EPA Region 10 HAP and VOC Emission Factors for Lumber Drying, December 2012

This spreadsheet calculates and compiles volatile organic compound (VOC) and hazardous air pollutant (HAP) emission factors (EF) in units of pounds of pollutant per thousand board feet of lumber dried (lb/mbf) that are preferred by EPA Region 10 for estimating emissions from lumber drying kilns. The EFs are based on actual lab-scale emission test data when available; when not available, EFs for similar species are substituted. When there are more than one similar species, the highest of the EF for the similar species is substituted.

A summary of the EFs for each species of wood is included on this sheet. The sheets that follow present the original test data as well as the calculations for creating each EF. There are two sheets per lumber species: one for HAPs and one for VOCs. To assure adequate conservatism for use in applicability determinations and compliance assurance applications, the EFs represent the 90th percentile of the data when three or more test values are available and the maximum test value of the data when less than three test values are available.

Species	Maximum Kiln Temperature (°F)	WPP1 VOC[1] (lb/mbf)	Total HAP (lb/mbf)	Methanol[2] (lb/mbf)	Formaldehyde[2] (lb/mbf)	Acetaldehyde (lb/mbf)	Propionaldehyde (lb/mbf)	Acrolein (lb/mbf)
Non-Resinous Softwood Species								
White Fir[3]	≤200	0.8388	0.2107	0.1480	0.0034	0.0550	0.0018	0.0026
	>200	1.0902	0.4956	0.4200	0.0163			
Western Hemlock	≤200	0.5253	0.2921	0.1484	0.0016	0.1378	0.0018	0.0026
	>200	0.6615	0.3661	0.2196	0.0044			
Western Red Cedar	≤200	0.3631	0.2939	0.1484	0.0034	0.1378	0.0018	0.0026
	>200	1.1453	0.5784	0.4200	0.0163			
Resinous Softwood Species (Non-Pine Family)								
Douglas Fir	≤200	1.1576	0.1409	0.0690	0.0019	0.0682	0.0007	0.0011
	>200	1.6969	0.1913	0.1170	0.0043			
Engelmann Spruce	≤200	0.1775	0.0640	0.0250	0.0013	0.0360	0.0007	0.0010
	>200	0.2161	0.1201	0.0780	0.0044			
Larch	≤200	1.1576	0.1409	0.0690	0.0019	0.0682	0.0007	0.0011
	>200	1.6969	0.1914	0.1170	0.0044			
Resinous Softwood Species (Pine Family)								
Lodgepole Pine	≤200	1.5293	0.1166	0.0628	0.0041	0.0420	0.0032	0.0045
	>200	1.5293	0.1166	0.0628	0.0041			
Ponderosa Pine	≤200	2.3450	0.1271	0.0740	0.0034	0.0420	0.0032	0.0045
	>200	3.8087	0.2029	0.1440	0.0092			
Western White Pine	≤200	2.8505	0.1271	0.0740	0.0034	0.0420	0.0032	0.0045
	>200	3.8087	0.2029	0.1440	0.0092			

[1] VOC emissions have been approximated consistent with EPA's Interim VOC Measurement Protocol for the Wood Products Industry - July 2007 (WPP1 VOC). Employing WPP1 VOC underestimates emissions when the mass-to-carbon ratio of unidentified VOC exceeds that of propane. Ethanol and acetic acid are examples of compounds that contribute to lumber drying VOC emissions (for some species more than others), and both have mass-to-carbon ratios exceeding that of propane.

[2] Because methanol and formaldehyde emissions appear to be dependent upon drying temperature, separate values are calculated for low and high-temperature drying.

[3] White fir in this context refers to any one of several species of true fir grown in the West. The collection of timber commonly referred to as "white fir" includes the following species: white fir, grand fir, noble fir and subalpine fir.

Hazardous Air Pollutant Emission Factors for Drying White Fir Lumber

This sheet presents lab-scale test data and calculations used to create HAP EF for drying any one of several species of true fir grown in the West commonly referred to as "white fir." True fir includes the following species: white fir, grand fir, noble fir and subalpine fir; all classified in the same Abies genus. The EFs are based on the 90th percentile value of actual lab-scale HAP test data when three or more data points are available and on the maximum value when less than three data points are available. When actual test data is not available for this wood species, data for a similar species is substituted as noted. When there are more than one similar species, the highest of the EF for the similar species is substituted.

Step One: Compile White Fir HAP Emission Test Data by Drying Temperature[1]

Maximum Dry Bulb Temperature (°F)	Methanol (lb/mbf)	Formaldehyde (lb/mbf)	Acetaldehyde (lb/mbf)	Propionaldehyde (lb/mbf)	Acrolein (lb/mbf)	Lumber Dimensions	Moisture Content[2] (%) (Initial / Final)	Time to Final Moisture Content (hours)	HAP Sample Collection Technique	Reference
180	0.096	0.0022	no data	no data	no data	2x6	122.0 / 15	42.6	NCASI Method IM/CAN/WP-99.01 without cannisters.	3, 4, 5, 12, 14
180	0.148	0.0034	no data	no data	no data	2x6	133.2 / 15	46.9		
225	no data	no data	0.0550	no data	no data	2x4	170 / 13	54	Dinitrophenylhydrazine coated cartridges.	7
240	0.42	0.0156	no data	no data	no data	2x6	126.3 / 15	24	NCASI chilled impinger method.	5
240	0.419	0.0163	no data	no data	no data	2x6	119.0 / 15	24		

[1] Yellow highlight denotes data not considered by EPA Region 10 in 2007 when providing notice of original EFs prior to initial PCWP (Plywood and Composite Wood Products) MACT compliance date.

[2] Dry basis. Moisture content = (weight of water / weight wood) x 100

Step Two: Calculate White Fir HAP Emission Factors Based on Maximum/90th Percentile Test Data

Maximum Dry Bulb Temperature[1] (°F)	Methanol (lb/mbf)	Formaldehyde (lb/mbf)	Acetaldehyde (lb/mbf)	Propionaldehyde[2] (lb/mbf)	Acrolein[2] (lb/mbf)
≤ 200°F	0.1480	0.0034	0.0550	0.0018	0.0026
> 200°F	0.4200	0.0163			

[1] Because methanol and formaldehyde emissions appear to be dependent upon drying temperature, separate values are calculated for low and high-temperature drying.

[2] In the absence of white fir test data for propionaldehyde and acrolein, western hemlock test data has been substituted. The two wood species are similar in that both are non-resinous softwood species in the scientific classification family Pinaceae. See western hemlock HAP sheet for lab-scale test data and calculations.

Volatile Organic Compound Emission Factors for Drying White Fir Lumber

This sheet presents lab-scale VOC and HAP test data and calculations used to create VOC EF for drying any one of several species of true fir grown in the West commonly referred to as "white fir." True fir includes the following species: white fir, grand fir, noble fir and subalpine fir; all classified in the same Abies genus. The VOC test method used (EPA Reference Method 25A) has some limitations in that it misses some HAP (or portions of HAP) compounds that are VOC and known to exist and reports the results "as carbon" which only accounts for the carbon portion of each compound measured. The missed HAP compounds are accounted for through separate testing. The VOC test data is adjusted to fully account for five known HAPs that are VOC using separate HAP (speciated) test data and is reported "as propane" to better represent all of the unspeciated VOC compounds. This technique is consistent with EPA's Interim VOC Measurement Protocol for the Wood Products Industry - July 2007 (WPP1 VOC) except that the VOC results are adjusted to account for not only methanol and formaldehyde but also acetaldehyde, propionaldehyde and acrolein.

Specifically, EFs are calculated from the VOC and HAP test data based on the 90 th percentile value of actual lab-scale test data when three or more data points are available and on the maximum value when less than three data points are available. When actual test data is not available for this wood species, data for a similar species is substituted as noted. When there are more than one similar species, the highest of the EF for the similar species is substituted. That portion of the (speciated) HAP compounds that are measured by the VOC test method (based on known flame ionization detector response factors) is subtracted from the VOC EF. The remaining "unspeciated" VOC EF is adjusted to represent propane rather than carbon and then added to the speciated HAP EF to provide the "total" VOC EF.

Note that reporting the unspeciated VOC as propane (mass-to-carbon ratio of 1.22 and a response factor of 1) may underestimate the actual mass of VOC for certain wood species because VOC compounds like ethanol and acetic acid with higher mass-to-carbon ratios (1.92 and 2.5, respectively) and lower response factors (0.66 and 0.575, respectively) can be a significant portion of the total VOC. Without reliable test data for such compounds, EPA assumes propane adequately represents the mix of unspeciated VOC.

Step One: Compile White Fir VOC Emission Test Data by Drying Temperature

Maximum Dry Bulb Temperature (°F)	Method 25A VOC as Carbon (lb/mbf)	Lumber Dimensions	Moisture Content[1] (%) (Initial/Final)	Time to Final Moisture Content (hours)	Method 25A Analyzer	Reference
180	0.26	2x6	106.3 / 15	36.6	JUM 3-200	3, 4
180	0.27	2x6	113.6 / 15	43.2		
180	0.22	2x6	122.0 / 15	42.6	JUM 3-200	3, 4, 5, 12
180	0.25	2x6	133.2 / 15	46.9		
190	0.63	2x4	138.1 / 15	70	JUM VE-7	2
190	0.50	2x4	138.1 / 15	75		
200	0.53	2x4	96.1 / 15	47		
225	0.39	2x4	170 / 13	54	JUM VE-7	7
240	0.62	2x6	126.3 / 15	25	JUM 3-200	5
240	0.6	2x6	119.0 / 15	25		

[1] Dry basis. Moisture content = (weight of water / weight wood) x 100

Step Two: Calculate White Fir VOC Emission Factors "as Carbon" Based on Maximum/90th Percentile Test Data

Maximum Dry Bulb Temperature[1] (°F)	Method 25A VOC as Carbon (lb/mbf)
≤ 200°F	0.5700
> 200°F	0.6160

[1] Because VOC emissions appear to be dependent upon drying temperature, separate values are calculated for low and high-temperature drying.

Step Three: Compile White Fir Speciated HAP Emission Factors Based on Maximum/90th Percentile Test Data[1]

Maximum Dry Bulb Temperature (°F)	Methanol (lb/mbf)	Formaldehyde (lb/mbf)	Acetaldehyde (lb/mbf)	Propionaldehyde (lb/mbf)	Acrolein (lb/mbf)
≤ 200°F	0.1480	0.0034	0.0550	0.0018	0.0026
> 200°F	0.4200	0.0163			

[1] See white fir HAP sheet for lab-scale test data and calculations.

Step Four: Convert White Fir Speciated HAP Emission Factors to "as Carbon" and Total

Speciated Compound "X" expressed as carbon = (RF_X) X (SC_X) X $[(MW_C) / (MW_X)]$ X $[(\#C_X) / (\#C_C)]$

where: RF_X represents the flame ionization detector (FID) response factor (RF) for speciated compound "X"

SC_X represents emissions of speciated compound "X" expressed as the entire mass of compound emitted

MW_C equals "12.0110" representing the molecular weight (MW) for carbon as carbon is becoming the "basis" for expressing mass of speciated compound "X"

MW_X represents the molecular weight for speciated compound "X"

$\#C_X$ represents the number of carbon atoms in speciated compound "X"

$\#C_C$ equals "1" as the single carbon atom is becoming the "basis" for expressing mass of speciated compound "X"

Maximum Dry Bulb Temperature (°F)	Methanol as Carbon (lb/mbf)	Formaldehyde as Carbon (lb/mbf)	Acetaldehyde as Carbon (lb/mbf)	Propionaldehyde as Carbon (lb/mbf)	Acrolein as Carbon (lb/mbf)		Speciated Compounds as Carbon (lb/mbf)
≤ 200°F	0.0399	0	0.0150	0.0007	0.0011	SUM ⇨	0.0567
> 200°F	0.1134	0					0.1302

Element and Compound Information

Element / Compound	FID RF[1]	Molecular Weight (lb/lb-mol)	Formula	Number of Carbon Atoms	Number of Hydrogen Atoms	Number of Oxygen Atoms	Reference
Methanol	0.72	32.042	CH_40	1	4	1	1
Formaldehyde	0	30.0262	CH_2O	1	2	1	16
Acetaldehyde	0.5	44.053	C_2H_4O	2	4	1	20
Propionaldehyde	0.66	58.0798	C_3H_6O	3	6	1	20
Acrolein	0.66	56.064	C_3H_4O	3	4	1	20
Propane	1	44.0962	C_3H_8	3	8	0	16
Carbon	-	12.0110	C	1	-	-	-
Hydrogen	-	1.0079	H	-	1	-	-
Oxygen	-	15.9994	O	-	-	1	-

[1] FID RF = volumetric concentration or "instrument display" / compound's actual known concentration. Numerator and denominator expressed on same basis (ie. carbon, propane, etc) and concentration in units of "ppm."

Step Five: Subtract Speciated HAP Compounds from White Fir VOC Emission Factors and Convert Result to "as Propane"

	FROM STEP TWO		FROM STEP FOUR		Method 25A VOC as Carbon without Speciated Compounds (lb/mbf)	Propane Mass Conversion Factor	Method 25A VOC as Propane without Speciated Compounds (lb/mbf)
Maximum Dry Bulb Temperature (°F)	Method 25A VOC as Carbon (lb/mbf)	MINUS ⇨	Speciated Compounds as Carbon (lb/mbf)	EQUALS ⇨			
≤ 200°F	0.5700		0.0567		0.5133	X 1.2238 =	0.6281
> 200°F	0.6160		0.1302		0.4858		0.5946

Method 25A VOC as propane without speciated compounds = (VOC_C) X $(1/RF_{C3H8})$ X $[(MW_{C3H8}) / (MW_C)]$ X $[(\#C_C) / (\#C_{C3H8})]$

where: VOC_C represents Method 25A VOC as carbon without speciated compounds

RF_{C3H8} equals "1" and represents the FID RF for propane. All alkanes, including propane, have a RF of 1.

MW_{C3H8} equals "44.0962" and represents the molecular weight for propane; the compound that is the "basis" for expressing mass of VOC per WPP1 VOC

MW_C equals "12.0110" and represents the molecular weight for carbon

$\#C_C$ equals "1" as the single carbon atom was the "basis" for which Method 25A VOC test results were determined as illustrated in Step One of this spreadsheet

$\#C_{C3H8}$ equals "3" as three carbon atoms are present within propane; the compound that is the "basis" for expressing mass of VOC per WPP1 VOC

Note: The following portion from the equation immediately above, $(1/RF_{C3H8})$ X $[(MW_{C3H8}) / (MW_C)]$ X $[(\#C_C) / (\#C_{C3H8})]$, equals 1.2238 and can be referred to as the "propane mass conversion factor."

Step Six: Calculate WPP1 VOC by Adding Speciated HAP Compounds to White Fir VOC Emission Factors "as Propane"

WPP1 VOC = Method 25A VOC as propane without speciated compounds + ∑ speciated compounds expressed as the entire mass of compound

	FROM STEP FIVE		FROM STEP THREE						
Maximum Dry Bulb Temperature (°F)	Method 25A VOC as Propane without Speciated Compounds (lb/mbf)	PLUS	Methanol (lb/mbf)	Formaldehyde (lb/mbf)	Acetaldehyde (lb/mbf)	Propionaldehyde (lb/mbf)	Acrolein (lb/mbf)	EQUALS	WPP1 VOC (lb/mbf)
≤ 200°F	0.6281	⇨	0.1480	0.0034	0.0550	0.0018	0.0026	⇨	0.8388
> 200°F	0.5946		0.4200	0.0163					1.0902

Hazardous Air Pollutant Emission Factors for Western Hemlock Lumber

This sheet presents lab-scale test data and calculations used to create HAP EF for drying western hemlock lumber. The EFs are based on the 90th percentile value of actual lab-scale HAP test data when three or more data points are available and on the maximum value when less than three data points are available. When actual test data is not available for this wood species, data for a similar species is substituted as noted. When there are more than one similar species, the highest of the EF for the similar species is substituted.

Step One: Compile Western Hemlock HAP Emission Test Data by Drying Temperature[1]

Maximum Dry Bulb Temperature (°F)	Methanol (lb/mbf)	Formaldehyde (lb/mbf)	Acetaldehyde (lb/mbf)	Propionaldehyde (lb/mbf)	Acrolein (lb/mbf)	Lumber Dimensions	Moisture Content[2] (%) (Initial / Final)	Time to Final Moisture Content (hours)	HAP Sample Collection Technique	Reference
180	0.083	0.0013	no data	no data	no data	2x4	102.3 / 14.7	49.5	NCASI Method 98.01	14, 15
180	0.075	0.0014	0.078	0.002	0.0012	2x4	102.3 / 14.7	49.5	NCASI Method 105	14, 15, 18
180	0.094	0.0015	0.141	0.0008	0.0012	2x4 or 2x6	93.5 / 17.5	no data	NCASI Method 105	18
180	0.052	0.0007	no data	no data	no data	2x4	88.8 / 15	46.2	NCASI Method CI//WP-98.01	13
180	0.0312	0.00082	no data	no data	no data	2x4	56.8 / 15	38.35	NCASI Method CI//WP-98.01	
180	0.0304	0.00082	no data	no data	no data	2x4	51.1 / 15	35.75		
200	0.098	0.0015	no data	no data	no data	2x6	81.0 / 15	45.2	NCASI Method CI//WP-98.01	11, 14
200	0.175	0.0016	no data	no data	no data	2x6	73.7 / 15	36.5		
200	0.154	0.0018	no data	no data	no data	2x6	100.1 / 15	47.4		
200	0.044	0.0008	0.133	0.0008	0.0024	2x4 or 2x6	83.9 / 15.0	no data	NCASI Method 105	14, 18
200	0.077	0.0014	0.128	0.001	0.0011	2x4 or 2x6	98.6 / 15.0	no data		
200	0.057	0.0014	no data	no data	no data	2x4	76.0 / 15	30.25	NCASI Method CI//WP-98.01	9, 11, 14
215	0.138	0.0043	no data	no data	0.0027	2x4	119.7 / 15	38	no data	6, 11, 14
225	0.189	0.0035	no data	no data		2x6	82 / 15	31.3	NCASI Method CI//WP-98.01	11, 14
225	0.167	0.0034	no data	no data	no data	2x6	77.4 / 15	28.6		
225	0.24	0.004	no data	no data	no data	2x6	101.7 / 15	33.5		
235	0.187	0.0045	0.084	0.0014	0.0019	2x4 or 2x6	76.2 / 15.0	no data	NCASI Method 105	18

[1] Yellow highlight denotes data not considered by EPA Region 10 in 2007 when providing notice of original EFs prior to initial PCWP (Plywood and Composite Wood Products) MACT compliance date.

[2] Dry basis. Moisture content = (weight of water / weight wood) x 100

Step Two: Calculate Western Hemlock HAP Emission Factors Based on Maximum/90th Percentile Test Data

Maximum Dry Bulb Temperature[1] (°F)	Methanol (lb/mbf)	Formaldehyde (lb/mbf)	Acetaldehyde (lb/mbf)	Propionaldehyde (lb/mbf)	Acrolein (lb/mbf)
≤ 200°F	0.1484	0.0016	0.1378	0.0018	0.0026
> 200°F	0.2196	0.0044			

[1] Because methanol and formaldehyde emissions appear to be dependent upon drying temperature, separate values are calculated for low and high-temperature drying.

Volatile Organic Compound Emission Factors for Drying Western Hemlock Lumber

This sheet presents lab-scale VOC and HAP test data and calculations used to create VOC EF for drying western hemlock lumber. The VOC test method used (EPA Reference Method 25A) has some limitations in that it misses some HAP (or portions of HAP) compounds that are VOC and known to exist and reports the results "as carbon" which only accounts for the carbon portion of each compound measured. The missed HAP compounds are accounted for through separate testing. The VOC test data is adjusted to fully account for five known HAPs that are VOC using separate HAP (speciated) test data and is reported "as propane" to better represent all of the unspeciated VOC compounds. This technique is consistent with EPA's Interim VOC Measurement Protocol for the Wood Products Industry - July 2007 (WPP1 VOC) except that the VOC results are adjusted to account for not only methanol and formaldehyde but also acetaldehyde, propionaldehyde and acrolein.

Specifically, EFs are calculated from the VOC and HAP test data based on the 90th percentile value of actual lab-scale test data when three or more data points are available and on the maximum value when less than three data points are available. When actual test data is not available for this wood species, data for a similar species is substituted as noted. When there are more than one similar species, the highest of the EF for the similar species is substituted. That portion of the (speciated) HAP compounds that are measured by the VOC test method (based on known flame ionization detector response factors) is subtracted from the VOC EF. The remaining "unspeciated" VOC EF is adjusted to represent propane rather than carbon and then added to the speciated HAP EF to provide the "total" VOC EF.

Note that reporting the unspeciated VOC as propane (mass-to-carbon ratio of 1.22 and a response factor of 1) may underestimate the actual mass of VOC for certain wood species because VOC compounds like ethanol and acetic acid with higher mass-to-carbon ratios (1.92 and 2.5, respectively) and lower response factors (0.66 and 0.575, respectively) can be a significant portion of the total VOC. Without reliable test data for such compounds, EPA assumes propane adequately represents the mix of unspeciated VOC.

Step One: Compile Western Hemlock VOC Emission Test Data by Drying Temperature[1]

Maximum Dry Bulb Temperature (°F)	Method 25A VOC as Carbon (lb/mbf)	Lumber Dimensions	Moisture Content[2] (%) (Initial/Final)	Time to Final Moisture Content (hours)	Method 25A Analyzer	Reference
180	~~0.73~~	2x6	126.6 / 15	66.5	no data	11
180	~~0.66~~	2x6	139.3 / 15	67.9		
180	~~0.6~~	2x6	127.8 / 15	65.7		
180	~~0.67~~	2x6	132.7 / 15	67		
180	0.17	2x4	114.8 / 15	45	no data	11
180	0.07	2x4	103.1 / 15	40.7		
180	0.12	2x4	98.0 / 15	37.5		
180	0.4	2x4	115.7 / 15	52.9		
180	0.236	2x4 or 2x6	93.5 / 17.5	no data	JUM VE-7	18
180	0.142	2x4	102.3 / 14.7	49.5	JUM VE-7	15, 18
180	0.18	2x4	88.8 / 15	46.2	JUM VE-7	13
180	0.198	2x4	56.8 / 15	38.35		8, 11
180	0.122	2x4	51.1 / 15	35.75		
200	0.24	2x4	112.8 / 15	40	JUM VE-7	2
200	0.2	2x6	81.0 / 15	45.2	no data	11
200	0.15	2x6	73.7 / 15	36.5		
200	0.3	2x6	100.1 / 15	47.4		
200	0.204	2x4	76.0 / 15	30.25	JUM 3-200	9, 11
200	0.214	2x4 or 2x6	83.9 / 15.0	no data	JUM VE-7	18
200	0.239	2x4 or 2x6	98.6 / 15.0	no data		
215	0.34	2x4	112.9 / 15	32.7	no data	11
215	0.34	2x4	119.7 / 15	38	JUM 3-200	6, 11
225	0.28	2x6	82 / 15	31.3	no data	11
225	0.27	2x6	77.4 / 15	28.6		
225	0.31	2x6	101.7 / 15	33.5		
235	0.247	2x4 or 2x6	81.6 / 15.0	no data	JUM VE-7	18
235	0.226	2x4 or 2x6	76.2 / 15.0	no data		

[1] Blue highlight denotes data not considered by EPA Region 10 in 2012. The four test runs not considered here were obtained from a single "sample" and appeared to use a much longer drying cycle than would be in common use in the Pacific Northwest. Therefore, these highlighted values were not used in the EF derivation.

[2] Dry basis. Moisture content = (weight of water / weight wood) x 100

Step Two: Calculate Western Hemlock VOC Emission Factors "as Carbon" Based on Maximum/90th Percentile Test Data

Maximum Dry Bulb Temperature[1] (°F)	Method 25A VOC as Carbon (lb/mbf)
≤ 200°F	0.2700
> 200°F	0.3400

[1] Because VOC emissions appear to be dependent upon drying temperature, separate values are calculated for low and high-temperature drying.

Step Three: Compile Western Hemlock Speciated HAP Emission Factors Based on Maximum/90th Percentile Test Data[1]

Maximum Dry Bulb Temperature (°F)	Methanol (lb/mbf)	Formaldehyde (lb/mbf)	Acetaldehyde (lb/mbf)	Propionaldehyde (lb/mbf)	Acrolein (lb/mbf)
≤ 200°F	0.1484	0.0016	0.1378	0.0018	0.0026
> 200°F	0.2196	0.0044			

[1] See western hemlock HAP sheet for lab-scale test data and calculations.

Step Four: Convert Western Hemlock Speciated HAP Emission Factors to "as Carbon" and Total

Speciated Compound "X" expressed as carbon = (RF_X) X (SC_X) X $[(MW_C) / (MW_X)]$ X $[(\#C_X) / (\#C_C)]$

where: RF_X represents the flame ionization detector (FID) response factor (RF) for speciated compound "X"

SC_X represents emissions of speciated compound "X" expressed as the entire mass of compound emitted

MW_C equals "12.0110" representing the molecular weight (MW) for carbon as carbon is becoming the "basis" for expressing mass of speciated compound "X"

MW_X represents the molecular weight for speciated compound "X"

$\#C_X$ represents the number of carbon atoms in speciated compound "X"

$\#C_C$ equals "1" as the single carbon atom is becoming the "basis" for expressing mass of speciated compound "X"

Maximum Dry Bulb Temperature (°F)	Methanol as Carbon (lb/mbf)	Formaldehyde as Carbon (lb/mbf)	Acetaldehyde as Carbon (lb/mbf)	Propionaldehyde as Carbon (lb/mbf)	Acrolein as Carbon (lb/mbf)		Speciated Compounds as Carbon (lb/mbf)
≤ 200°F	0.0401	0	0.0376	0.0007	0.0011	SUM ⇨	0.0794
> 200°F	0.0593	0					0.0986

Element and Compound Information

Element / Compound	FID RF[1]	Molecular Weight (lb/lb-mol)	Formula	Number of Carbon Atoms	Number of Hydrogen Atoms	Number of Oxygen Atoms	Reference
Methanol	0.72	32.042	CH_40	1	4	1	1
Formaldehyde	0	30.0262	CH_2O	1	2	1	16
Acetaldehyde	0.5	44.053	C_2H_4O	2	4	1	20
Propionaldehyde	0.66	58.0798	C_3H_6O	3	6	1	20
Acrolein	0.66	56.064	C_3H_4O	3	4	1	20
Propane	1	44.0962	C_3H_8	3	8	0	16
Carbon	-	12.0110	C	1	-	-	-
Hydrogen	-	1.0079	H	-	1	-	-
Oxygen	-	15.9994	O	-	-	1	-

[1] FID RF = volumetric concentration or "instrument display" / compound's actual known concentration. Numerator and denominator expressed on same basis (ie. carbon, propane, etc) and concentration in units of "ppm."

Step Five: Subtract Speciated HAP Compounds from Western Hemlock VOC Emission Factors and Convert Result to "as Propane"

	FROM STEP TWO		FROM STEP FOUR		Method 25A VOC as Carbon without Speciated Compounds (lb/mbf)	Propane Mass Conversion Factor	Method 25A VOC as Propane without Speciated Compounds (lb/mbf)
Maximum Dry Bulb Temperature (°F)	Method 25A VOC as Carbon (lb/mbf)	MINUS	Speciated Compounds as Carbon (lb/mbf)	EQUALS			
≤ 200°F	0.2700		0.0794		0.1906	X 1.2238 =	0.2332
> 200°F	0.3400		0.0986		0.2414		0.2954

Method 25A VOC as propane without speciated compounds = (VOC_C) X $(1/RF_{C3H8})$ X $[(MW_{C3H8}) / (MW_C)]$ X $[(\#C_C) / (\#C_{C3H8})]$

where: VOC_C represents Method 25A VOC as carbon without speciated compounds

RF_{C3H8} equals "1" and represents the FID RF for propane. All alkanes, including propane, have a RF of 1.

MW_{C3H8} equals "44.0962" and represents the molecular weight for propane; the compound that is the "basis" for expressing mass of VOC per WPP1 VOC

MW_C equals "12.0110" and represents the molecular weight for carbon

$\#C_C$ equals "1" as the single carbon atom was the "basis" for which Method 25A VOC test results were determined as illustrated in Step One of this spreadsheet

$\#C_{C3H8}$ equals "3" as three carbon atoms are present within propane; the compound that is the "basis" for expressing mass of VOC per WPP1 VOC

Note: The following portion from the equation immediately above, $(1/RF_{C3H8})$ X $[(MW_{C3H8}) / (MW_C)]$ X $[(\#C_C) / (\#C_{C3H8})]$, equals 1.2238 and can be referred to as the "propane mass conversion factor."

Step Six: Calculate WPP1 VOC by Adding Speciated HAP Compounds to Western Hemlock VOC Emission Factors "as Propane"

WPP1 VOC = Method 25A VOC as propane without speciated compounds + ∑ speciated compounds expressed as the entire mass of compound

	FROM STEP FIVE		FROM STEP THREE						
Maximum Dry Bulb Temperature (°F)	Method 25A VOC as Propane without Speciated Compounds (lb/mbf)	PLUS	Methanol (lb/mbf)	Formaldehyde (lb/mbf)	Acetaldehyde (lb/mbf)	Propionaldehyde (lb/mbf)	Acrolein (lb/mbf)	EQUALS	WPP1 VOC (lb/mbf)
≤ 200°F	0.2332		0.1484	0.0016	0.1378	0.0018	0.0026		0.5253
> 200°F	0.2954		0.2196	0.0044					0.6615

Hazardous Air Pollutant Emission Factors for Drying Western Red Cedar Lumber

This sheet presents the HAP EF for drying western red cedar lumber. The EFs are based on the 90th percentile value of actual lab-scale HAP test data when three or more data points are available and on the maximum value when less than three data points are available. EPA Region 10 is not aware of any HAP emission testing of western red cedar. Consistent with other species, when actual test data is not available, data for a similar species is substituted as noted. When there are more than one similar species, the highest of the EF for the similar species is substituted.

Western Red Cedar HAP Emission Factors[1]

Maximum Dry Bulb Temperature[2] (°F)	Methanol (lb/mbf)	Formaldehyde (lb/mbf)	Acetaldehyde (lb/mbf)	Propionaldehyde (lb/mbf)	Acrolein (lb/mbf)
≤ 200°F	0.1484	0.0034	0.1378	0.0018	0.0026
> 200°F	0.4200	0.0163			

[1] In the absence of western red cedar test data, white fir test data has been substituted for methanol and high-temperature formaldehyde and western hemlock test data has been substituted for acetaldehyde, propionaldehyde, acrolein and low-temperature formaldehyde. Western red cedar is similar to white fir and western hemlock in that all three species are non-resinous softwood species in the scientific classification order Pinales. See the white fir and western hemlock HAP sheets for lab-scale test data and calculations.

[2] Because methanol and formaldehyde emissions appear to be dependent upon drying temperature in other species (no observations for western red cedar), separate values are calculated for low and high-temperature drying.

Volatile Organic Compound Emission Factors for Western Red Cedar Lumber

This sheet presents lab-scale VOC and HAP test data and calculations used to create VOC EF for drying western red cedar. The VOC test method used (EPA Reference Method 25A) has some limitations in that it misses some HAP (or portions of HAP) compounds that are VOC and known to exist and reports the results "as carbon" which only accounts for the carbon portion of each compound measured. The missed HAP compounds are accounted for through separate testing. The VOC test data is adjusted to fully account for five known HAPs that are VOC using separate HAP (speciated) test data and is reported "as propane" to better represent all of the unspeciated VOC compounds. This technique is consistent with EPA's Interim VOC Measurement Protocol for the Wood Products Industry - July 2007 (WPP1 VOC) except that the VOC results are adjusted to account for not only methanol and formaldehyde but also acetaldehyde, propionaldehyde and acrolein.

Specifically, EFs are calculated from the VOC and HAP test data based on the 90th percentile value of actual lab-scale test data when three or more data points are available and on the maximum value when less than three data points are available. When actual test data is not available for this wood species, data for a similar species is substituted as noted. When there are more than one similar species, the highest of the EF for the similar species is substituted. That portion of the (speciated) HAP compounds that are measured by the VOC test method (based on known flame ionization detector response factors) is subtracted from the VOC EF. The remaining "unspeciated" VOC EF is adjusted to represent propane rather than carbon and then added to the speciated HAP EF to provide the "total" VOC EF.

Note that reporting the unspeciated VOC as propane (mass-to-carbon ratio of 1.22 and a response factor of 1) may underestimate the actual mass of VOC for certain wood species because VOC compounds like ethanol and acetic acid with higher mass-to-carbon ratios (1.92 and 2.5, respectively) and lower response factors (0.66 and 0.575, respectively) can be a significant portion of the total VOC. Without reliable test data for such compounds, EPA assumes propane adequately represents the mix of unspeciated VOC.

Step One: Compile Western Red Cedar VOC Emission Test Data by Drying Temperature

Maximum Dry Bulb Temperature (°F)	Method 25A VOC as Carbon (lb/mbf)	Lumber Dimensions	Moisture Content[1] (%) (Initial/Final)	Time to Final Moisture Content (hours)	Method 25A Analyzer	Reference
160	0.096	1x4	33.3 / 15	21	JUM VE-7	2
160	0.136	1x4	44.9 / 15	18		
> 200°F	no data					

[1] Dry basis. Moisture content = (weight of water / weight wood) x 100

Step Two: Calculate Western Red Cedar VOC Emission Factors "as Carbon" Based on Maximum/90th Percentile Test Data [1]

Maximum Dry Bulb Temperature[2] (°F)	Method 25A VOC as Carbon (lb/mbf)
≤ 200°F	0.1360
> 200°F	0.6160

[1] In the absence of western red cedar test data for high-temperature drying, white fir test data has been substituted. Western red cedar, white fir and western hemlock are similar in that all three are non-resinous softwood species in the scientific classification order Pinales. See the white fir and western hemlock VOC sheets for lab-scale test data and calculations.

[2] Because VOC emissions appear to be dependent upon drying temperature in other species (no observed high-temperature observations for western red cedar), separate values are calculated for low and high-temperature drying.

Step Three: Compile Western Red Cedar Speciated HAP Emission Factors Based on Maximum/90th Percentile Test Data [1]

Maximum Dry Bulb Temperature (°F)	Methanol (lb/mbf)	Formaldehyde (lb/mbf)	Acetaldehyde (lb/mbf)	Propionaldehyde (lb/mbf)	Acrolein (lb/mbf)
≤ 200°F	0.1484	0.0034	0.1378	0.0018	0.0026
> 200°F	0.4200	0.0163			

[1] See western red cedar HAP sheet for lab-scale test data and calculations.

Step Four: Convert Western Red Cedar Speciated HAP Emission Factors to "as Carbon" and Total

Speciated Compound "X" expressed as carbon = (RF_X) X (SC_X) X $[(MW_C) / (MW_X)]$ X $[(\#C_X) / (\#C_C)]$

where: RF_X represents the flame ionization detector (FID) response factor (RF) for speciated compound "X"

SC_X represents emissions of speciated compound "X" expressed as the entire mass of compound emitted

MW_C equals "12.0110" representing the molecular weight (MW) for carbon as carbon is becoming the "basis" for expressing mass of speciated compound "X"

MW_X represents the molecular weight for speciated compound "X"

$\#C_X$ represents the number of carbon atoms in speciated compound "X"

$\#C_C$ equals "1" as the single carbon atom is becoming the "basis" for expressing mass of speciated compound "X"

Maximum Dry Bulb Temperature (°F)	Methanol as Carbon (lb/mbf)	Formaldehyde as Carbon (lb/mbf)	Acetaldehyde as Carbon (lb/mbf)	Propionaldehyde as Carbon (lb/mbf)	Acrolein as Carbon (lb/mbf)		Speciated Compounds as Carbon (lb/mbf)
≤ 200°F	0.0401	0	0.0376	0.0007	0.0011	SUM ⇨	0.0794
> 200°F	0.1134	0					0.1527

Element and Compound Information

Element / Compound	FID RF[1]	Molecular Weight (lb/lb-mol)	Formula	Number of Carbon Atoms	Number of Hydrogen Atoms	Number of Oxygen Atoms	Reference
Methanol	0.72	32.042	CH_40	1	4	1	1
Formaldehyde	0	30.0262	CH_2O	1	2	1	16
Acetaldehyde	0.5	44.053	C_2H_4O	2	4	1	20
Propionaldehyde	0.66	58.0798	C_3H_6O	3	6	1	20
Acrolein	0.66	56.064	C_3H_4O	3	4	1	20
Propane	1	44.0962	C_3H_8	3	8	0	16
Carbon	-	12.0110	C	1	-	-	-
Hydrogen	-	1.0079	H	-	1	-	-
Oxygen	-	15.9994	O	-	-	1	-

[1] FID RF = volumetric concentration or "instrument display" / compound's actual known concentration. Numerator and denominator expressed on same basis (ie. carbon, propane, etc) and concentration in units of "ppm."

Step Five: Subtract Speciated HAP Compounds from Western Red Cedar VOC Emission Factors and Convert Result to "as Propane"

	FROM STEP TWO		FROM STEP FOUR		Method 25A VOC as Carbon without Speciated Compounds (lb/mbf)	Propane Mass Conversion Factor	Method 25A VOC as Propane without Speciated Compounds (lb/mbf)
Maximum Dry Bulb Temperature (°F)	Method 25A VOC as Carbon (lb/mbf)		Speciated Compounds as Carbon (lb/mbf)				
≤ 200°F	0.1360	MINUS ⇨	0.0794	EQUALS ⇨	0.0566	X 1.2238 =	0.0692
> 200°F	0.6160		0.1527		0.4633		0.5669

Method 25A VOC as propane without speciated compounds = (VOC_C) X $(1/RF_{C3H8})$ X $[(MW_{C3H8}) / (MW_C)]$ X $[(\#C_C) / (\#C_{C3H8})]$

where: VOC_C represents Method 25A VOC as carbon without speciated compounds

RF_{C3H8} equals "1" and represents the FID RF for propane. All alkanes, including propane, have a RF of 1.

MW_{C3H8} equals "44.0962" and represents the molecular weight for propane; the compound that is the "basis" for expressing mass of VOC per WPP1 VOC

MW_C equals "12.0110" and represents the molecular weight for carbon

$\#C_C$ equals "1" as the single carbon atom was the "basis" for which Method 25A VOC test results were determined as illustrated in Step One of this spreadsheet

$\#C_{C3H8}$ equals "3" as three carbon atoms are present within propane; the compound that is the "basis" for expressing mass of VOC per WPP1 VOC

Note: The following portion from the equation immediately above, $(1/RF_{C3H8})$ X $[(MW_{C3H8}) / (MW_C)]$ X $[(\#C_C) / (\#C_{C3H8})]$, equals 1.2238 and can be referred to as the "propane mass conversion factor."

Step Six: Calculate WPP1 VOC by Adding Speciated HAP Compounds to Western Red Cedar VOC Emission Factors "as Propane"

WPP1 VOC = Method 25A VOC as propane without speciated compounds + ∑ speciated compounds expressed as the entire mass of compound

	FROM STEP FIVE		FROM STEP THREE						
Maximum Dry Bulb Temperature (°F)	Method 25A VOC as Propane without Speciated Compounds (lb/mbf)	PLUS	Methanol (lb/mbf)	Formaldehyde (lb/mbf)	Acetaldehyde (lb/mbf)	Propionaldehyde (lb/mbf)	Acrolein (lb/mbf)	EQUALS	WPP1 VOC (lb/mbf)
≤ 200°F	0.0692	⇨	0.1484	0.0034	0.1378	0.0018	0.0026	⇨	0.3631
> 200°F	0.5669		0.4200	0.0163					1.1453

Hazardous Air Pollutant Emission Factors for Drying Douglas Fir Lumber

This sheet presents lab-scale test data and calculations used to create HAP EF for drying douglas fir lumber. The EFs are based on the 90th percentile value of actual lab-scale HAP test data when three or more data points are available and on the maximum value when less than three data points are available. When actual test data is not available for this wood species, data for a similar species is substituted as noted. When there are more than one similar species, the highest of the EF for the similar species is substituted.

Step One: Compile Douglas Fir HAP Emission Test Data by Drying Temperature[1]

Maximum Dry Bulb Temperature (°F)	Methanol (lb/mbf)	Formaldehyde (lb/mbf)	Acetaldehyde (lb/mbf)	Propionaldehyde (lb/mbf)	Acrolein (lb/mbf)	Lumber Dimensions	Moisture Content[2] (%) (Initial / Final)	Time to Final Moisture Content (hours)	HAP Sample Collection Technique	Reference
160	0.025	0.0008	no data	no data	no data	2x6	37.3 / 15	23.5	NCASI Method IM/CAN/WP-99.01 without cannisters.	3, 4, 12, 14
160	0.023	0.0008	no data	no data	no data	2x6	44.9 / 15	28.5		
160	0.026	0.0017	no data	no data	no data	2x6	40.3 / 15	27.1		
160	0.018	0.0011	no data	no data	no data	2x6	31.9 / 15	25.2		
170	0.015	0.0005	no data	no data	no data	2x4	79.9 / 15	40.5	NCASI Method CI//WP-98.01	
170	0.026	0.0008	no data	no data	no data	2x4	56.9 / 15	27.5	NCASI Method 98.01	15
170	0.024	0.0008	0.03	0.0004	0.0005	2x4	56.9 / 15	27.5	NCASI Method 105	15, 18
180	0.050	0.0023	0.050	0.0005	0.0009	2x4	43.7 / 15	48	NCASI Method 105	18, 22
180	0.084	0.0019	0.061	0.0003	0.0007	4x4	44.7 / 15	111	NCASI Method 105	19
200	0.068	0.0018	0.043	0.0005	0.0009	2x4	64.3 / 15	60	NCASI Method 105	14, 18, 22
200	0.069	0.0019	0.071	0.0006	0.0004	2x4	59.5 / 15	56		
220	no data	no data	0.030	no data	no data	2x4	73 / 12	46	Dinitrophenylhydrazine coated cartridges.	7
220	no data	no data	0.022	no data	no data	2x4	73 / 15	46		
235	0.117	0.0043	0.067	0.0008		2x4 or 2x6	47.7 / 15	19	NCASI Method 105	18, 21

[1] Yellow highlight denotes data not considered by EPA Region 10 in 2007 when providing notice of original EFs prior to initial PCWP (Plywood and Composite Wood Products) MACT compliance date.

[2] Dry basis. Moisture content = (weight of water / weight wood) x 100

Step Two: Calculate Douglas Fir HAP Emission Factors Based on Maximum/90th Percentile Test Data

Maximum Dry Bulb Temperature[2] (°F)	Methanol (lb/mbf)	Formaldehyde (lb/mbf)	Acetaldehyde (lb/mbf)	Propionaldehyde (lb/mbf)	Acrolein (lb/mbf)
≤ 200°F	0.0690	0.0019	0.0682	0.0007	0.0009
> 200°F	0.1170	0.0043			

[1] Because methanol and formaldehyde emissions appear to be dependent upon drying temperature, separate values are calculated for low and high-temperature drying.

Volatile Organic Compound Emission Factors for Drying Douglas Fir Lumber

This sheet presents lab-scale VOC and HAP test data and calculations used to create VOC EF for drying douglas fir lumber. The VOC test method used (EPA Reference Method 25A) has some limitations in that it misses some HAP (or portions of HAP) compounds that are VOC and known to exist and reports the results "as carbon" which only accounts for the carbon portion of each compound measured. The missed HAP compounds are accounted for through separate testing. The VOC test data is adjusted to fully account for five known HAPs that are VOC using separate HAP (speciated) test data and is reported "as propane" to better represent all of the unspeciated VOC compounds. This technique is consistent with EPA's Interim VOC Measurement Protocol for the Wood Products Industry - July 2007 (WPP1 VOC) except that the VOC results are adjusted to account for not only methanol and formaldehyde but also acetaldehyde, propionaldehyde and acrolein.

Specifically, EFs are calculated from the VOC and HAP test data based on the 90th percentile value of actual lab-scale test data when three or more data points are available and on the maximum value when less than three data points are available. When actual test data is not available for this wood species, data for a similar species is substituted as noted. When there are more than one similar species, the highest of the EF for the similar species is substituted. That portion of the (speciated) HAP compounds that are measured by the VOC test method (based on known flame ionization detector response factors) is subtracted from the VOC EF. The remaining "unspeciated" VOC EF is adjusted to represent propane rather than carbon and then added to the speciated HAP EF to provide the "total" VOC EF.

Note that reporting the unspeciated VOC as propane (mass-to-carbon ratio of 1.22 and a response factor of 1) may underestimate the actual mass of VOC for certain wood species because VOC compounds like ethanol and acetic acid with higher mass-to-carbon ratios (1.92 and 2.5, respectively) and lower response factors (0.66 and 0.575, respectively) can be a significant portion of the total VOC. Without reliable test data for such compounds, EPA assumes propane adequately represents the mix of unspeciated VOC.

Step One: Compile Douglas Fir VOC Emission Test Data by Drying Temperature

Maximum Dry Bulb Temperature (°F)	Method 25A VOC as Carbon (lb/mbf)	Lumber Dimensions	Moisture Content[1] (%) (Initial/Final)	Time to Final Moisture Content (hours)	Method 25A Analyzer	Reference
160	0.51	2x6	37.3 / 15	23.5	JUM 3-200	3, 4, 12
160	0.55	2x6	44.9 / 15	28.5		
160	0.45	2x6	40.3 / 15	27.1		
160	0.46	2x6	31.9 / 15	25.2		
170	0.65	2x4	79.9 / 15	40.5	JUM VE-7	13
170	0.24	2x4	56.9 / 15	27.5	JUM VE-7	15, 18
180	0.942	2x4	38.9 / 15	63	JUM VE-7	2
180	0.669	2x4	44.9 / 15	42		
180	0.21	2x4	56.3 / 15	27		
180	0.575	2x4 or 2x6	43.7 / 15	no data	JUM VE-7	18
180	0.39	4x4	29.8 / 19	67.5	JUM 3-200	10
180	0.845	4x4	44.7 / 15	111		19
200	0.707	2x4 or 2x6	64.3 / 15	no data	JUM VE-7	18
200	0.879	2x4 or 2x6	59.5 / 15	no data		
220	1.2	2x4	73 / 12	46	JUM VE-7	7
220	1.3	2x4	73 / 15	46		
235	1.206	2x4 or 2x6	47.7 / 15	19	JUM VE-7	18, 21

[1] Dry basis. Moisture content = (weight of water / weight wood) x 100

Step Two: Calculate Douglas Fir VOC Emission Factors "as Carbon" Based on Maximum/90th Percentile Test Data

Maximum Dry Bulb Temperature[1] (°F)	Method 25A VOC as Carbon (lb/mbf)
≤ 200°F	0.8688
> 200°F	1.2812

[1] Because VOC emissions appear to be dependent upon drying temperature, separate values are calculated for low and high-temperature drying.

Step Three: Compile Douglas Fir Speciated HAP Emission Factors Based on Maximum/90th Percentile Test Data [1]

Maximum Dry Bulb Temperature (°F)	Methanol (lb/mbf)	Formaldehyde (lb/mbf)	Acetaldehyde (lb/mbf)	Propionaldehyde (lb/mbf)	Acrolein (lb/mbf)
≤ 200°F	0.0690	0.0019	0.0682	0.0007	0.0009
> 200°F	0.1170	0.0043			

[1] See douglas fir HAP sheet for lab-scale test data and calculations.

Step Four: Convert Douglas Fir Speciated HAP Emission Factors to "as Carbon" and Total

Speciated Compound "X" expressed as carbon = (RF_X) X (SC_X) X $[(MW_C) / (MW_X)]$ X $[(\#C_X) / (\#C_C)]$

where: RF_X represents the flame ionization detector (FID) response factor (RF) for speciated compound "X"

SC_X represents emissions of speciated compound "X" expressed as the entire mass of compound emitted

MW_C equals "12.0110" representing the molecular weight (MW) for carbon as carbon is becoming the "basis" for expressing mass of speciated compound "X"

MW_X represents the molecular weight for speciated compound "X"

$\#C_X$ represents the number of carbon atoms in speciated compound "X"

$\#C_C$ equals "1" as the single carbon atom is becoming the "basis" for expressing mass of speciated compound "X"

Maximum Dry Bulb Temperature (°F)	Methanol as Carbon (lb/mbf)	Formaldehyde as Carbon (lb/mbf)	Acetaldehyde as Carbon (lb/mbf)	Propionaldehyde as Carbon (lb/mbf)	Acrolein as Carbon (lb/mbf)		Speciated Compounds as Carbon (lb/mbf)
≤ 200°F	0.0186	0	0.0186	0.0003	0.0004	SUM ⇨	0.0379
> 200°F	0.0316	0					0.0508

Element and Compound Information

Element / Compound	FID RF[1]	Molecular Weight (lb/lb-mol)	Formula	Number of Carbon Atoms	Number of Hydrogen Atoms	Number of Oxygen Atoms	Reference
Methanol	0.72	32.042	CH_40	1	4	1	1
Formaldehyde	0	30.0262	CH_2O	1	2	1	16
Acetaldehyde	0.5	44.053	C_2H_4O	2	4	1	20
Propionaldehyde	0.66	58.0798	C_3H_6O	3	6	1	20
Acrolein	0.66	56.064	C_3H_4O	3	4	1	20
Propane	1	44.0962	C_3H_8	3	8	0	16
Carbon	-	12.0110	C	1	-	-	-
Hydrogen	-	1.0079	H	-	1	-	-
Oxygen	-	15.9994	O	-	-	1	-

[1] FID RF = volumetric concentration or "instrument display" / compound's actual known concentration. Numerator and denominator expressed on same basis (ie. carbon, propane, etc) and concentration in units of "ppm."

Step Five: Subtract Speciated HAP Compounds from Douglas Fir VOC Emission Factors and Convert Result to "as Propane"

	FROM STEP TWO		FROM STEP FOUR		Method 25A VOC as Carbon without Speciated Compounds (lb/mbf)	Propane Mass Conversion Factor	Method 25A VOC as Propane without Speciated Compounds (lb/mbf)
Maximum Dry Bulb Temperature (°F)	Method 25A VOC as Carbon (lb/mbf)	MINUS	Speciated Compounds as Carbon (lb/mbf)	EQUALS			
≤ 200°F	0.8688		0.0379		0.8309	X 1.2238 =	1.0169
> 200°F	1.2812		0.0508		1.2304		1.5057

Method 25A VOC as propane without speciated compounds = (VOC_C) X $(1/RF_{C3H8})$ X $[(MW_{C3H8}) / (MW_C)]$ X $[(\#C_C) / (\#C_{C3H8})]$

where: VOC_C represents Method 25A VOC as carbon without speciated compounds

RF_{C3H8} equals "1" and represents the FID RF for propane. All alkanes, including propane, have a RF of 1.

MW_{C3H8} equals "44.0962" and represents the molecular weight for propane; the compound that is the "basis" for expressing mass of VOC per WPP1 VOC

MW_C equals "12.0110" and represents the molecular weight for carbon

$\#C_C$ equals "1" as the single carbon atom was the "basis" for which Method 25A VOC test results were determined as illustrated in Step One of this spreadsheet

$\#C_{C3H8}$ equals "3" as three carbon atoms are present within propane; the compound that is the "basis" for expressing mass of VOC per WPP1 VOC

Note: The following portion from the equation immediately above, $(1/RF_{C3H8})$ X $[(MW_{C3H8}) / (MW_C)]$ X $[(\#C_C) / (\#C_{C3H8})]$, equals 1.2238 and can be referred to as the "propane mass conversion factor."

Step Six: Calculate WPP1 VOC by Adding Speciated HAP Compounds to Douglas Fir VOC Emission Factors "as Propane"

WPP1 VOC = Method 25A VOC as propane without speciated compounds + ∑ speciated compounds expressed as the entire mass of compound

	FROM STEP FIVE		FROM STEP THREE						
Maximum Dry Bulb Temperature (°F)	Method 25A VOC as Propane without Speciated Compounds (lb/mbf)	PLUS	Methanol (lb/mbf)	Formaldehyde (lb/mbf)	Acetaldehyde (lb/mbf)	Propionaldehyde (lb/mbf)	Acrolein (lb/mbf)	EQUALS	WPP1 VOC (lb/mbf)
≤ 200°F	1.0169		0.0690	0.0019	0.0682	0.0007	0.0009		1.1576
> 200°F	1.5057		0.1170	0.0043					1.6968

Hazardous Air Pollutant Emission Factors for Engelmann Spruce Lumber

This sheet presents the HAP EF for drying engelmann spruce lumber. The EFs are based on the 90th percentile value of actual lab-scale HAP test data when three or more data points are available and on the maximum value when less than three data points are available. EPA is not aware of any HAP emission testing of englemann spruce. Consistent with other species, when actual test data is not available, data for a similar species is substituted as noted. When there are more than one similar species, the highest of the EF for the similar species is substituted.

Step One: Compile HAP Emission Test Data for Similar Species (White Spruce) by Drying Temperature[1,2]

Maximum Dry Bulb Temperature (°F)	Methanol (lb/mbf)	Formaldehyde (lb/mbf)	Acetaldehyde (lb/mbf)	Propionaldehyde (lb/mbf)	Acrolein (lb/mbf)	Lumber Dimensions	Moisture Content[3] (%) (Initial / Final)	Time to Final Moisture Content (hours)	HAP Sample Collection Technique	Reference
180	0.025	0.0013	0.036	0.0003	0.0005	2x4 or 2x6	33.5 / 15	no data	NCASI Method 105	18
235	0.078	0.0044	0.031	0.0007	0.001	2x4 or 2x6	32.7 / 15	no data		

[1] In the absence of engelmann spruce test data, white spruce test data has been substituted. The two wood species are similar in that both are resinous softwood species in the scientific classification genus Picea.

[2] Yellow highlight denotes data not considered by EPA Region 10 in 2007 when providing notice of original EFs prior to initial PCWP (Plywood and Composite Wood Products) MACT compliance date.

[3] Dry basis. Moisture content = (weight of water / weight wood) x 100

Step Two: Calculate Engelmann Spruce HAP Emission Factors Based on Maximum/90th Percentile Test Data

Maximum Dry Bulb Temperature[1] (°F)	Methanol (lb/mbf)	Formaldehyde (lb/mbf)	Acetaldehyde (lb/mbf)	Propionaldehyde (lb/mbf)	Acrolein (lb/mbf)
≤ 200°F	0.0250	0.0013	0.0360	0.0007	0.0010
> 200°F	0.0780	0.0044			

[1] Because methanol and formaldehyde emissions appear to be dependent upon drying temperature, separate values are calculated for low and high-temperature drying.

Volatile Organic Compound Emission Factors for Drying Engelmann Spruce Lumber

This sheet presents lab-scale VOC and HAP test data and calculations used to create VOC EF for engelmann spruce lumber. The VOC test method used (EPA Reference Method 25A) has some limitations in that it misses some HAP (or portions of HAP) compounds that are VOC and known to exist and reports the results "as carbon" which only accounts for the carbon portion of each compound measured. The missed HAP compounds are accounted for through separate testing. The VOC test data is adjusted to fully account for five known HAPs that are VOC using separate HAP (speciated) test data and is reported "as propane" to better represent all of the unspeciated VOC compounds. This technique is consistent with EPA's Interim VOC Measurement Protocol for the Wood Products Industry - July 2007 (WPP1 VOC) except that the VOC results are adjusted to account for not only methanol and formaldehyde but also acetaldehyde, propionaldehyde and acrolein.

Specifically, EFs are calculated from the VOC and HAP test data based on the 90th percentile value of actual lab-scale test data when three or more data points are available and on the maximum value when less than three data points are available. When actual test data is not available for this wood species, data for a similar species is substituted as noted. When there are more than one similar species, the highest of the EF for the similar species is substituted. That portion of the (speciated) HAP compounds that are measured by the VOC test method (based on known flame ionization detector response factors) is subtracted from the VOC EF. The remaining "unspeciated" VOC EF is adjusted to represent propane rather than carbon and then added to the speciated HAP EF to provide the "total" VOC EF.

Note that reporting the unspeciated VOC as propane (mass-to-carbon ratio of 1.22 and a response factor of 1) may underestimate the actual mass of VOC for certain wood species because VOC compounds like ethanol and acetic acid with higher mass-to-carbon ratios (1.92 and 2.5, respectively) and lower response factors (0.66 and 0.575, respectively) can be a significant portion of the total VOC. Without reliable test data for such compounds, EPA assumes propane adequately represents the mix of unspeciated VOC.

Step One: Compile VOC Emission Test Data for Similar Species (White Spruce) by Drying Temperature[1]

Maximum Dry Bulb Temperature (°F)	Method 25A VOC as Carbon (lb/mbf)	Lumber Dimensions	Moisture Content[2] (%) (Initial/Final)	Time to Final Moisture Content (hours)	Method 25A Analyzer	Reference
≤ 200°F	no data					
235	0.11	2x4 or 2x6	32.7 / 15	no data	JUM VE-7	18

[1] In the absence of engelmann spruce test data, white spruce test data has been substituted. The two wood species are similar in that both are resinous softwood species in the scientific classification genus Picea.

[2] Dry basis. Moisture content = (weight of water / weight wood) x 100

Step Two: Calculate Engelmann Spruce VOC Emission Factors "as Carbon" Based on Maximum/90th Percentile Test Data[1]

Maximum Dry Bulb Temperature[2] (°F)	Method 25A VOC as Carbon (lb/mbf)
≤ 200°F	0.1100
> 200°F	0.1100

[1] In the absence of white spruce test data for low-temperature drying, high-temperature test data has been substituted.

[2] Because VOC emissions appear to be dependent upon drying temperature in other species (no observed low-temperature observations for white spruce), separate values are calculated for low and high-temperature drying.

Step Three: Compile Engelmann Spruce Speciated HAP Emission Factors Based on Maximum/90th Percentile Test Data[1]

Maximum Dry Bulb Temperature (°F)	Methanol (lb/mbf)	Formaldehyde (lb/mbf)	Acetaldehyde (lb/mbf)	Propionaldehyde (lb/mbf)	Acrolein (lb/mbf)
≤ 200°F	0.0250	0.0013	0.0360	0.0007	0.0010
> 200°F	0.0780	0.0044			

[1] See engelmann spruce HAP sheet for lab-scale test data and calculations.

Step Four: Convert Engelmann Spruce Speciated HAP Emission Factors to "as Carbon" and Total

Speciated Compound "X" expressed as carbon = (RF_X) X (SC_X) X $[(MW_C) / (MW_X)]$ X $[(\#C_X) / (\#C_C)]$

where: RF_X represents the flame ionization detector (FID) response factor (RF) for speciated compound "X"

SC_X represents emissions of speciated compound "X" expressed as the entire mass of compound emitted

MW_C equals "12.0110" representing the molecular weight (MW) for carbon as carbon is becoming the "basis" for expressing mass of speciated compound "X"

MW_X represents the molecular weight for speciated compound "X"

$\#C_X$ represents the number of carbon atoms in speciated compound "X"

$\#C_C$ equals "1" as the single carbon atom is becoming the "basis" for expressing mass of speciated compound "X"

Maximum Dry Bulb Temperature (°F)	Methanol as Carbon (lb/mbf)	Formaldehyde as Carbon (lb/mbf)	Acetaldehyde as Carbon (lb/mbf)	Propionaldehyde as Carbon (lb/mbf)	Acrolein as Carbon (lb/mbf)		Speciated Compounds as Carbon (lb/mbf)
≤ 200°F	0.0067	0	0.0098	0.0003	0.0004	SUM ⇨	0.0173
> 200°F	0.0211	0					0.0316

Element and Compound Information

Element / Compound	FID RF[1]	Molecular Weight (lb/lb-mol)	Formula	Number of Carbon Atoms	Number of Hydrogen Atoms	Number of Oxygen Atoms	Reference
Methanol	0.72	32.042	CH_40	1	4	1	1
Formaldehyde	0	30.0262	CH_2O	1	2	1	16
Acetaldehyde	0.5	44.053	C_2H_4O	2	4	1	20
Propionaldehyde	0.66	58.0798	C_3H_6O	3	6	1	20
Acrolein	0.66	56.064	C_3H_4O	3	4	1	20
Propane	1	44.0962	C_3H_8	3	8	0	16
Carbon	-	12.0110	C	1	-	-	-
Hydrogen	-	1.0079	H	-	1	-	-
Oxygen	-	15.9994	O	-	-	1	-

[1] FID RF = volumetric concentration or "instrument display" / compound's actual known concentration. Numerator and denominator expressed on same basis (ie. carbon, propane, etc) and concentration in units of "ppm."

Step Five: Subtract Speciated HAP Compounds from Engelmann Spruce VOC Emission Factors and Convert Result to "as Propane"

	FROM STEP TWO		FROM STEP FOUR		Method 25A VOC as Carbon without Speciated Compounds (lb/mbf)	Propane Mass Conversion Factor	Method 25A VOC as Propane without Speciated Compounds (lb/mbf)
Maximum Dry Bulb Temperature (°F)	Method 25A VOC as Carbon (lb/mbf)		Speciated Compounds as Carbon (lb/mbf)				
≤ 200°F	0.1100	MINUS ⇨	0.0173	EQUALS ⇨	0.0927	X 1.2238 =	0.1135
> 200°F	0.1100		0.0316		0.0784		0.0960

Method 25A VOC as propane without speciated compounds = (VOC_C) X $(1/RF_{C3H8})$ X $[(MW_{C3H8}) / (MW_C)]$ X $[(\#C_C) / (\#C_{C3H8})]$

where: VOC_C represents Method 25A VOC as carbon without speciated compounds

RF_{C3H8} equals "1" and represents the FID RF for propane. All alkanes, including propane, have a RF of 1.

MW_{C3H8} equals "44.0962" and represents the molecular weight for propane; the compound that is the "basis" for expressing mass of VOC per WPP1 VOC

MW_C equals "12.0110" and represents the molecular weight for carbon

$\#C_C$ equals "1" as the single carbon atom was the "basis" for which Method 25A VOC test results were determined as illustrated in Step One of this spreadsheet

$\#C_{C3H8}$ equals "3" as three carbon atoms are present within propane; the compound that is the "basis" for expressing mass of VOC per WPP1 VOC

Note: The following portion from the equation immediately above, $(1/RF_{C3H8})$ X $[(MW_{C3H8}) / (MW_C)]$ X $[(\#C_C) / (\#C_{C3H8})]$, equals 1.2238 and can be referred to as the "propane mass conversion factor."

Step Six: Calculate WPP1 VOC by Adding Speciated HAP Compounds to Engelmann Spruce VOC Emission Factors "as Propane"

WPP1 VOC = Method 25A VOC as propane without speciated compounds + ∑ speciated compounds expressed as the entire mass of compound

	FROM STEP FIVE		FROM STEP THREE						
Maximum Dry Bulb Temperature (°F)	Method 25A VOC as Propane without Speciated Compounds (lb/mbf)	PLUS	Methanol (lb/mbf)	Formaldehyde (lb/mbf)	Acetaldehyde (lb/mbf)	Propionaldehyde (lb/mbf)	Acrolein (lb/mbf)	EQUALS	WPP1 VOC (lb/mbf)
≤ 200°F	0.1135	⇨	0.0250	0.0013	0.0360	0.0007	0.0010	⇨	0.1775
> 200°F	0.0960		0.0780	0.0044					0.2161

Hazardous Air Pollutant Emission Factors for Drying Larch Lumber

This sheet presents the HAP EF for drying larch lumber. The EFs are based on the 90th percentile value of actual lab-scale HAP test data when three or more data points are available and on the maximum value when less than three data points are available. EPA Region 10 is not aware of any HAP emission testing of larch. Consistent with other species, when actual test data is not available, data for a similar species is substituted as noted. When there are more than one similar species, the highest of the EF for the similar species is substituted.

Larch HAP Emission Factors[1]

Maximum Dry Bulb Temperature[2] (°F)	Methanol (lb/mbf)	Formaldehyde (lb/mbf)	Acetaldehyde (lb/mbf)	Propionaldehyde (lb/mbf)	Acrolein (lb/mbf)
≤ 200°F	0.0690	0.0019	0.0682	0.0007	0.0010
> 200°F	0.1170	0.0044			

[1] In the absence of larch test data, douglas fir test data has been substituted for methanol, acetaldehyde, propionaldehyde, acrolein and low-temperature formaldehyde while white spruce test data has been substituted for high-temperature formaldehyde. Larch is similar to douglas fir, engelmann spruce, white spruce, lodgepole pine, ponderosa pine and western white pine in that all seven species are resinous softwood species in the scientific classification order Pinaceae, but larch does not share a common genus with any of these species. It appears to be most similar to douglas fir, engelmann spruce and white spruce in that the four species have small, sparse resin canals as opposed to the large numerous resin canals of the pines. See hhtp://www.faculty.sfasu.edu/mcbroommatth/lectures/wood_science/lab_2_resin_canal_species.pdf. See the douglas fir and englemann spruce HAP sheets for lab-scale test data and calculations.

[2] Because methanol and formaldehyde emissions appear to be dependent upon drying temperature in other species (no observations for larch), separate values are calculated for low and high-temperature drying.

Volatile Organic Compound Emission Factors for Drying Larch Lumber

This sheet presents lab-scale VOC and HAP test data and calculations used to create VOC EF for drying larch lumber. The VOC test method used (EPA Reference Method 25A) has some limitations in that it misses some HAP (or portions of HAP) compounds that are VOC and known to exist and reports the results "as carbon" which only accounts for the carbon portion of each compound measured. The missed HAP compounds are accounted for through separate testing. The VOC test data is adjusted to fully account for five known HAPs that are VOC using separate HAP (speciated) test data and is reported "as propane" to better represent all of the unspeciated VOC compounds. This technique is consistent with EPA's Interim VOC Measurement Protocol for the Wood Products Industry - July 2007 (WPP1 VOC) except that the VOC results are adjusted to account for not only methanol and formaldehyde but also acetaldehyde, propionaldehyde and acrolein.

Specifically, EFs are calculated from the VOC and HAP test data based on the 90th percentile value of actual lab-scale test data when three or more data points are available and on the maximum value when less than three data points are available. When actual test data is not available for this wood species, data for a similar species is substituted as noted. When there are more than one similar species, the highest of the EF for the similar species is substituted. That portion of the (speciated) HAP compounds that are measured by the VOC test method (based on known flame ionization detector response factors) is subtracted from the VOC EF. The remaining "unspeciated" VOC EF is adjusted to represent propane rather than carbon and then added to the speciated HAP EF to provide the "total" VOC EF.

Note that reporting the unspeciated VOC as propane (mass-to-carbon ratio of 1.22 and a response factor of 1) may underestimate the actual mass of VOC for certain wood species because VOC compounds like ethanol and acetic acid with higher mass-to-carbon ratios (1.92 and 2.5, respectively) and lower response factors (0.66 and 0.575, respectively) can be a significant portion of the total VOC. Without reliable test data for such compounds, EPA assumes propane adequately represents the mix of unspeciated VOC.

Larch WPP1 VOC Emission Factors[1]

Maximum Dry Bulb Temperature[2] (°F)	WPP1 VOC (lb/mbf)
≤200	1.1576
>200	1.6968

[1] In the absence of larch test data, douglas fir test data has been substituted. Larch is similar to douglas fir, engelmann spruce, white spruce, lodgepole pine, ponderosa pine and western white pine in that all seven species are resinous softwood species in the scientific classification order Pinaceae, but larch does not share a common genus with any of these species. It appears to be most similar to douglas fir, engelmann spruce and white spruce in that the four species have small, sparse resin canals as opposed to the large numerous resin canals of the pines. See hhtp://www.faculty.sfasu.edu/mcbroommatth/lectures/wood_science/lab_2_resin_canal_species.pdf. See the douglas fir and englemann spruce VOC sheets for lab-scale test data and calculations.

[2] Because VOC emissions appear to be dependent upon drying temperature in other species (no observations for larch), separate values are calculated for low and high-temperature drying.

Hazardous Air Pollutant Emission Factors for Drying Lodgepole Pine Lumber

This sheet presents lab-scale test data and calculations used to create HAP EF for drying lodgepole pine lumber. The EFs are based on the 90th percentile value of actual lab-scale HAP test data when three or more data points are available and on the maximum value when less than three data points are available. When actual test data is not available for this wood species, data for a similar species is substituted as noted. When there are more than one similar species, the highest of the EF for the similar species is substituted.

Step One: Compile Lodgepole Pine HAP Emission Test Data by Drying Temperature[1]

Maximum Dry Bulb Temperature (°F)	Methanol (lb/mbf)	Formaldehyde (lb/mbf)	Acetaldehyde (lb/mbf)	Propionaldehyde (lb/mbf)	Acrolein (lb/mbf)	Lumber Dimensions	Moisture Content[2] (%) (Initial / Final)	Time to Final Moisture Content (hours)	HAP Sample Collection Technique	Reference
195	~~0.073~~	~~no data~~	~~0.012~~	~~no data~~	~~no data~~	no data	no data	no data	no data	14
195	~~0.092~~	~~no data~~	~~no data~~	~~no data~~	~~no data~~	no data	no data	no data	no data	
195	~~0.064~~	~~no data~~	~~no data~~	~~no data~~	~~no data~~	no data	no data	no data	no data	
195	~~0.028~~	~~no data~~	~~no data~~	~~no data~~	~~no data~~	no data	no data	no data	no data	
195	~~0.02~~	~~no data~~	~~no data~~	~~no data~~	~~no data~~	no data	no data	no data	no data	
≤ 200°F	no data									
236	0.063	0.0041	no data	no data	no data	2x4	59.1 / 15	16	NCASI Method IM/CAN/WP-99.01 without cannisters.	3, 4, 12, 14
237	0.062	0.0041	no data	no data	no data	2x4	59.7 / 15	16.6		
238	0.056	0.0039	no data	no data	no data	2x4	56.9 / 15	16		

[1] Blue highlight denotes data not considered by EPA Region 10 in 2012. Five test runs considered by EPA Region 10 in 2007 are not considered here due to lack of documentation. The omitted test values are presented in Oregon Department of Environmental Quality memorandum May 8, 2007 entitled, "Title III Implications of Drying Kiln Source Test Results." The memorandum lists "Forintec #1, #2 and #5" along with "OSU QA # 1 and #2 " as the test data sources.

[2] Dry basis. Moisture content = (weight of water / weight wood) x 100

Step Two: Calculate Lodgepole Pine HAP Emission Factors Based on Maximum/90th Percentile Test Data

Maximum Dry Bulb Temperature[1] (°F)	Methanol[2] (lb/mbf)	Formaldehyde[2] (lb/mbf)	Acetaldehyde[3] (lb/mbf)	Propionaldehyde[3] (lb/mbf)	(lb/mbf)
≤ 200°F	0.0628	0.0041	0.0420	0.0032	0.0045
> 200°F	0.0628	0.0041			

[1] Because methanol and formaldehyde emissions appear to be dependent upon drying temperature in other species (no confirmed low-temperature observations for lodgepole pine), separate values are calculated for low and high-temperature drying.

[2] In the absence of lodgepole pine test data for low-temperature drying, high-temperature test data has been substituted.

[3] In the absence of lodgepole pine test data for acetaldeyde, propionaldehyde and acrolein, ponderosa pine test data has been substituted. Lodgepole pine, ponderosa pine and western white pine are similar in that all three are resinous softwood species in the scientific classification genus Pinus. See the ponderosa pine and western white pine HAP sheets for lab-scale test data and calculations.

Volatile Organic Compound Emission Factors for Drying Lodgepole Pine Lumber

This sheet presents lab-scale VOC and HAP test data and calculations used to create VOC EF for drying lodgepole pine lumber. The VOC test method used (EPA Reference Method 25A) has some limitations in that it misses some HAP (or portions of HAP) compounds that are VOC and known to exist and reports the results "as carbon" which only accounts for the carbon portion of each compound measured. The missed HAP compounds are accounted for through separate testing. The VOC test data is adjusted to fully account for five known HAPs that are VOC using separate HAP (speciated) test data and is reported "as propane" to better represent all of the unspeciated VOC compounds. This technique is consistent with EPA's Interim VOC Measurement Protocol for the Wood Products Industry - July 2007 (WPP1 VOC) except that the VOC results are adjusted to account for not only methanol and formaldehyde but also acetaldehyde, propionaldehyde and acrolein.

Specifically, EFs are calculated from the VOC and HAP test data based on the 90th percentile value of actual lab-scale test data when three or more data points are available and on the maximum value when less than three data points are available. When actual test data is not available for this wood species, data for a similar species is substituted as noted. When there are more than one similar species, the highest of the EF for the similar species is substituted. That portion of the (speciated) HAP compounds that are measured by the VOC test method (based on known flame ionization detector response factors) is subtracted from the VOC EF. The remaining "unspeciated" VOC EF is adjusted to represent propane rather than carbon and then added to the speciated HAP EF to provide the "total" VOC EF.

Note that reporting the unspeciated VOC as propane (mass-to-carbon ratio of 1.22 and a response factor of 1) may underestimate the actual mass of VOC for certain wood species because VOC compounds like ethanol and acetic acid with higher mass-to-carbon ratios (1.92 and 2.5, respectively) and lower response factors (0.66 and 0.575, respectively) can be a significant portion of the total VOC. Without reliable test data for such compounds, EPA assumes propane adequately represents the mix of unspeciated VOC.

Step One: Compile Lodgepole Pine VOC Emission Test Data by Drying Temperature

Maximum Dry Bulb Temperature (°F)	Method 25A VOC as Carbon (lb/mbf)	Lumber Dimensions	Moisture Content[1] (%) (Initial/Final)	Time to Final Moisture Content (hours)	Method 25A Analyzer	Reference
≤ 200°F	no data					
236	1.17	2x4	59.1 / 15	16.01	JUM 3-200	3, 4, 12
238	0.87	2x4	56.9 / 15	16.01		
240	1.19	2x4	64.9 / 15	16.81		

[1] Dry basis. Moisture content = (weight of water / weight wood) x 100

Step Two: Calculate Lodgepole Pine VOC Emission Factors "as Carbon" Based on Maximum/90th Percentile Test Data [1]

Maximum Dry Bulb Temperature[2] (°F)	Method 25A VOC as Carbon (lb/mbf)
≤ 200°F	1.1860
> 200°F	1.1860

[1] In the absence of lodgepole pine test data for low-temperature drying, high-temperature test data has been substituted.

[2] Because VOC emissions appear to be dependent upon drying temperature in other species (no observed low-temperature observations for lodgepole pine), separate values are calculated for low and high-temperature drying.

Step Three: Compile Lodgepole Pine Speciated HAP Emission Factors Based on Maximum/90th Percentile Test Data [1]

Maximum Dry Bulb Temperature (°F)	Methanol (lb/mbf)	Formaldehyde (lb/mbf)	Acetaldehyde (lb/mbf)	Propionaldehyde (lb/mbf)	Acrolein (lb/mbf)
≤ 200°F	0.0628	0.0041	0.0420	0.0032	0.0045
> 200°F	0.0628	0.0041			

[1] See lodgepole pine HAP sheet for lab-scale test data and calculations.

Step Four: Convert Lodgepole Pine Speciated HAP Emission Factors to "as Carbon" and Total

Speciated Compound "X" expressed as carbon = (RF_X) X (SC_X) X $[(MW_C) / (MW_X)]$ X $[(\#C_X) / (\#C_C)]$

where: RF_X represents the flame ionization detector (FID) response factor (RF) for speciated compound "X"

SC_X represents emissions of speciated compound "X" expressed as the entire mass of compound emitted

MW_C equals "12.0110" representing the molecular weight (MW) for carbon as carbon is becoming the "basis" for expressing mass of speciated compound "X"

MW_X represents the molecular weight for speciated compound "X"

$\#C_X$ represents the number of carbon atoms in speciated compound "X"

$\#C_C$ equals "1" as the single carbon atom is becoming the "basis" for expressing mass of speciated compound "X"

Maximum Dry Bulb Temperature (°F)	Methanol as Carbon (lb/mbf)	Formaldehyde as Carbon (lb/mbf)	Acetaldehyde as Carbon (lb/mbf)	Propionaldehyde as Carbon (lb/mbf)	Acrolein as Carbon (lb/mbf)		Speciated Compounds as Carbon (lb/mbf)
≤ 200°F	0.0169	0	0.0115	0.0013	0.0019	SUM ⇨	0.0316
> 200°F	0.0169	0					0.0316

Element and Compound Information

Element / Compound	FID RF[1]	Molecular Weight (lb/lb-mol)	Formula	Number of Carbon Atoms	Number of Hydrogen Atoms	Number of Oxygen Atoms	Reference
Methanol	0.72	32.042	CH_40	1	4	1	1
Formaldehyde	0	30.0262	CH_2O	1	2	1	16
Acetaldehyde	0.5	44.053	C_2H_4O	2	4	1	20
Propionaldehyde	0.66	58.0798	C_3H_6O	3	6	1	20
Acrolein	0.66	56.064	C_3H_4O	3	4	1	20
Propane	1	44.0962	C_3H_8	3	8	0	16
Carbon	-	12.0110	C	1	-	-	-
Hydrogen	-	1.0079	H	-	1	-	-
Oxygen	-	15.9994	O	-	-	1	-

[1] FID RF = volumetric concentration or "instrument display" / compound's actual known concentration. Numerator and denominator expressed on same basis (ie. carbon, propane, etc) and concentration in units of "ppm."

Step Five: Subtract Speciated HAP Compounds from Lodgepole Pine VOC Emission Factors and Convert Result to "as Propane"

	FROM STEP TWO		FROM STEP FOUR		Method 25A VOC as Carbon without Speciated Compounds (lb/mbf)	Propane Mass Conversion Factor	Method 25A VOC as Propane without Speciated Compounds (lb/mbf)
Maximum Dry Bulb Temperature (°F)	Method 25A VOC as Carbon (lb/mbf)		Speciated Compounds as Carbon (lb/mbf)				
≤ 200°F	1.1860	MINUS ⇨	0.0316	EQUALS ⇨	1.1544	X 1.2238 =	1.4127
> 200°F	1.1860		0.0316		1.1544		1.4127

Method 25A VOC as propane without speciated compounds = (VOC_C) X $(1/RF_{C3H8})$ X $[(MW_{C3H8}) / (MW_C)]$ X $[(\#C_C) / (\#C_{C3H8})]$

where: VOC_C represents Method 25A VOC as carbon without speciated compounds

RF_{C3H8} equals "1" and represents the FID RF for propane. All alkanes, including propane, have a RF of 1.

MW_{C3H8} equals "44.0962" and represents the molecular weight for propane; the compound that is the "basis" for expressing mass of VOC per WPP1 VOC

MW_C equals "12.0110" and represents the molecular weight for carbon

$\#C_C$ equals "1" as the single carbon atom was the "basis" for which Method 25A VOC test results were determined as illustrated in Step One of this spreadsheet

$\#C_{C3H8}$ equals "3" as three carbon atoms are present within propane; the compound that is the "basis" for expressing mass of VOC per WPP1 VOC

Note: The following portion from the equation immediately above, $(1/RF_{C3H8})$ X $[(MW_{C3H8}) / (MW_C)]$ X $[(\#C_C) / (\#C_{C3H8})]$, equals 1.2238 and can be referred to as the "propane mass conversion factor."

Step Six: Calculate WPP1 VOC by Adding Speciated HAP Compounds to Lodgepole Pine VOC Emission Factors "as Propane"

WPP1 VOC = Method 25A VOC as propane without speciated compounds + ∑ speciated compounds expressed as the entire mass of compound

	FROM STEP FIVE		FROM STEP THREE						
Maximum Dry Bulb Temperature (°F)	Method 25A VOC as Propane without Speciated Compounds (lb/mbf)	PLUS	Methanol (lb/mbf)	Formaldehyde (lb/mbf)	Acetaldehyde (lb/mbf)	Propionaldehyde (lb/mbf)	Acrolein (lb/mbf)	EQUALS	WPP1 VOC (lb/mbf)
≤ 200°F	1.4127	⇨	0.0628	0.0041	0.0420	0.0032	0.0045	⇨	1.5293
> 200°F	1.4127		0.0628	0.0041					1.5293

Hazardous Air Pollutant Emission Factors for Drying Ponderosa Pine Lumber

This sheet presents lab-scale test data and calculations used to create HAP EF for drying ponderosa pine lumber. The EFs are based on the 90th percentile value of actual lab-scale HAP test data when three or more data points are available and on the maximum value when less than three data points are available. When actual test data is not available for this wood species, data for a similar species is substituted as noted. When there are more than one similar species, the highest of the EF for the similar species is substituted.

Step One: Compile Ponderosa Pine HAP Emission Test Data by Drying Temperature[1]

Maximum Dry Bulb Temperature (°F)	Methanol (lb/mbf)	Formaldehyde (lb/mbf)	Acetaldehyde (lb/mbf)	Propionaldehyde (lb/mbf)	Acrolein (lb/mbf)	Lumber Dimensions	Moisture Content[2] (%) (Initial / Final)	Time to Final Moisture Content (hours)	HAP Sample Collection Technique	Reference
170	0.035	0.0027	0.042	0.0019	0.0017	2x4	82.6 / 15	42	NCASI Method 105	17, 18
176	0.05	0.0022	no data	no data	no data	2x10 & 2x12	107.1 / 12	55	NCASI Method IM/CAN/WP-99.01 without cannisters	3, 4, 12, 14
176	0.08	0.0036	no data	no data	no data	2x10 & 2x12	124.1 / 12	57		
235	0.144	0.0092	0.028	0.0032	0.0045	2x4 or 2x6	89.1 / 15	19	NCASI Method 105	18, 21

[1] Yellow highlight denotes data not considered by EPA Region 10 in 2007 when providing notice of original EFs prior to initial PCWP (Plywood and Composite Wood Products) MACT compliance date.

[2] Dry basis. Moisture content = (weight of water / weight wood) x 100

Step Two: Calculate Ponderosa Pine HAP Emission Factors Based on Maximum/90th Percentile Test Data

Maximum Dry Bulb Temperature[1] (°F)	Methanol (lb/mbf)	Formaldehyde (lb/mbf)	Acetaldehyde (lb/mbf)	Propionaldehyde (lb/mbf)	Acrolein (lb/mbf)
≤ 200°F	0.0740	0.0034	0.0420	0.0032	0.0045
> 200°F	0.1440	0.0092			

[1] Because methanol and formaldehyde emissions appear to be dependent upon drying temperature, separate values are calculated for low and high-temperature drying.

Volatile Organic Compound Emission Factors for Drying Ponderosa Pine Lumber

This sheet presents lab-scale VOC and HAP test data and calculations used to create VOC EF for drying ponderosa pine lumber. The VOC test method used (EPA Reference Method 25A) has some limitations in that it misses some HAP (or portions of HAP) compounds that are VOC and known to exist and reports the results "as carbon" which only accounts for the carbon portion of each compound measured. The missed HAP compounds are accounted for through separate testing. The VOC test data is adjusted to fully account for five known HAPs that are VOC using separate HAP (speciated) test data and is reported "as propane" to better represent all of the unspeciated VOC compounds. This technique is consistent with EPA's Interim VOC Measurement Protocol for the Wood Products Industry - July 2007 (WPP1 VOC) except that the VOC results are adjusted to account for not only methanol and formaldehyde but also acetaldehyde, propionaldehyde and acrolein.

Specifically, EFs are calculated from the VOC and HAP test data based on the 90th percentile value of actual lab-scale test data when three or more data points are available and on the maximum value when less than three data points are available. When actual test data is not available for this wood species, data for a similar species is substituted as noted. When there are more than one similar species, the highest of the EF for the similar species is substituted. That portion of the (speciated) HAP compounds that are measured by the VOC test method (based on known flame ionization detector response factors) is subtracted from the VOC EF. The remaining "unspeciated" VOC EF is adjusted to represent propane rather than carbon and then added to the speciated HAP EF to provide the "total" VOC EF.

Note that reporting the unspeciated VOC as propane (mass-to-carbon ratio of 1.22 and a response factor of 1) may underestimate the actual mass of VOC for certain wood species because VOC compounds like ethanol and acetic acid with higher mass-to-carbon ratios (1.92 and 2.5, respectively) and lower response factors (0.66 and 0.575, respectively) can be a significant portion of the total VOC. Without reliable test data for such compounds, EPA assumes propane adequately represents the mix of unspeciated VOC.

Step One: Compile Ponderosa Pine VOC Emission Test Data by Drying Temperature

Maximum Dry Bulb Temperature (°F)	Method 25A VOC as Carbon (lb/mbf)	Lumber Dimensions	Moisture Content[1] (%) (Initial/Final)	Time to Final Moisture Content (hours)	Method 25A Analyzer	Reference
170	1.59	2x4	82.6 / 15	42	JUM VE-7	17, 18
170	1.795	1x4	112.8 / 15	29	JUM VE-7	2
170	1.925	1x4	88.7 / 15	28		
176	1.29	2x10 & 2x12	107.1 / 12	55	JUM 3-200	3, 4, 12
176	1.54	2x10 & 2x12	124.1 / 12	57		
176	1.40	2x10 & 2x12	114.8 / 12	58.5	JUM 3-200	3, 4
176	1.30	2x10 & 2x12	93.0 / 12	57.1		
235	3.00	2x4 or 2x6	89.1 / 15	19	JUM VE-7	18, 21

[1] Dry basis. Moisture content = (weight of water / weight wood) x 100

Step Two: Calculate Ponderosa Pine VOC Emission Factors "as Carbon" Based on Maximum/90th Percentile Test Data

Maximum Dry Bulb Temperature[1] (°F)	Method 25A VOC as Carbon (lb/mbf)
≤ 200°F	1.8470
> 200°F	3.0000

[1] Because VOC emissions appear to be dependent upon drying temperature, separate values are calculated for low and high-temperature drying.

Step Three: Compile Ponderosa Pine Speciated HAP Emission Factors Based on Maximum/90th Percentile Test Data[1]

Maximum Dry Bulb Temperature (°F)	Methanol (lb/mbf)	Formaldehyde (lb/mbf)	Acetaldehyde (lb/mbf)	Propionaldehyde (lb/mbf)	Acrolein (lb/mbf)
≤ 200°F	0.0740	0.0034	0.0420	0.0032	0.0045
> 200°F	0.1440	0.0092			

[1] See ponderosa pine HAP sheet for lab-scale test data and calculations.

Step Four: Convert Ponderosa Pine Speciated HAP Emission Factors to "as Carbon" and Total

Speciated Compound "X" expressed as carbon = (RF_X) X (SC_X) X $[(MW_C) / (MW_X)]$ X $[(\#C_X) / (\#C_C)]$

where: RF_X represents the flame ionization detector (FID) response factor (RF) for speciated compound "X"

SC_X represents emissions of speciated compound "X" expressed as the entire mass of compound emitted

MW_C equals "12.0110" representing the molecular weight (MW) for carbon as carbon is becoming the "basis" for expressing mass of speciated compound "X"

MW_X represents the molecular weight for speciated compound "X"

$\#C_X$ represents the number of carbon atoms in speciated compound "X"

$\#C_C$ equals "1" as the single carbon atom is becoming the "basis" for expressing mass of speciated compound "X"

Maximum Dry Bulb Temperature (°F)	Methanol as Carbon (lb/mbf)	Formaldehyde as Carbon (lb/mbf)	Acetaldehyde as Carbon (lb/mbf)	Propionaldehyde as Carbon (lb/mbf)	Acrolein as Carbon (lb/mbf)		Speciated Compounds as Carbon (lb/mbf)
≤ 200°F	0.0200	0	0.0115	0.0013	0.0019	SUM ⇨	0.0346
> 200°F	0.0389	0					0.0535

Element and Compound Information

Element / Compound	FID RF[1]	Molecular Weight (lb/lb-mol)	Formula	Number of Carbon Atoms	Number of Hydrogen Atoms	Number of Oxygen Atoms	Reference
Methanol	0.72	32.042	CH_40	1	4	1	1
Formaldehyde	0	30.0262	CH_2O	1	2	1	16
Acetaldehyde	0.5	44.053	C_2H_4O	2	4	1	20
Propionaldehyde	0.66	58.0798	C_3H_6O	3	6	1	20
Acrolein	0.66	56.064	C_3H_4O	3	4	1	20
Propane	1	44.0962	C_3H_8	3	8	0	16
Carbon	-	12.0110	C	1	-	-	-
Hydrogen	-	1.0079	H	-	1	-	-
Oxygen	-	15.9994	O	-	-	1	-

[1] FID RF = volumetric concentration or "instrument display" / compound's actual known concentration. Numerator and denominator expressed on same basis (ie. carbon, propane, etc) and concentration in units of "ppm."

Step Five: Subtract Speciated HAP Compounds from Ponderosa Pine VOC Emission Factors and Convert Result to "as Propane"

	FROM STEP TWO		FROM STEP FOUR		Method 25A VOC as Carbon without Speciated Compounds (lb/mbf)	Propane Mass Conversion Factor	Method 25A VOC as Propane without Speciated Compounds (lb/mbf)
Maximum Dry Bulb Temperature (°F)	Method 25A VOC as Carbon (lb/mbf)		Speciated Compounds as Carbon (lb/mbf)				
≤ 200°F	1.8470	MINUS ⇨	0.0346	EQUALS ⇨	1.8124	X 1.2238 =	2.2179
> 200°F	3.0000		0.0535		2.9465		3.6058

Method 25A VOC as propane without speciated compounds = (VOC_C) X $(1/RF_{C3H8})$ X $[(MW_{C3H8}) / (MW_C)]$ X $[(\#C_C) / (\#C_{C3H8})]$

where: VOC_C represents Method 25A VOC as carbon without speciated compounds

RF_{C3H8} equals "1" and represents the FID RF for propane. All alkanes, including propane, have a RF of 1.

MW_{C3H8} equals "44.0962" and represents the molecular weight for propane; the compound that is the "basis" for expressing mass of VOC per WPP1 VOC

MW_C equals "12.0110" and represents the molecular weight for carbon

$\#C_C$ equals "1" as the single carbon atom was the "basis" for which Method 25A VOC test results were determined as illustrated in Step One of this spreadsheet

$\#C_{C3H8}$ equals "3" as three carbon atoms are present within propane; the compound that is the "basis" for expressing mass of VOC per WPP1 VOC

Note: The following portion from the equation immediately above, $(1/RF_{C3H8})$ X $[(MW_{C3H8}) / (MW_C)]$ X $[(\#C_C) / (\#C_{C3H8})]$, equals 1.2238 and can be referred to as the "propane mass conversion factor."

Step Six: Calculate WPP1 VOC by Adding Speciated HAP Compounds to Ponderosa Pine VOC Emission Factors "as Propane"

WPP1 VOC = Method 25A VOC as propane without speciated compounds + ∑ speciated compounds expressed as the entire mass of compound

	FROM STEP FIVE		FROM STEP THREE						
Maximum Dry Bulb Temperature (°F)	Method 25A VOC as Propane without Speciated Compounds (lb/mbf)	PLUS	Methanol (lb/mbf)	Formaldehyde (lb/mbf)	Acetaldehyde (lb/mbf)	Propionaldehyde (lb/mbf)	Acrolein (lb/mbf)	EQUALS	WPP1 VOC (lb/mbf)
≤ 200°F	2.2179	⇨	0.0740	0.0034	0.0420	0.0032	0.0045	⇨	2.3450
> 200°F	3.6058		0.1440	0.0092					3.8087

Hazardous Air Pollutant Emission Factors for Drying Western White Pine Lumber

This sheet presents the HAP EF for drying western white pine lumber. The EFs are based on the 90th percentile value of actual lab-scale HAP test data when three or more data points are available and on the maximum value when less than three data points are available. EPA Region 10 is not aware of any HAP emission testing of western white pine. Consistent with other species, when actual test data is not available, data for a similar species is substituted as noted. When there are more than one similar species, the highest of the EF for the similar species is substituted.

Western White Pine HAP Emission Factors[1]

Maximum Dry Bulb Temperature[2] (°F)	Methanol (lb/mbf)	Formaldehyde (lb/mbf)	Acetaldehyde (lb/mbf)	Propionaldehyde (lb/mbf)	Acrolein (lb/mbf)
≤ 200°F	0.0740	0.0034	0.0420	0.0032	0.0045
> 200°F	0.1440	0.0092			

[1] In the absence of western white pine test data, ponderosa pine test data has been substituted for all HAP. Western white pine is similar to ponderosa pine and lodgepole pine in that all three species are resinous softwood species in the scientific classification genus Pinus. See the ponderosa pine and lodgepole pine HAP sheets for lab-scale test data and calculations.

[2] Because methanol and formaldehyde emissions appear to be dependent upon drying temperature in other species (no observations for western white pine), separate values are calculated for low and high-temperature drying.

Volatile Organic Compound Emission Factors for Drying Western White Pine Lumber

This sheet presents lab-scale VOC and HAP test data and calculations used to create VOC EF for drying western white pine lumber. The VOC test method used (EPA Reference Method 25A) has some limitations in that it misses some HAP (or portions of HAP) compounds that are VOC and known to exist and reports the results "as carbon" which only accounts for the carbon portion of each compound measured. The missed HAP compounds are accounted for through separate testing. The VOC test data is adjusted to fully account for five known HAPs that are VOC using separate HAP (speciated) test data and is reported "as propane" to better represent all of the unspeciated VOC compounds. This technique is consistent with EPA's Interim VOC Measurement Protocol for the Wood Products Industry - July 2007 (WPP1 VOC) except that the VOC results are adjusted to account for not only methanol and formaldehyde but also acetaldehyde, propionaldehyde and acrolein.

Specifically, EFs are calculated from the VOC and HAP test data based on the 90th percentile value of actual lab-scale test data when three or more data points are available and on the maximum value when less than three data points are available. When actual test data is not available for this wood species, data for a similar species is substituted. When there are more than one similar species, the highest of the EF for the similar species is substituted. That portion of the (speciated) HAP compounds that are measured by the VOC test method (based on known flame ionization detector response factors) is subtracted from the VOC EF. The remaining "unspeciated" VOC EF is adjusted to represent propane rather than carbon and then added to the speciated HAP EF to provide the "total" VOC EF.

Note that reporting the unspeciated VOC as propane (mass-to-carbon ratio of 1.22 and a response factor of 1) may underestimate the actual mass of VOC for certain wood species because VOC compounds like ethanol and acetic acid with higher mass-to-carbon ratios (1.92 and 2.5, respectively) and lower response factors (0.66 and 0.575, respectively) can be a significant portion of the total VOC. Without reliable test data for such compounds, EPA assumes propane adequately represents the mix of unspeciated VOC.

Step One: Compile Western White Pine VOC Emission Test Data by Drying Temperature

Max Dry Bulb Temperature,°F	Method 25A VOC as Carbon, lb/mbf	Lumber Dimension	Moisture Content[1] (%) (Initial/Final)	Time to Final Moisture Content (hours)	Method 25A Analyzer	Reference
170	2.26	1x4	117.4 / 15	44	JUM VE-7	2
> 200°F	no data					

[1] Dry basis. Moisture content = (weight of water / weight wood) x 100

Step Two: Calculate Western White Pine VOC Emission Factors "as Carbon" Based on Maximum/90th Percentile Test Data[1]

Maximum Dry Bulb Temperature[2] (°F)	Method 25A VOC as Carbon (lb/mbf)
≤ 200°F	2.2600
> 200°F	3.0000

[1] In the absence of western white pine test data for high-temperature drying, ponderosa pine test data has been substituted. Western white pine, ponderosa pine and lodgepole pine are similar in that all three are resinous softwood species in the scientific classification genus Pinus. See the ponderosa pine and lodgepole pine sheets for lab-scale test data and calculations.

[2] Because VOC emissions appear to be dependent upon drying temperature in other species (no high-temperature observations for western white pine), separate values are calculated for low and high-temperature drying.

Step Three: Compile Western White Pine Speciated HAP Emission Factors Based on Maximum/90th Percentile Test Data[1]

Maximum Dry Bulb Temperature (°F)	Methanol (lb/mbf)	Formaldehyde (lb/mbf)	Acetaldehyde (lb/mbf)	Propionaldehyde (lb/mbf)	Acrolein (lb/mbf)
≤ 200°F	0.0740	0.0034	0.0420	0.0032	0.0045
> 200°F	0.1440	0.0092			

[1] See western white pine HAP sheet for lab-scale test data and calculations.

Step Four: Convert Western White Pine Speciated HAP Emission Factors to "as Carbon" and Total

Speciated Compound "X" expressed as carbon = (RF_X) X (SC_X) X $[(MW_C) / (MW_X)]$ X $[(\#C_X) / (\#C_C)]$

where: RF_X represents the flame ionization detector (FID) response factor (RF) for speciated compound "X"

SC_X represents emissions of speciated compound "X" expressed as the entire mass of compound emitted

MW_C equals "12.0110" representing the molecular weight (MW) for carbon as carbon is becoming the "basis" for expressing mass of speciated compound "X"

MW_X represents the molecular weight for speciated compound "X"

$\#C_X$ represents the number of carbon atoms in speciated compound "X"

$\#C_C$ equals "1" as the single carbon atom is becoming the "basis" for expressing mass of speciated compound "X"

Maximum Dry Bulb Temperature (°F)	Methanol as Carbon (lb/mbf)	Formaldehyde as Carbon (lb/mbf)	Acetaldehyde as Carbon (lb/mbf)	Propionaldehyde as Carbon (lb/mbf)	Acrolein as Carbon (lb/mbf)		Speciated Compounds as Carbon (lb/mbf)
≤ 200°F	0.0200	0	0.0115	0.0013	0.0019	SUM ⇨	0.0346
> 200°F	0.0389	0					0.0535

Element and Compound Information

Element / Compound	FID RF[1]	Molecular Weight (lb/lb-mol)	Formula	Number of Carbon Atoms	Number of Hydrogen Atoms	Number of Oxygen Atoms	Reference
Methanol	0.72	32.042	CH_40	1	4	1	1
Formaldehyde	0	30.0262	CH_2O	1	2	1	16
Acetaldehyde	0.5	44.053	C_2H_4O	2	4	1	20
Propionaldehyde	0.66	58.0798	C_3H_6O	3	6	1	20
Acrolein	0.66	56.064	C_3H_4O	3	4	1	20
Propane	1	44.0962	C_3H_8	3	8	0	16
Carbon	-	12.0110	C	1	-	-	-
Hydrogen	-	1.0079	H	-	1	-	-
Oxygen	-	15.9994	O	-	-	1	-

[1] FID RF = volumetric concentration or "instrument display" / compound's actual known concentration. Numerator and denominator expressed on same basis (ie. carbon, propane, etc) and concentration in units of "ppm."

Step Five: Subtract Speciated HAP Compounds from Western White Pine VOC Emission Factors and Convert Result to "as Propane"

	FROM STEP TWO		FROM STEP FOUR		Method 25A VOC as Carbon without Speciated Compounds (lb/mbf)	Propane Mass Conversion Factor	Method 25A VOC as Propane without Speciated Compounds (lb/mbf)
Maximum Dry Bulb Temperature (°F)	Method 25A VOC as Carbon (lb/mbf)		Speciated Compounds as Carbon (lb/mbf)				
≤ 200°F	2.2600	MINUS ⇨	0.0346	EQUALS ⇨	2.2254	X 1.2238 =	2.7233
> 200°F	3.0000		0.0535		2.9465		3.6058

Method 25A VOC as propane without speciated compounds = (VOC_C) X $(1/RF_{C3H8})$ X $[(MW_{C3H8}) / (MW_C)]$ X $[(\#C_C) / (\#C_{C3H8})]$

where: VOC_C represents Method 25A VOC as carbon without speciated compounds

RF_{C3H8} equals "1" and represents the FID RF for propane. All alkanes, including propane, have a RF of 1.

MW_{C3H8} equals "44.0962" and represents the molecular weight for propane; the compound that is the "basis" for expressing mass of VOC per WPP1 VOC

MW_C equals "12.0110" and represents the molecular weight for carbon

$\#C_C$ equals "1" as the single carbon atom was the "basis" for which Method 25A VOC test results were determined as illustrated in Step One of this spreadsheet

$\#C_{C3H8}$ equals "3" as three carbon atoms are present within propane; the compound that is the "basis" for expressing mass of VOC per WPP1 VOC

Note: The following portion from the equation immediately above, $(1/RF_{C3H8})$ X $[(MW_{C3H8}) / (MW_C)]$ X $[(\#C_C) / (\#C_{C3H8})]$, equals 1.2238 and can be referred to as the "propane mass conversion factor."

Step Six: Calculate WPP1 VOC by Adding Speciated HAP Compounds to Western White Pine VOC Emission Factors "as Propane"

WPP1 VOC = Method 25A VOC as propane without speciated compounds + ∑ speciated compounds expressed as the entire mass of compound

	FROM STEP FIVE		FROM STEP THREE						
Maximum Dry Bulb Temperature (°F)	Method 25A VOC as Propane without Speciated Compounds (lb/mbf)	PLUS	Methanol (lb/mbf)	Formaldehyde (lb/mbf)	Acetaldehyde (lb/mbf)	Propionaldehyde (lb/mbf)	Acrolein (lb/mbf)	EQUALS	WPP1 VOC (lb/mbf)
≤ 200°F	2.7233		0.0740	0.0034	0.0420	0.0032	0.0045		2.8505
> 200°F	3.6058		0.1440	0.0092					3.8087

Index to References Appearing in
EPA Region 10 HAP and VOC Emission Factors for Lumber Drying, December 2012

Reference No. 1
(Undated) J.U.M. Flame Ionization Detector Response Factor Technical Information presented at http://www.jum-aerosol.com/images/E-Fakt-02.pdf

Notes
Methanol response factor (RF) of 0.72 equals average of three response factors 0.69, 0.68 and 0.79 for J.U.M. models 3-200 and VE-7. These two models were exclusively employed to determine Method 25A VOC in the testing EPA Region 10 is relying upon to support VOC emission factor derivation.

An alternative RF of 0.65 from Appendix 3 to EPA's Interim VOC Measurement Protocol for the Wood Products Industry - July 2007 at http://www.epa.gov/ttn/emc/prelim/otm26.pdf could have been employed instead.

Employing RF of 0.72 (as opposed to 0.65) generates lower VOC emission factors (EF). A higher RF means that the EPA Method 25A flame ionization detector (FID) measures more of the compound. With the methanol EF having already been determined through speciated sampling and analysis, assuming the FID measures a greater portion of the methanol leaves less of the Method 25A measurement to be accounted for as unspeciated VOC.

Reference No. 2
National Council of the Paper Industry for Air and Stream Improvement, Inc. Technical Bulletin No. 718. July 1, 1996. A Small-Scale Kiln Study on Method 25A Measurements of Volatile Organic Compound Emissions from Lumber Drying.

Notes
To convert Method 25A VOC from "lb C/ODT" to "lb C/mbf," the following calculations were performed:

White Fir – Runs 15 and 16.
(0.85 lb/ODT) X (0.57 lb/mbf) / (0.77 lb/ODT) = 0.63 lb/mbf
(0.68 lb/ODT) X (0.57 lb/mbf) / (0.77 lb/ODT) = 0.50 lb/mbf
See pages 14 and 15 of the reference document.

Western Red Cedar – Runs 10 and 11.
(0.12 lb/ODT) X (0.12 lb/mbf) / (0.15 lb/ODT) = 0.096 lb/mbf
(0.17 lb/ODT) X (0.12 lb/mbf) / (0.15 lb/ODT) = 0.136 lb/mbf
See pages 14 and 15 of the reference document.

Douglas fir – Runs 1 and 3.
(1.00 lb/ODT) X (0.81 lb/mbf) / (0.86 lb/ODT) = 0.942
(0.71 lb/ODT) X (0.81 lb/mbf) / (0.86 lb/ODT) = 0.669
See pages 12 and 15 of the reference document.

Ponderosa Pine – Runs 5 and 6.
(1.92 lb/ODT) X (1.86 lb/mbf) / (1.99 lb/ODT) = 1.795 lb/mbf
(2.06 lb/ODT) X (1.86 lb/mbf) / (1.99 lb/ODT) = 1.925 lb/mbf
See pages 14 and 15 of the reference document.

The moisture content of wood was originally reported on a wet basis. It has been corrected to be on a dry basis using the following equation:
(moisture content on dry basis) = (moisture content on wet basis) / [1 – (moisture content on wet basis)]

Reference No. 3
Small-scale Kiln Study Utilizing Ponderosa Pine, Lodgepole Pine, White Fir, and Douglas-fir. Report by Michael R. Milota to Intermountain Forest Association. September 29, 2000.

Reference No. 4
Milota, Michael. VOC and HAP Emissions from Western Species. Western Dry Kiln Association: May 2001, p. 62-68.

Reference No. 5
Milota, M.R. 2003. HAP and VOC Emissions from White Fir Lumber Dried at High and Conventional Temperatures. Forest Prod. J. 53(3):60-64.

Reference No. 6
VOC and HAP Emissions from the High Temperature Drying of Hemlock Lumber. Report by Michael R. Milota to Hampton Affiliates. June 21, 2004.

Reference No. 7
Fritz, Brad. 2004. Pilot- and Full-Scale Measurements of VOC Emissions from Lumber Drying of Inland Northwest Species. Forest Prod. J. 54(7/8):50-56.

Notes
To convert acetaldehyde from "µg/min-bf" to "lb/mbf," the following calculations were performed:

White fir.
0.0550 lb/mbf = (7.7 µg/min-bf) X (60 min/hr) X (54 hr) X (kg/1x10^9g) X (2.205 lb/kg) X (1,000 bf/mbf).
See page 54 of the reference document.

Douglas fir.
0.030 lb/mbf = (4.9 µg/min-bf) X (60 min/hr) X (46 hr) X (kg/1x10^9g) X (2.205 lb/kg) X (1,000 bf/mbf).
0.022 lb/mbf = (3.6 µg/min-bf) X (60 min/hr) X (46 hr) X (kg/1x10^9g) X (2.205 lb/kg) X (1,000 bf/mbf).
See page 53 of the reference document.

Reference No. 8
VOC and Methanol Emissions from the Drying of Hemlock Lumber. Report by Michael R. Milota to Hampton Affiliates. August 24, 2004.

Reference No. 9
VOC, Methanol, and Formaldehyde Emissions from the Drying of Hemlock Lumber. Report by Michael R. Milota to Hampton Affiliates. October 15, 2004.

Reference No. 10
VOC Emissions from the Drying of Douglas-fir Lumber. Report by Michael R. Milota to Columbia Vista Corporation. June 14, 2005.

Reference No. 11
Milota, M.R. and P. Mosher. 2006. Emissions from Western Hemlock Lumber During Drying. Forest Prod. J. 56(5):66-70.

Reference No. 12
Milota, M.R. 2006. Hazardous Air Pollutant Emissions from Lumber Drying. Forest Prod. J. 56(7/8):79-84.

Reference No. 13
VOC, Methanol, and Formaldehyde Emissions from the Drying of Hemlock, ESLP, and Douglas Fir Lumber. Report by Michael R. Milota to Hampton Affiliates. March 23, 2007.

Reference No. 14
Oregon Department of Environmental Quality memorandum May 8, 2007 entitled, "Title III Implications of Drying Kiln Source Test Results."

Notes
The reference document presents a compilation of EF.

Reference No. 15
HAP Emissions from the Drying of Hemlock and Douglas-fir Lumber by NCASI 98.01 and 105. Report by Michael R. Milota to Hampton Affiliates. May 22, 2007 report.

Reference No. 16
EPA Interim VOC Measurement Protocol for the Wood Products Industry - July 2007 presented at http://www.epa.gov/ttn/emc/prelim/otm26.pdf

Notes
VOC determined through use of this document is referred to as WPP1 VOC. The document is alternatively known as EPA Other Test Method 26 or "OTM26."

Default formaldehyde RF of 0 and propane (an alkane) RF of 1 appear in Appendix 3 – Procedure for Response Factor Determination for the Interim VOC Measurement Protocol for the Wood Products Industry.

Reference No. 17
HAP Emissions by NCASI 98.01 and 105 from Drying of Ponderosa Pine and White Wood Lumber. Report by Michael R. Milota to Hampton Affiliates. July 25, 2007.

Reference No. 18
Milota, M.R. and P. Mosher. 2008. Emission of Hazardous Air Pollutants from Lumber Drying. Forest Prod. J. 58(7/8):50-55.

Reference No. 19
VOC Emissions From the Drying of Douglas-fir Lumber. Report by Michael R. Milota to Columbia Vista Corp. November 12, 2010.

Reference No. 20
NCASI Technical Bulletin No. 991. September 2011. Characterization, Measurement, and Reporting of Volatile Organic Compounds Emitted from Southern Pine Wood Products Sources.

Notes
Acetaldehyde and propionaldehyde RF appear in Table C-1 of Appendix C. The values are estimates based upon dividing the compound's effective carbon numbers (ECN) by the number of carbon atoms in the compound. See Attachment 2 to Appendix C.

Acrolein RF is also an estimate based upon dividing the compound's ECN by the number of carbon atoms in the compound. In this case, the RF estimate does not appear in Table C-1 of Appendix C. The value is calculated as described above pursuant to Attachment 2 to Appendix C.
RF = (ECN) / (number of carbon atoms in compound)
where ECN = 2 given the aliphatic carbon contribution of CH_2CHCHO (see Table 2.1 to Appendix C) and the number of carbon atoms in acrolein = 3.
RF = 2/3 or 0.66

Reference No. 21
Email of 03/26/12 email from Oregon State University's Michael Milota to EPA Region 10's Dan Meyer.

Reference No. 22
Email of 03/27/12 from Oregon State University's Michael Milota to EPA Region 10's Dan Meyer.