10.5 Plywood Manufacturing

10.5.1 General

Plywood is a building material consisting of veneers (thin wood layers or plies) bonded with an adhesive. The outer layers (face and back) surround a core that is usually lumber, veneer, or particleboard. Plywood has many uses, including wall siding, sheathing, roof decking, concrete formboards, floors, and containers.

10.5.2 Process Description[1-3,15]

The manufacture of plywood consists of seven main processes: log debarking and bucking, heating the logs, peeling the logs into veneers, drying the veneers, gluing the veneers together, pressing the veneers in a hot press, and finishing processes such as sanding and trimming. Figure 10.5-1 provides a generic process flow diagram for a plywood mill.

The initial step of debarking is accomplished by feeding logs through one of several types of debarking machines. The purpose of this operation is to remove the outer bark of the tree without substantially damaging the wood. Although the different types of machines function somewhat differently, emissions from the different machines are comparable. After the bark is removed, the logs are cut to appropriate lengths in a step known as bucking.

The logs (now referred to as blocks) then are heated to improve the cutting action of the veneer lathe or slicer, thereby generating a product from the lathe or slicer with better surface finish. Blocks are heated to around 93°C (200°F) using a variety of methods--hot water baths, steam heat, hot water spray, or a combination of the three.

After heating, the logs are processed to generate veneer. For most applications, a veneer lathe is used, but some decorative, high quality veneer is generated with a veneer slicer. The slicer and veneer lathe both work on the same principle; the wood is compressed with a nosebar while the veneer knife cuts the blocks into veneers that are typically 3 mm (1/8 in.) thick. These pieces are then clipped to a useable width, typically 1.37 m (54 in.), to allow for shrinkage and trim.

Veneers are taken from the clipper to a veneer dryer where they are dried to moisture contents that range from less than 1 to 15 percent. Target moisture contents depend on the type of resin used in subsequent gluing steps. The typical drying temperature ranges from 150° to 200°C (300° to 400°F). The veneer dryer may be a longitudinal dryer, which circulates air parallel to the veneer, or a jet dryer. The jet dryers direct hot, high velocity air at the surface of the veneers in order to create a more turbulent flow of air. The increased turbulence provides more effective use of dryer energy, thereby reducing drying time. In direct-heated wood-fired dryers, the combustion gases are blended with recirculated exhaust from the dryer to reduce the combustion gas temperature. In such cases, the gases entering the dryer generally are maintained in the range of 316° to 427°C (600° to 800°F).

When the veneers have been dried to their specified moisture content, they are glued together with a thermosetting resin. The two main types of resins are phenol-formaldehyde, which is used for softwood and exterior grades of hardwood, and urea-formaldehyde, which is used to glue interior grades of hardwood. The resins are applied by glue spreaders, curtain coaters, or spray systems. Spreaders have a

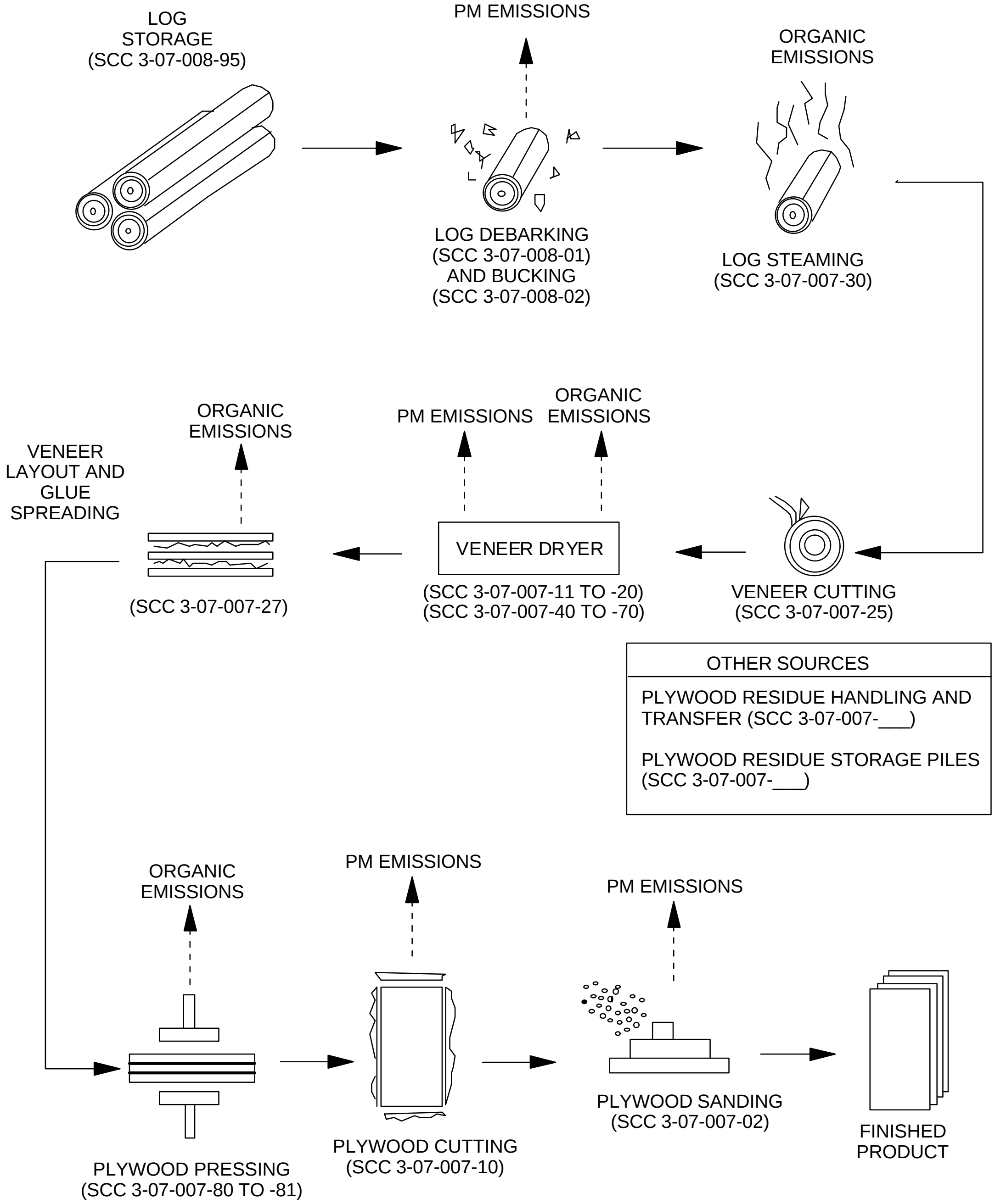

Figure 10.5-1. Generic process flow diagram for a plywood mill.
(SCC = Source Classification Code.)

series of rubber-covered grooved application rolls that apply the resin to the sheet of veneer. Generally, resin is spread on two sides of one ply of veneer, which is then placed between two plies of veneer that are not coated with resin.

Assembly of the plywood panels must be symmetrical on either side of a neutral center in order to avoid excessive warpage. For example, a five-ply panel would be laid up in the following manner. A back, with the grain direction parallel to the long axis of the panel, is placed on the assembly table. The next veneer has a grain direction perpendicular to that of the back, and is spread with resin on both sides. Then, the center is placed, with no resin, and with the grain perpendicular to the previous veneer (parallel with the back). The fourth veneer has a grain perpendicular to the previous veneer (parallel with the short axis of the panel) and is spread with resin on both sides. The final, face, veneer with no resin is placed like the back with the grain parallel to the long axis of the plywood panel.

The laid-up assembly of veneers then is sent to a hot press in which it is consolidated under heat and pressure. Hot pressing has two main objectives: (1) to press the glue into a thin layer over each sheet of veneer; and (2) to activate the thermosetting resins. Typical press temperatures range from 132° to 165°C (270° to 330°F) for softwood plywood, and 107° to 135°C (225° to 275°F) for hardwood plywood. Press times range from 2 to 7 minutes. The time and temperature vary depending on the wood species used, the resin used, and the press design.

The plywood then is taken to a finishing process where edges are trimmed; the face and back may or may not be sanded smooth. The type of finishing depends on the end product desired.

10.5.3 Emissions and Controls[2-20]

The primary emissions from the manufacture of plywood include filterable particulate matter (PM) and PM less than 10 micrometers in aerodynamic diameter (PM-10) from log debarking and bucking, and plywood cutting and sanding; filterable and condensible PM/PM-10 from drying and pressing; organic compounds from steaming and drying operations; and organic compounds, including formaldehyde and other hazardous air pollutants (HAPs), from gluing and hot pressing. However, trace amounts of combustion by-products, which may include HAPs (e. g., aldehydes), may be present in direct-fired, veneer dryer exhausts as a result of fossil fuel or wood combustion gases being passed through the dryer. Fuel combustion for material drying also can generate carbon monoxide (CO), carbon dioxide (CO_2), sulfur dioxide (SO_2), and nitrogen oxide (NO_x) emissions.

The main source of emissions is the veneer dryer, which emits significant quantities of organic compounds. The quantity and type of organic compounds emitted varies depending on the wood species, the dryer type, and its method of operation. The two discernible fractions released from the dryer are condensibles and volatiles. The condensible organic compounds consist largely of sesqui-terpenes, resin acids, fatty acids, and alcohols. As these condensible compounds cool after being emitted from the stack, they often combine with water vapor to form aerosols, which can cause a blue haze. The other fraction, volatile organic compounds (VOCs), comprises terpenes along with small quantities of volatile combustion by-products where direct-fired dryers are used.

Measurement of VOC and condensible PM emission rates are highly dependent on stack gas and sampling train filter temperatures. When the sampling train filter temperature is higher than the stack gas temperature, the rate of VOC and condensible PM emissions measured will increase with increasing filter temperature, because as filter temperature increases less organic material will condense on the sampling train filter. The available data are inadequate to determine the effect on emissions of recirculating the exhaust from wood-fired veneer dryers to a combustion gas blend box.

The hot pressing operation is also a source of organic emissions. The quantity and composition of emissions from this operation are expected to vary with wood species and resin components. However, few test data are available for hot presses to characterize this variability.

Significant quantities of sawdust and other small wood particles are generated by plywood cutting and sanding operations. Sanders and trim saws typically have control devices to recover the material for use as a fuel in the dryer or boiler. However, small amounts of PM may be released from cutting and sanding. Log debarking, log bucking, and sawdust handling are additional sources of PM emissions. Finally, fugitive dust emissions are generated from open sources such as sawdust storage piles and vehicular traffic. Emissions from these operations are discussed in more detail in AP-42 Chapter 13.

Particulate matter and PM-10 emissions from log debarking, sawing, sanding, and material handling operations can be controlled through capture in an exhaust system connected to a sized cyclone and/or fabric filter collection system. These wood dust capture and collection systems are used not only to control atmospheric emissions, but also to collect the dust as a by-product fuel for a boiler or dryer.

Methods of controlling PM emissions from the veneer dryer include multiple spray chambers, a packed tower combined with a cyclonic collector, a sand filter scrubber, an ionizing wet scrubber (IWS), an electrified filter bed (EFB), and a wet electrostatic precipitator (WESP). The first three devices are older technologies that are being replaced with newer technologies that combine electrostatic processes with other scrubbing or filtration processes. Wet PM controls, such as IWS and WESP systems also may reduce VOC emissions from veneer dryers, but to a lesser extent than PM emissions are reduced by such systems.

In multiple spray chamber systems, the dryer exhaust is routed through a series of chambers in which water is used to capture pollutants. The water is then separated from the exhaust stream in a demisting zone. Multiple spray chambers are the most common control technology used on veneer dryers today. However, because they provide only limited removal of PM, PM-10, and condensible organic emissions, they are being replaced with newer, more effective techniques. The packed tower/cyclonic collector comprises a spray chamber, a cyclonic collector, and a packed tower in series. Applications of this system are also limited as newer, more efficient controls are applied. The sand filter scrubber incorporates a wet scrubbing section followed by a wet-sand filter and mist eliminator. The larger PM is removed in the scrubber, while a portion of the remaining organic material is collected in the filter bed or the mist eliminator. This scrubbing system is also becoming obsolete as newer, more efficient controls are applied.

Three newer technologies for controlling veneer dryer emissions are the IWS, the EFB, and the WESP. Because applications of these systems are relatively recent, there are limited data on their performance for veneer dryer emission control. The IWS combines electrostatic forces with packed bed scrubbing techniques to remove pollutants from the exhaust stream. The EFB uses electrostatic forces to attract pollutants to an electrically charged gravel bed. The WESP uses electrostatic forces to attract pollutants to either a charged metal plate or a charged metal tube. The collecting surfaces are continually rinsed with water to wash away the pollutants.

Little information is available on control devices for plywood pressing operations, as these operations are generally uncontrolled. However, one test report indicates that hot press emissions at one facility are captured by a large hood placed over and around the hot press and cooling station. The captured emissions are ducted to a packed-bed caustic scrubber. Formaldehyde collected in the scrubber is converted to sodium formate and discharged to the sewer.

A VOC control technology gaining popularity in the wood products industry for controlling both dryer and press exhaust gases is regenerative thermal oxidation. Thermal oxidizers destroy VOCs, CO, and condensible organics by burning them at high temperatures. Regenerative thermal oxidizers (RTOs) are designed to preheat the inlet emission stream with heat recovered from the incineration exhaust gases. Up to 98 percent heat recovery is possible, although 95 percent is typically specified. Gases entering an RTO are heated by passing through pre-heated beds packed with a ceramic media. A gas burner brings the preheated emissions up to an incineration temperature between 788° and 871°C (1450° and 1600°F) in a combustion chamber with sufficient gas residence time to complete the combustion. Combustion gases then pass through a cooled ceramic bed where heat is extracted. By reversing the flow through the beds, the heat transferred from the combustion exhaust air preheats the gases to be treated, thereby reducing auxiliary fuel requirements. Industry experience has shown that RTOs typically achieve 95 percent reduction for VOC (except at inlet concentrations below 20 parts per million by volume as carbon [ppm-vC]), 70 to 80 percent reduction for CO, and typical NO_x increase of 10 to 20 ppm.

Biofiltration systems can be used effectively for control of a variety of pollutants including organic compounds (including formaldehyde and benzene), NO_x, CO, and PM from both dryer and press exhaust streams. Data from pilot plant studies in U. S. oriented strandboard mills indicate that biofilters can achieve VOC control efficiencies of 70 to 90 percent, formaldehyde control efficiencies of 85 to 98 percent, CO control efficiencies of 30 to 50 percent, NO_x control efficiencies of 80 to 95 percent, and resin/fatty acid control efficiencies of 83 to 99 percent.

Other potential control technologies for plywood veneer dryers and presses include exhaust gas recycle, regenerative catalytic oxidation (RCO), absorption systems (scrubbers), and adsorption systems.

Table 10.5-1 presents emission factors for veneer dryer emissions of PM, including filterable PM and condensible PM. Table 10.5-2 presents emission factors for veneer dryer emissions of SO_2, NO_x, CO, and CO_2. Table 10.5-3 presents emission factors for veneer dryer emissions of organic pollutants. Table 10.5-4 presents emission factors for plywood press emissions of PM, including filterable PM and condensible PM. Table 10.5-5 presents emission factors for plywood press emissions of formaldehyde and VOC. Table 10.5-6 presents emission factors for plywood manufacturing miscellaneous sources.

Table 10.5-1. EMISSION FACTORS FOR PLYWOOD VENEER DRYERS--PARTICULATE MATTER[a]

Source	Emission Control[c]	Filterable[b]				Condensible[d]	EMISSION FACTOR RATING
		PM	EMISSION FACTOR RATING	PM-10	EMISSION FACTOR RATING		
Direct wood-fired							
Douglas fir (SCC-3-07-007-47)	WESP	0.26	D	ND		0.045	D
Direct natural gas-fired							
Unspecified pines[e] (SCC-3-07-007-50)	None	0.079	E	ND		0.42	E
Indirect heated							
Unspecified pines[e] (SCC-3-07-007-60)	None	0.35	D	ND		1.0	D
Douglas fir (SCC-3-07-007-67)	None	0.070[f]	D	ND		0.82[f]	D
Douglas fir (SCC-3-07-007-67)	WESP	0.040	E	ND		0.11	E
Unspecified firs[g] (SCC-3-07-007-66)	WESP	0.034	E	ND		0.065	E
Radio frequency heated							
Unspecified pines[e] (SCC-3-07-007-70)	None	0.0050	E	ND		0.0060	E

[a] Emission factor units are pounds per thousand square feet of 3/8-inch thick veneer (lb/MSF 3/8). One lb/MSF 3/8 = 0.5 kg/m^3. SCC = source classification code. Reference 19 except where noted otherwise. ND = no data available.

[b] Filterable PM is that PM collected on or prior to the filter of an EPA Method 5 (or equivalent) sampling train.

[c] Emission control device: WESP = wet electrostatic precipitator.

[d] Condensible PM is that PM collected in the impinger portion of a PM sampling train.

[e] Based on data on the drying of mixed pine species or the drying of veneers which are identified only as pines.

[f] References 11,14.

[g] Based on data on the drying of mixed fir species or the drying of veneers which are identified only as firs.

Table 10.5-2. EMISSION FACTORS FOR PLYWOOD VENEER DRYERS--SO_2, NO_x, CO, AND CO_2[a]

Source	Emission Control	SO_2	EMISSION FACTOR RATING	NO_x	EMISSION FACTOR RATING	CO	EMISSION FACTOR RATING	CO_2[c]	EMISSION FACTOR RATING
Direct wood-fired (SCC-3-07-007-40 to -46)	None	0.058	D	0.24	D	5.1	D	ND	
Direct natural gas-fired (SCC-3-07-007-50)	None	ND		0.012	E	0.57	E	ND	
Indirect heated (SCC-3-07-007-60 to -69)	None	NA		NA		NA		ND	
Radio-frequency heated (SCC-3-07-007-70)	None	ND		ND		ND		ND	

[a] Factors represent uncontrolled emissions. SCC = Source Classification Code. ND = no data available. NA = not applicable. All emission factors in units of pounds per thousand square feet of 3/8-inch thick veneer (lb/MSF 3/8). One lb/MSF 3/8 = 0.5 kg/m^3. Reference 19.

Table 10.5-3. EMISSION FACTORS FOR PLYWOOD VENEER DRYERS--ORGANICS[a]

Source	Emission Control[b]	VOC[c]	EMISSION FACTOR RATING	Formaldehyde	EMISSION FACTOR RATING
Direct wood-fired					
Unspecified pines[d] (SCC 3-07-007-40)	None	3.3[e]	E	ND	
Hemlock (SCC 3-07-007-44)	None	0.70[e,f]	E	ND	
Douglas fir (SCC 3-07-007-47)	WESP	0.50[e]	D	ND	
Unspecified firs[g] (SCC 3-07-007-46)	IWS	0.61[e,f]	E	ND	
Direct natural gas-fired					
Unspecified pines[d] (SCC 3-07-007-50)	None	2.1[e]	E	ND	
Indirect heated					
Unspecified pines[d] (SCC 3-07-007-60)	None	2.7[e,h]	D	ND	
Douglas fir (SCC 3-07-007-67)	None	1.3[e,j]	D	ND	
Poplar (SCC 3-07-007-69)	None	0.033[k,m]	E	0.0023[k]	E
Radio-frequency heated					
Unspecified pines[d] (SCC 3-07-007-70)	None	0.22[e]	E	ND	

[a] Factors represent uncontrolled emissions unless noted. SCC = Source Classification Code. ND = no data available. All emission factors in units of pounds per thousand square feet of 3/8-inch thick veneer (lb/MSF 3/8). One lb/MSF 3/8 = 0.5 kg/m^3. Reference 19 except where noted.

[b] Emission control device: WESP = wet electrostatic precipitator; IWS = ionizing wet scrubber.

[c] Volatile organic compounds as propane.

[d] Based on data on the drying of mixed pine species or on the drying of veneers which are identified only as pines.

[e] Emission factor may not account for formaldehyde, which is suspected to be present; VOC factor indicated is likely to be biased low.

[f] Reference 10.

[h] References 10,19.

[j] References 10,14.

[g] Based on data on the drying of mixed fir species or on the drying of veneers which are identified only as firs.

[k] Reference 12.

[m] Emission factor calculated as the sum of the factor for VOC and the factor for formaldehyde, based on a separate measurement.

Table 10.5-4. EMISSION FACTORS FOR PLYWOOD PRESSES--PARTICULATE MATTER[a]

Source	Filterable[b]				Condensible[c]	EMISSION FACTOR RATING
	PM	EMISSION FACTOR RATING	PM-10	EMISSION FACTOR RATING		
Plywood press						
PF resin (SCC 3-07-007-80)	0.12	D	ND		0.083	D

[a] Reference 19. Emission factors units are pounds per thousand square feet of 3/8-inch thick panel (lb/MSF 3/8). One lb/MSF 3/8 = 0.5 kg/m^3. SCC = Source Classification Code. ND = no data available. Factors represent uncontrolled emissions. PF = phenol-formaldehyde.

[b] Filterable PM is that PM collected on or prior to the filter of an EPA Method 5 (or equivalent) sampling train.

[c] Condensible PM is that PM collected in the impinger portion of a PM sampling train.

Table 10.5-5. EMISSION FACTORS FOR PLYWOOD PRESSES--FORMALDEHYDE AND VOC[a]

Source	FORMALDEHYDE	EMISSION FACTOR RATING	VOC[b]	EMISSION FACTOR RATING
Plywood press				
PF resin (SCC 3-07-007-80)	ND		0.33[c,d]	D
UF resin (SCC 3-07-007-81)	0.0042	E	0.021[e]	E
UF resin, wet scrubber (SCC 3-07-007-81)	0.0025	E	0.018[e]	E

[a] Factors represent uncontrolled emissions unless noted. SCC = Source Classification Code. Reference 12 unless otherwise noted. ND = no data available. Emission factor units are pounds per thousand square feet of 3/8-inch thick panel (lb/MSF 3/8). One lb/MSF 3/8 = 0.5 kg/m^3. PF = phenol-formaldehyde; UF = urea-formaldehyde.

[b] Volatile organic compounds on a propane basis.

[c] Reference 19.

[d] Emission factor may not account for formaldehyde, which is suspected to be present; VOC factor indicated is likely to be biased low.

[e] Emission factor calculated as the sum of the factor for VOC and the factor for formaldehyde, based on a separate measurement.

Table 10.5-6. EMISSION FACTORS FOR PLYWOOD MANUFACTURING--MISCELLANEOUS SOURCES[a]

Source	Pollutant	Emission factor	EMISSION FACTOR RATING
Log storage (SCC 3-07-008-95)	ND		
Log debarking (SCC 3-07-008-01)	ND		
Log bucking (SCC 3-07-008-02)	ND		
Log steaming (SCC 3-07-007-30)	ND		
Veneer cutting (SCC 3-07-007-25)	ND		
Veneer layout and glue spreading (SCC 3-07-007-27)	ND		
Plywood cutting (SCC 3-07-007-10)	ND		
Plywood sanding (SCC 3-07-007-02)	ND		
Plywood residue handling and transfer (SCC 3-07-007-___)	ND		
Plywood residue storage piles (SCC 3-07-007-___)	ND		

[a] SCC = Source Classification Code; ND = no data available.

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APPENDIX A

EMISSION FACTOR CALCULATION SPREADSHEETS

This appendix presents printouts of the detailed spreadsheets that were constructed in order to calculate emission factors for plywood veneer dryers and presses. Table A-1 presents the calculations for plywood veneer dryers. Table A-2 presents the calculations for plywood presses. Table A-3 presents a summary of Method 25 and Method 25A VOC data and available formaldehyde data for plywood veneer dryers and presses.

As discussed in Section 4.3.1 of this report, the data available for some of the specific emission factors developed included the results of multiple tests on the same emission source. In such cases, the test-specific emission factors for the same source were averaged first, and that average emission factor then was averaged with the factors for the other sources to yield the candidate emission factors for AP-42. In Table A-1, the emission factor column is divided into two subcolumns, "Test," and "Dryer". The emission factor column labeled "Test" includes the available test-specific emission factors. The emission factor column labeled "Dryer" includes averages of test-specific emission factors for the same dryer. For dryers where only one test-specific emission factor was available, that emission factor appears in both the "Test" and "Dryer" columns. The AP-42 candidate emission factors were developed by averaging the dryer average emission factors in the "Dryer" column. A parallel structure applies to Table A-2 for plywood presses.