	3.91E − 01	98.1%	1.77E − 01	3.91E − 01	98.1%
Phenol	4.41E − 02	9.72E − 02	99.0%	1.08E − 02	2.39E − 02	98.1%
NOx	1.47E + 00	3.24E + 00	98.5%	3.18E − 01	7.00E − 01	98.1%
SO2	1.08E − 01	2.37E − 01	99.0%	2.64E − 02	5.81E − 02	98.1%
SOx	2.52E + 00	5.56E + 00	98.4%	2.74E − 04	6.05E − 04	95.5%
Methane	6.26E − 01	1.38E + 00	98.4%	—	—	—
Particulates (PM10)	3.04E − 01	6.70E − 01	98.1%	2.75E − 01	6.06E − 01	98.1%
Particulates	1.08E − 02	2.37E − 02	99.1%	3.48E − 04	7.68E − 04	96.1%
Particulates (unspecified)	1.32E − 01	2.90E − 01	97.8%	—	—	—
VOC	1.70E + 00	3.74E + 00	98.4%	9.75E − 01	2.15E + 00	98.1%
MDI (isocyanate)	7.17E − 05	1.58E − 04	98.1%	7.17E − 05	1.58E − 04	98.1%

TABLE 8. *Emissions to water for cumulative on-site and off-site impact and gate-to-gate (on-site impact) for a standard production unit of OSB (0.88 m^3/1000 ft^2, 3/8-inch basis). Burden is the allocation of emissions to primary OSB product.*

Substance	Cumulative			On-site		
	kg	lb	Burden	kg	lb	Burden
BOD	5.58E − 03	1.23E − 02	99.0%	— No Values Reported —		
Suspended solids	9.89E − 02	2.18E − 01	98.0%			
Dissolved solids	2.61E + 00	5.75E + 00	98.6%			
COD	3.99E − 02	8.80E − 02	98.9%			
Cl-	6.44E − 01	1.42E + 00	99.1%			
Oil	4.63E − 02	1.02E − 01	98.6%			

TABLE 9. *Emissions to land for cumulative on-site and off-site impact and gate-to-gate (on-site impact) for a standard production unit of OSB (0.88 m^3/1000 ft^2, 3/8-inch basis). Burden is the allocation of emissions to primary OSB product.*

Substance	Cumulative			On-site		
	kg	lb	Burden	kg	lb	Burden
Wood	4.94E − 02	1.09E − 01	99.2%	4.94E − 02	1.09E − 01	99.2%
Ash	1.96E + 00	4.31E + 00	98.3%	1.88E + 00	4.15E + 00	98.2%
Other solid waste	2.81E + 01	6.20E + 01	97.9%	—	—	—

All CO_2 from biomass and a majority of CO (78%), VOC (58%) and particulates (62%) are generated on-site. All methane, and a majority of SOx (99%), CO_2 from fossil (81%), and NOx (78%) air emissions are generated off-site (e.g. for the production and delivery of fuels, resin, wax, and electricity). Sixty-one (61)% of total CO_2 (generated both on- and off-site) is from biomass. However, when considering the

amount of CO_2 generated on-site only, the percentage from biomass is much higher at 89%.

When considering OSB sub-unit processes, significant emissions are generated as a result of either the drying, pressing, or emission control processes. The flaking and finishing processes contribute very little to air emissions. Because the emission control process uses a large amount of natural gas, it contributes (on-site) nearly

50% of fossil CO_2 and the most SOx (99.5%) and NOx (97.7%) emissions released to air.

Burdens, a method of assigning allocations of emissions to products, were allocated to OSB products and by-products on a mass basis. Emissions for the various products reported for OSB in Tables 7, 8, and 9 had varying burdens depending at which sub-unit process an emission occurred. For example, if an emission would arise only at the OSB finishing stage, then a higher burden of 99.3% would be assigned to finished OSB since very little co-product is produced during this stage. However, if an emission would occur for each of the OSB processing stages, this burden for finished OSB could be less because more mass of co-products is produced in earlier stages of OSB manufacturing. Burdens for air emissions for finished OSB ranged from 97.8% to 99.3% with an average burden of about 98.5%. The remaining burdens are assigned to the co-products of bark mulch, screening fines, and sawdust.

CARBON BALANCE

Approximately 423 kg (930 lb) of carbon are involved in the manufacture of one standard OSB production unit. Based on data from Skog and Nicholson (1998), the weighted-average carbon content used for southeastern roundwood input (75% softwood and 25% hardwood) was calculated at 51.3%. The carbon balance shown in Figs. 5 (carbon input) and 6 (carbon output) excludes forestry processes and transportation of logs and other ancillary materials to the manufacturing site. For each standard OSB production unit, 396 kg (873 lb, 94.4% of total carbon input) of carbon from wood raw material is utilized. Other carbon input is utilized in the form of resins/wax (11.4 kg/25 lb) and fuels (12.3 kg/27 lb). One standard OSB production unit holds 290 kg (640 lb, 69% of total carbon input) carbon. A very small percentage of carbon (4%) is held in the form of co-products (e.g. mulch and other wood residues). The remainder of carbon is released back to nature in the form of non-fossil CO_2 (24%), fossil CO_2 (3%), VOCs, and other emissions (0.4%).
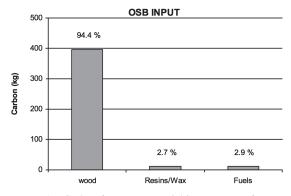

FIG. 5. Carbon from raw material input sources for one standard OSB production unit (0.88 m^3/1000 ft^2, 3/8-inch basis).

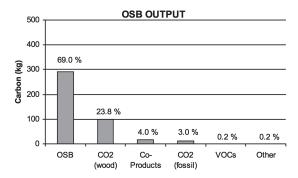

FIG. 6. Carbon output destinations for one standard OSB production unit (0.88 m^3/1000 ft^2, 3/8-inch basis).

SUMMARY

Studies to conduct a life-cycle inventory for southeast OSB manufacturing were conducted by surveying four OSB manufacturing plants in the Southeast. The survey responses represented 1999 production data and represented approximately 18% of OSB production in the survey region.

In the manufacture of southeastern OSB, 71% yield was found (OSB product from wood and bark raw material input). The remaining 29% of this input ends as wood residue for fuel (25%), wood residues sold as co-products (4%), and wood waste sent to the landfill (less than 0.01%).

Over half of the energy required to manufacture OSB (54.5%) is added on-site. Wood fuel generated on site provides for 89.6% of on-site

heat demand. The remainder of heat demand is supplemented with natural gas, LPG, and DFO. Resin, which includes MDI, phenol-formalde-hyde, and slack wax, represents 68% of off-site energy input (i.e. heat value of feed stocks and energy required for manufacturing) for the manufacture of OSB.

All CO_2 from biomass and a majority of CO (78%), VOC (58%) and particulates (62%) are generated on-site. All methane, and a majority of SOx (99%), CO_2 from fossil (81%), and NOx (78%) air emissions are generated off-site for the production and delivery of fuels, resin, wax, and electricity. Sixty-one (61)% of total CO_2 (gen-erated both on- and off-site) is from biomass. However when considering the amount of CO_2 generated on-site only, the percentage from bio-mass is much higher at 89%.

Considering the carbon cycle for on-site OSB production, 94.4% of the total carbon input is from wood raw materials. Other carbon input is utilized in the form of resins/wax (2.7%) and fuels (2.9%). OSB holds 69% of total carbon input as the final manufactured product. A very small percentage of carbon (4%) is held in the form of co-products (e.g. mulch and other wood residues). The remainder of carbon is released back to nature in the form of non-fossil CO_2 (24%), fossil CO_2 (3%), VOCs and other emis-sions (0.4%).

ACKNOWLEDGMENTS

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